Analysis and Research on the effect of the Operation of Small Hydropower in the Regional Power Grid

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Abstract: The analysis of reactive power balance and voltage of power network not only affects the system voltage quality, but also affects the economic operation of power grid. In the calculation of reactive power balance and voltage analysis in the past, the problem of low power and low system voltage has been the concern of people. When small hydropower stations in the wet period of low load, the analysis of reactive power surplus and high voltage for the system, if small hydropower unit the capability of running in phase is considered, it can effectively solve the system low operation voltage of the key point on the high side.

1. Introduction

For the reactive power in the grid is too high, the grid voltage is too low, the usual solution to the operating state of the generator to adjust the phase into the running state, with the working principle of the phase to solve the power grid in the absence of Power power is too much, the grid voltage to reduce the problem. The specific approach is: First of all, to fully understand the power system voltage levels on the reactive power of what are the main aspects. Secondly, the characteristics of the phase of the operation and the working principle of mastery, and finally, the two fully integrated, play their respective roles, so that the hydropower station to get a better run.

With the construction and development of modern power grid with high voltage, large capacity and long distance transportation, the problem of high voltage at the peak point of the power system is becoming more and more serious, which seriously affects the safe operation of the transmission and distribution equipment. Commonly used in the grid regulation mode, the generator into the phase with a smooth operation, no additional investment, easy to real. Commonly used voltage regulating method in power grid, the generator into the phase with a smooth operation, without additional investment,
easy to implement and other unique advantages and gradually applied.

The phase-running operation and the late-phase operation together constitute the operation of the entire generator. The phase-running operation and the late-phase operation of the generator have their own characteristics, both between each other, but also promote each other and mutual conversion, mutual cooperation, the generous function of the generator to play out. Among them, the late operation means that the generator does not issue active power, only to the grid output inductive reactive power running state, which play a regulatory system power, to maintain the role of system voltage level. And the phase of the operation and the late phase of the opposite operation, the phase is running in the power system running reactive power over the process, the system voltage is high, the normal operation of the system blocked, etc., when the generator running to adjust the state Phase operation of the turntable, phase operation can be issued active power, and active power to the excess reactive power can be absorbed, so you can be too high in the power system to reduce the voltage, so that the power system to resume normal operation. But the phase of the operation also will be subject to a number of factors, limiting the function of play into play.

2. Theoretical Analysis on the Operation of Small Hydropower Development

1.1 Definition of generator phase advance operation

With the increasing number of hydropower stations in China, the scale of hydropower stations has been expanding, and some problems in hydropower systems have also changed. It is very difficult for traditional single generators to run a relatively satisfactory answer to some new situations and problems. And some of the advantages of the phase of the operation is being constantly highlighted, in the solution of these new situations and new problems have certain advantages, so the generator phase is very necessary to run. Because the current number of reactive power in China's power grid is increasing, but the voltage anomaly in the power grid is more serious, more serious situation is the voltage on the wire exceeds the upper limit of the specified value, which is more serious reactive power increase. The increase of reactive power is a common phenomenon in the field of power grid in China. Because with the continuous improvement of China's motor manufacturing technology and the rapid development of the power industry, the current power industry, the main direction of development of the main direction of the transition to the direction of large units, combined with high-voltage transmission lines, large power grid system, these two constitute a common The general characteristics of the current power system. These features make the reactive power in the grid continue to accumulate, increase, which is an urgent need to run into the orderly implementation.

1.2 generator into the basic principles of the operation

The generator operating conditions are running at a later time, where the stator current lags the terminal voltage and the generator is in the over excitation state. The phase-to-phase operation is relative to the generator's late-running operation, where the stator current is ahead of the terminal voltage and the generator is in underexcitation operation state. When the generator is running at the same time, the active power and inductive reactive power are supplied to the system. The active power table and the reactive power meter are all positive. The active power and capacitive reactive power are supplied to the system. The power meter indicates a positive value and the reactive power meter indicates a negative value, where the generator absorbs inductive reactive power from the system. The electrical parameters of the generator are still symmetrical when the generator enters the
phase, and the generator still maintains the synchronous speed, which is an operating condition when the power factor changes in the normal operation mode of the generator, but only widens the normal operation of the generator range. Therefore, in the allowable phase of the operating range, as long as the grid needs, the generator can run for a long time into the phase. As shown in Figure 1, respectively, for the phasor diagram of lagging and leading phase.

If the generator G is directly connected to the infinite system S, the terminal voltage \( U_G \) is constant, the generator potential is \( E_q \), the stator current is I, the power factor angle is \( \phi \), the excitation current is If, the synchronous reactance is \( X_d \), Angle is \( \delta \).

When \( I_f \) increases, \( E_q \) then increases, I produce demagnetization armature reaction, then I lag behind \( U_G \), \( \phi \) at the same time change, is lagging, G issued active power P and reactive power Q, then G For the late phase of operation, as shown in Figure 1 (1); on the contrary, when reducing \( I_f \), so that \( E_q \) decreases, \( \phi \) ahead of the \( U_G \), I generate the armature reaction, At this point, G is converted to Q and G is running in leading phase, as shown in fig.1 (2).

![Figure 1. Phasor diagram of lagging and leading phase](image)

3. Small hydropower access grid operation characteristics

Small hydropower refers to a single capacity of 5 MW below the transmission station to use power generation. It changed the load of grid and was susceptible to seasonal changes during seasonal changes. After a long period of research, the heavy load of the wet season and low load of the dry season can run normally. The voltage of the grid system does not change greatly. The whole grid system is very stable. The dam head of dam type hydropower station depends on dam height. At present, the maximum head of dam type hydropower station is not more than 300 meters. The reference flow of dam type hydropower station is large, the scale of power station is large, and the utilization of water power is sufficient. (Due to dams, the formation of reservoir upstream, can be used to adjust the flow) At present the world's installed capacity of more than 2000 megawatts of large hydropower stations are mostly dam-type hydropower station. In addition, the comprehensive utilization of reservoirs of dam-type hydropower stations is high, which can meet the requirements of flood control, power generation and water supply. The dam type hydropower station has large investment and long construction period. Due to the large scale of the project, the flooded area caused by the reservoir is large and the migration population is too large. Applicable to the river slope is slow, the flow is bigger, and has the condition of dam construction.

When the grid is in the low trough load, it will cause some nodes to have the problem of excessive voltage. Through personnel research and analysis, through a variety of means to conduct a comprehensive study of the system and make in-depth study on the voltage and reactive power. Through the theory of reactive power flow and voltage and power grid, combined with the network to
select the appropriate reactive power control mode, the characteristics and performance of the reactive power compensation equipment are used to determine the influence caused by the operation of the small hydropower access grid. Dam-type power station is the water for the storage medium, from the regulatory role. Mainly to solve the power system peak peaking problem. When system load is low, the excess power of the system will be used to drive the pumping station to the upper reservoir (motor + water pump) and store it in the form of water potential energy. When the system load is high, the water on the reservoir will be pushed down to propel hydroelectric generator (turbine + generator) to generate electricity to supplement the lack of electricity in the system. With the reform of the power industry, the implementation of load peak high price, low load low price, the economic benefit of pumped storage power station will be remarkable.

(1) scattered spots, local development, the nearest power supply;
Due to the control of river flow and fall, small hydropower stations have small installed capacity, from thousands of kilowatts to tens of thousands of kilowatts, small storage capacity, poor regulation of power plants, and most of them are runoff type power generation. The power station is scattered and distributed, developed locally and supplied by the nearest power supply. As a result, small hydropower stations are small in size and wide in distribution.

(2) small hydropower near the network, into a piece of power supply
As the small hydropower station installed capacity is small, stand-alone capacity is also small, the corresponding lower power supply voltage level, generally the following voltage near power supply, power supply radius is short. In order to improve the reliability of power supply and the stability of the generator set, the small hydropower stations are connected to each other, and the electric power is complement each other and the mutual adjustment is carried out to form a small distribution network.

(3) small hydropower operation and maintenance is simple
Small power station, such as the distribution of power, as the installed capacity is small, the output line voltage level is low, there are 110kV, 35kV, 10kV, etc., the output line of the wire cross-sectional area is small, pole and tower relative to 220kV and 500kV tower The. So the line operation and maintenance is relatively easy to ultra-high pressure, do not need a lot of manpower and large machinery and equipment, encountered natural disasters easy to repair. In 2008, China's snow disaster in the south, the large power supply, ultra-high voltage line 500kV line down tower, broken line, power station to send electricity, restore 500V line to mobilize a lot of manpower and resources, equipment support was able to recover, Time is relatively long, under the same circumstances, the distribution of small hydropower than the reliability of large power grid is also high.

(4) small hydropower station as a black power supply for large power grids
In January 2008, the southern provinces of China suffered 50 years of extreme frozen disasters, large power grid 500kV and 220kV lines have broken down the tower, the external power to send into a county or even a city to become an island, power outages, The whole network crash all black, large power supply due to disconnection can not send, can not start the grid, only to small hydropower station as a black start power, start the grid, and gradually restore the grid to run.

4. Reactive power balance and voltage stability of small hydropower networks

4.1 Reactive power
When the voltage and current are sinusoidal waveforms and the load is linear, the instantaneous value expression of voltage and current can be written as

\[ u = \sqrt{2}U \sin \omega t \]  
(1)

\[ i = \sqrt{2}I \sin(\omega t - \phi) = \sqrt{2}I \cos \phi \sin \omega t - \sqrt{2}I \sin \phi \cos \omega t \]  
(2)

If the current \( i \) is decomposed into an active component \( i_p \) in phase with the voltage and a reactive component \( i_q \) which is 90° out of phase with the voltage, can be written

\[ i_p = \sqrt{2}I \cos \phi \sin \omega t \]  
(3)

\[ i_q = \sqrt{2}I \sin \phi \cos \omega t \]

The instantaneous power \( P \) is:

\[ p = ui = 2UI \sin \omega t \sin(\omega t - \phi) = UI \cos \phi(1 - \cos 2\omega t) - UI \sin \phi \sin 2\omega t \]  
(4)

The instantaneous power can be divided into two parts that are non-sinusoidal, \( UI \cos \phi(1 - \cos 2\omega t) \), which is the irreversible component of the input or output instantaneous power; \( UI \sin \phi \sin 2\omega t \), the sine quantity is the reversible component of the instantaneous power, which alternates alternately in one cycle, to exchange energy.

Reactive power \( Q \)

\[ Q = UI \sin \phi \]  
(5)

It is the magnitude of the reversible component in the equation, when \( \sin \phi > 0 \) is considered that the port absorbs reactive power when \( \sin \phi < 0 \) is assumed that the port is generating reactive power. Respectively, \( I \sin \phi, U \sin \phi \) for the current, voltage reactive components, reactive power reflects the internal and external exchange of energy between the situation. For a single component is also applicable, that is \( Q_R = 0, Q_L = UI, I_L > 0, Q_C = U_C < 0 \).

The reactive power loss in the transformer is divided into two parts, namely, the loss of the excitation branch and the leakage in the winding leakage. Wherein the percentage of the loss of the excitation branch is substantially equal to the percentage of no-load current, about 1% to 2%, and the percentage loss in the leakage of the winding is substantially equal to the short-circuit voltage when the transformer is fully loaded Percentage, about 10%.

\[ Q_{r} = \Delta Q_R + \Delta Q_L 
= U^2B_L + \frac{P^2 + Q^2}{U^2}X_T 
\approx \frac{I_o}{100}S_N + U_o \frac{S_N}{100} \left( \frac{U}{U_N} \right)^2 \]  
(6)

\[ \Delta Q_L = \frac{I_o}{100}S_N + \frac{P^2 + Q^2}{U^2}X_T \]  
(7)

The excitation power is roughly proportional to the square of the voltage. When the apparent power
through the transformer does not change, the reactive power loss in the leakage resistance is proportional to the square of the voltage. For a transformer or a transformer network, the transformer reactive power loss is not large, full load is about a few percent of its rated capacity. But the multi-voltage level network, the transformer reactive power loss is considerable.

Transmission line with the equivalent circuit \( \Pi \) that the line series reactance in the reactive power loss \( \Delta Q_L \) is proportional to the square of the current through, that is,

\[
\Delta Q_L = \frac{P_i^2 + Q_i^2}{U_i^2} X = \frac{P_i^2 + Q_i^2}{U_i^2} X
\]

\( B/2 \) is the equivalent charge in the shape circuit. The total reactive loss of the line is:

\[
\Delta Q_L + \Delta Q_B = \frac{P_i^2 + Q_i^2}{U_i^2} X - \frac{U_i^2 + U_i^2}{2} B
\]

4.2 Reactive power balance

Reactive power balance means that at every moment the grid is running, the reactive power of all reactive power sources is equal to the reactive power consumed by all loads and the sum of reactive power losses in each link in the system. According to the distribution of the trend, the statistics of the data, you can determine whether the system reactive power balance. The voltage level of the power system is the specific performance of the system reactive power supply and demand balance, but the system frequency and the system active power supply and demand balance situation is very different. The transmission of reactive power not only produces a large amount of active loss but also has a large voltage drop along the transmission path, so the voltage characteristics of each hub in the system are more regional in nature. As the reactive power supply and demand distribution varies, the same time at different points of the voltage level varies. The voltage regulation at each point in the system is mainly dependent on the local balance of reactive power to achieve the mutual support and adjustment of the reactive power supply and demand between different points, often limited, especially in the distance between the electrical distance.

4.3 Voltage control of power systems

(1) to change the grid reactive power distribution. If you can change the lines, transformers and other power components on the voltage loss, it will change the voltage of the power grid nodes. In practice, the reactive power of the generator alone is far from meeting the needs of the reactive power of the grid, and it is necessary to configure various reactive power compensation devices. Reactive power compensation principle is to do reactive power hierarchical partition balance, and to leave enough accident reactive power reserve. Application of reactive power compensation device to adjust the voltage. In the appropriate location of the power grid access to the parallel reactive power compensation device, can reduce the line and transformer reactive power transmission, which can reduce the line and transformer voltage loss and improve the power grid voltage level, while reducing the power grid Power loss, improve economic efficiency. When the system load changes, by adjusting the reactive power compensation device output reactive power, you can control the power grid voltage. Commonly used reactive power compensation equipment is a parallel capacitor and shunt reactor, in the peak load into the parallel capacitor can improve the voltage level of the whole network, the load is low, you can remove some of the capacitors, and even all the cut and then into the parallel reactor.
To prevent the voltage level is too high.
(2) change the transformer variable ratio regulator. By switching the transformer tap to change the ratio, you can adjust the transformer low voltage side or high voltage side of the voltage, only when the system reactive power supply capacity is sufficient, with the transformer to change the ratio of pressure to work. Otherwise, not only by the voltage regulator point change is not, but also cause a further decline in its voltage, which will lead to the entire system voltage collapse. So when the system reactive power is insufficient, the first should be installed reactive power compensation equipment, the system reactive power capacity has a certain margin.
(3) change the generator terminal voltage. Application of generator voltage regulator is no need to increase the investment regulator. The generator terminal voltage is controlled by the excitation regulator, changing the voltage setting of the regulator to change the terminal voltage. The voltage of the generator is closely related to the reactive power output of the generator. When increasing the terminal voltage of the generator, it also increases the reactive power output of the generator. Instead, the terminal voltage of the generator is reduced, and the reactive power output of the generator is reduced. Therefore, the generator terminal voltage adjustment by the generator reactive power limit limit, when the generator output reactive power reaches its upper or lower limit, the generator can not continue to pressure regulator. The reactive power output limit of the generator is related to the active output of the generator. When the active output is small, the range of the reactive power adjustment will be larger and the capacity of the regulator will be stronger.

4.4 Voltage stability of power systems
Voltage stabilization is initially considered a static problem, so the mechanism of voltage instability is also explained from a static point of view. As the former Soviet Union, Markovic proposed the first voltage stability criterion, the \( \frac{dQ}{dU} \) criterion, on a single load-infinite system as a classic and intuitive physical interpretation of voltage stability problems. When the reactive power is excessive, the voltage rise also has a great impact on the stability of the grid. Through the trend calculation can be observed and analyzed.

Figure 2 shows a schematic diagram of the power supply wiring for a single load infinite system. The system is affected by the terminal voltage power characteristics of the system by the power supply electromotive force \( E \) by the transmission impedance \( jX \) to a load by the end of the system operating voltage characteristics.

\[
P = \frac{2 \sin \delta}{E} \sin \delta
\]

\[
Q = \frac{2 \cos \delta - \left(\frac{U}{E}\right)^2}{E} \cos \delta - \left(\frac{U}{E}\right)^2
\]

\[
\left(\frac{P}{E^2}\right)^2 + \left[\frac{Q}{E^2} + \left(\frac{U}{E}\right)^2\right] = \left(\frac{U}{E}\right)^2
\]
\[ \left( \frac{U}{E} \right)^2 = \frac{1}{2} \left[ 1 - 2 \frac{QX}{E^2} \pm \sqrt{1 - 4 \left( \frac{QX}{E^2} - 4 \left( \frac{PX}{E^2} \right)^2 \right)} \right] \]  

(13)

In the above expression, each quantity is the value of a voltage (kV) and a certain capacity (MVA). In particular, when the load is absorbed by the system reactive power, \( Q \) is positive; and when the load to the system to send reactive power, \( Q \) is negative. All \( P \) and \( Q \) values correspond to the value of the corresponding voltage \( U \) value, rather than the value of the rated voltage.

The voltage stability problem is related to the power generation system, the transmission system and the load system. Transmission network strength and power transmission level, the generator reactive power voltage control restrictions, the load voltage characteristics, reactive power compensation equipment characteristics and the role of voltage control equipment together determine the level of system voltage stability.

The power supply line produces both reactive and reactive power, and its net reactive value must be equal to the amount of power that the two ports of the line absorb or emit from the system. The shunt capacitor or the charging capacitor sends a reactive power proportional to the square of the voltage. Since the node voltage must remain within the rated voltage (1 ± 5%), the reactive power generated by the line is relatively constant. Transmission line series inductance consumption and the current square is proportional to the reactive power. Because the current from heavy to light load changes greatly, power line reactive power consumption also will have a big change. In this way, the net reactive power of the transmission line changes in a load cycle.

## 5 Analysis of Feed - in Operation and Stability of Hydro - generator

### 5.1 Water turbine generator working principle

The hydro-generator is a salient-pole synchronous generator. The stator is the stationary part of the hydro-generator, mainly composed of the base, the core and the armature winding stator winding. The rotor is composed of the magnetic pole, the rotor winding and the rotating shaft. They constitute two main parts of the hydro-generator. As the two parts are equipped with windings, the current generated by the cohesive magnetic field. The structure of the hydro-generator must be such that the energy dissipation of the combined magnetic field is a function of the angular displacement of the rotor in order to produce a continuous motor energy conversion during rotation. Specifically, the stator, the rotor winding is a field winding that is the rotor winding, through the shaft on the collector ring and brush device to introduce DC current, the introduction of the current in the rotor magnetic pole to produce the main magnetic flux and the formation of the main pole magnetic field, And the other is the armature winding stator winding, which is mounted on the other side of the air gap to have relative movement between the main magnetic field and the main magnetic field. When the turbine drags the generator shaft rotor rotation, the rotor main pole magnetic field rotation, cutting armature winding, so that the induction in the winding potential, when the armature winding and the outside three symmetrical load connected, the armature winding will have AC current, the whole process of work is the basic working principle of hydro-generators.

Excitation system by the excitation of the main circuit and excitation circuit composed of two parts. The excitation main circuit includes the excitation winding of the synchronous generator, the excitation power supply, the rectifying device and the demagnetizing circuit. The excitation circuit includes automatic and manual excitation adjustment device.
5.2 Static stability analysis of hydroelectric generator in phase

The principle of the hydrodynamic phase of the hydro-generator is described in detail in Section 1.2. The hydro-generator is a salient-pole synchronous generator. The static stability limit is the same as the power angle between the static stability limit and the variable angle. At the moment, the relationship between the active power and the reactive power of the salient-pole generator in the system when the static stability limit is reached:

\[
P^2 = \frac{(Q + U^2)}{X_s} = \frac{(Q + U^2)}{X_s} - (Q + U^2)
\]

(14)

\[
P^2 = \frac{(Q + U^2)}{X_s} = \frac{(Q + U^2)}{X_s} - (Q + U^2)
\]

(15)

The above equation shows the relationship between the active power and the reactive power of the system when the static stability limit is obtained after the system impedance. After taking into account the effect, the same P value is allowed to enter the phase of the reactive power reduction. If the generator to maintain a certain stability reserve, the phase of the operation of the safety limit should be further reduced. At this point, static stability will be the main limit for the output of the generator to allow the output of the generator.

Figure 3. Power-angle diagram in different excitation

Figure 4. LD power grid topology

6. Case study

For a region of Hainan LD power grid, the regional power grid is rich in a large number of small hydropower stations, in the event of natural disasters, can effectively provide electricity to support it, to ensure that the county power supply, but when the low load period, often make LD power grid node voltage Too high, this paper through the trend of the calculation and analysis, in the technical conditions of small hydropower units can enter phase operation. In the actual investigation of the situation of hydropower stations also proved that small hydropower units can enter the phase to run.

The small hydropower output and load values in LD grid are shown in Tables B1 and B2.

The voltage of each node before and after the operation of small hydropower is shown in Fig:
Figure 5. Comparison of voltage before and after the operation of small hydropower

As can be seen from the figure, in the hydropower overdue period to avoid the network node voltage is too high, you can consider the small hydropower phase into the run, and can be a good drop in a node voltage.

7. Conclusion

In summary, through the above experimental study, the grid system voltage adjustment method, for the small hydropower network in the wet period of low load, the grid voltage changes and the reasons for the increase in the grid has a comprehensive understanding. The non-power balance of the power grid has a certain control effect on the voltage stability of the power grid system, and can effectively stabilize the voltage of the grid in the low water load during the wet period. As long as the control voltage within the specified range, it is necessary to control the power of the grid, and then the grid voltage control in a reasonable range.

In the representative small hydropower station carried out on-site tuning magnetic operation, showing the phase of the operation of the power grid has a certain effect, and that the small hydropower units have the ability to enter the phase. In the water during the full period to avoid the network node voltage is too high, you can test

Consider small hydropower into phase operation, and can be a good way to reduce the node voltage.

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