

# Overall setting and cooperation method for power protection of large hydropower plants

Lei Yang<sup>1</sup>, Chuan Xiang<sup>1</sup>, Xin He<sup>1</sup>, Chao Xing<sup>1</sup>, Xinze Xi<sup>1</sup>, Shixian Sheng<sup>2</sup>, Can Xiao<sup>2</sup>, Jiasi Liao<sup>2</sup>

<sup>1</sup>Electric Power Research Institute of Yunan, Kunming, Yunan Province, China

<sup>2</sup>Southwest Jiaotong University, School of Electrical Engineering, Chengdu, Sichuan Province, China

E-mail: 1373591113@qq.com

**Abstract:** Aiming at solving the operation risk problems caused by the improper protection settings, this paper proposed a new method for the protection setting of the auxiliary power of large hydropower plants. This method applied the idea of setting from LV grade to HV grade, where each type of protection sets the value based on the setting principles and calibrates their sensitivity with their own protection range. This method handled the insufficient sensitivities of protection at the price of sacrificing the lower levels of the protection. Then based on the settings from the dispatch and control center, it vertically conducted the verification of protection setting coordination, preventing the override tripping and expanded scope of accidents. The practical applications indicate that this method could improve the protection setting accuracy of large hydropower plants and limit the operation risks of the auxiliary power within a low level.

## 1.Introduction

Yunnan is rich in water resources. In recent years, large hydropower plants connected to the Yunnan 500kV main network have: A power plant in Zhaotong area with a total installed capacity of  $9 \times 700\text{MW}$ ; and B power plant in Pu'er area with a total installed capacity of  $9 \times 650\text{MW}$ ; Lijiang area C power plant, the total installed capacity of  $5 \times 360\text{MW}$ ; Lijiang D power plant, with a total installed capacity of  $5 \times 360\text{MW}$ ; Lijiang area E power plant, the total installed capacity of  $5 \times 400\text{MW}$ ; In addition, there are F power plants and G power plants. Yunnan Power Grid not only plays an important role in power supply in the South Network, but also has a large amount of power transmission to neighboring countries in the southwest. Therefore, ensuring the accuracy of relay protection setting of the large hydropower plants in Yunnan is one of the important links to ensure the stability of the power supply of the South Network and neighboring countries.

Comparatively speaking, the operation mode of the plant power consumption of large hydropower



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plants and the requirements for the accuracy of protection settings have their own characteristics. First of all, the impact of large hydropower plant failures on grid stability is large. The analysis of "Yunnan Power Grid Operation Mode" shows that the fault of the A power plant in the flood season will cause 220kV I line overload, and the grid frequency will drop by about 0.3Hz. The fault of the B power plant will cause the grid frequency to drop 0.3Hz, both have exceeded the frequency fluctuation range of the South Network. Secondly, large hydropower plants have large single-unit capacity and a large number of units. In order to ensure the reliability and flexibility of the power supply of the plant, many plant power supplies and power supply points are often set up. The wiring and operation modes of the plant power system are complicated. It brings great difficulties to relay protection setting and protection value matching. If the setting and coordination are not proper, it will lead to the chain reaction of the plant power system, causing multiple units to trip, and even affect the entire power plant. In addition, due to the repeatability of the large hydropower plants, the structure and setting of the power consumption of the plant often adopt uniform principles and setting methods. If the method is improper, it will usually result in the error of consistency of multiple units, leaving great security risks to the stability of the power grid. The stability calculation criterion of Yunnan Power Grid requires that any generator set in the system trip or lose its magnetism, and the protection and circuit breakers operate correctly, which can maintain the stable operation of the system and the normal power supply of the power grid. However, the setting calculation and coordination errors of the plant power supply usually cause multiple units to trip at the same time. Therefore, it is urgent to sort out the protection and setting methods of power consumption in large hydropower plants, verify whether all levels of protection cooperate with each other, ensure the power supply reliability of large hydropower plants, and avoid the occurrence of over-grade tripping that leads to the disalignment of multiple units [1]~[13].

In recent years, many scholars have proposed ways to improve the rationality and accuracy of power plant setting values for large power plants. Reference [10] proposes to shorten the time difference to 0.2s to ensure the quickness of the main protection. Reference [11] proposes to improve the wiring of the system to make the operation mode of the plant power system clearer and more reasonable. Reference [12] pointed out that the selectivity of over-current protection can be realized according to the step-by-step matching principle of over-current protection time limit, which will make the fault current increase and the damage degree of equipment more serious when the fault occurs closer to the power side. It is suggested to reasonably determine the timing matching grade difference. Reference [13] proposes to design and develop a set of engineering and practical tuning software platform that can meet different protection configurations of different manufacturers.

The existing literature mainly tends to improve some aspects of the plant power setting, and lacks the analysis of the existing problems of the existing large-scale hydropower plant protection settings, and does not sort out the setting process and method. This paper proposes a holistic approach and method for plant power setting by analyzing the actual over-the-counter trip of plant power in Yunnan Power Grid. The practical application shows that the proposed method is of great significance to ensure the quality and accuracy of the fixed value setting of large-scale hydropower plants.

## **2. Power operation risk of large hydropower plants**

### *2.1. Current status of power plant setting in large hydropower plants*

The existing power plant setting of large hydropower plants mainly faces the following problems:

1) The operation mode is complicated. With the increase of power plant units and the increase of installed capacity, the system wiring of large-scale hydropower plants is complicated and the operation modes are numerous. Any omission of operation mode may lead to incorrect operation of protection.

2) There is a contradiction between the sensitivity and the step-by-step coordination of protection. In order to satisfy the stepwise coordination of protection, the upper relay protection may be required to have a higher overcurrent setting value, but this value cannot meet the requirements of the upper relay protection's sensitivity, causing a contradiction.

3) The backup protection value of the high-voltage transformer used in the factory is given by the central dispatch. The protection of other parts of the power system of the plant is self-tuned by the power plant. If the two lack effective communication and coordination with the protection value, it may cause a leap-level trip of the protection.

### *2.2. Large-scale hydropower plant power consumption risk*

The following two typical plant power over-the-counter trip events occurred in Yunnan Power Grid are used to detail the operational risks of existing plant power.

Accident 1: In 2012, the high-variable backup protection action of a No. 3 generating unit of a power station jumped off the 500kV two-side circuit breaker, the #3 generator outlet short-circuiter, and the #4 generator outlet short-circuiter, causing the two units to be shut down. The two overhaul drain pumps of the 400V fourth group of common electric B sections are started at the same time, and the starting current and starting time exceed the fixed value of the high-variable over-current section II of the No. 3 plant, resulting in protection action.

Accident 2: In 2012, the protection of generators and transformers of No. 4 and No. 5 of a power plant "protection action of the high-voltage transformer over-current II section of the plant" caused the shutdown of Units 4 and 5. The cause of the accident was that the 400V bridge machine was approaching during the completion of the power transmission. The friction between the B and C phase cables on the power supply side of the slip wire and the steel structure bracket causes a phase-to-phase short circuit. 0.4, 10.5kV protection failed to work because: the setting value of the main body protection of the power switch of the bridge machine inlet line, the setting value of the main body protection of the main body protection of the b section of the first group of 400V public electricity and the setting value of the power transformer protection device of the b section of the first group of public electricity is too large; and this short circuit is short-circuited by the transition resistor so that the short-circuit current is too small. The 10.5kV protection timing calculation is low in sensitivity and improperly matched with high plant overcurrent protection, which eventually leads to the No.5 high plant overcurrent II protection action, and the 4th and 5th sections of the plant use the power reserve action, the 4th and 5th sections of the plant to be closed by the tie switch. Then the maintenance personnel see that the power transmission voltage is abnormal. Manually disconnect the 400V power supply of the bridge machine, and the fault point is cut off. Otherwise, the 5th and 6th sections are prepared for self-injection, and the #6 unit will also be cut off.

Based on the above two accidents, it can be seen that the operational risks caused by the improper setting of the protection value of the existing large hydropower plants are as follows:

1) There is no step-by-step coordination of plant power protection (including time coordination and reference volume coordination), which is one of the operational risks of existing hydropower plants. The main reason for causing accident 1 and accident 2 is that the fixed value of the plant power protection is not coordinated step by step, resulting in over level tripping in the event of a fault, loss of selectivity, and an increase in the scope of the accident.

2) There is no uniform setting principle and mutual cooperation between the plant protection and the same level, especially through the parts that are connected by self-injection. Accident 2 reflects that the 400V bus-coupled circuit breaker cannot reflect the fault on the connected busbar, resulting in a chain reaction, and the fault is difficult to remove, which greatly expands the scope of the accident. At the same time, the plant change backup protection action should make the self-injection action lock and prevent the switch from being connected to the faulty line.

3) The sensitivity of protection is lacking. Next level of protection is less sensitive, resulting in over level tripping; the sensitivity of the same-stage bus-coupled short-circuit protection is low, resulting in the transmission of faults.

In summary, the setting of the power protection rating of the plant needs to be improved from the depth and breadth of the propagation.

## **3. Setting of power protection value for large hydropower plants**

The process of setting up electricity for hydropower plants is shown in Figure 1. The setting of the power system of large hydropower plants mainly includes the following parts: calculation of plant power system parameters, calculation of 10.5kV short-circuit current, calculation of 400V short-circuit current, calculation of 400V protection setting, calculation of 10.5kV protection setting, and inspection of protection coordination.

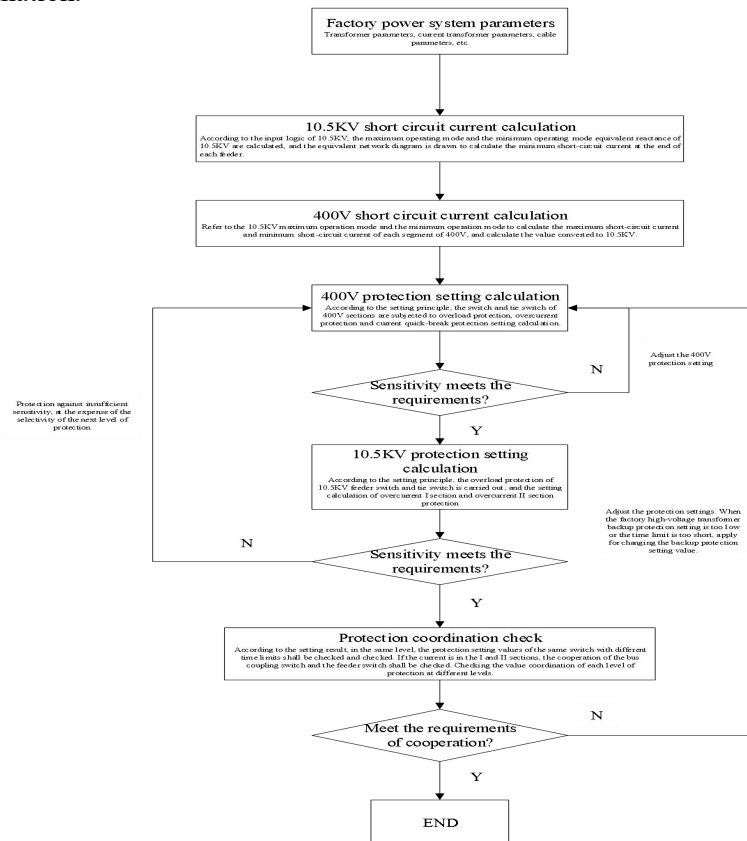


Figure 1. Flow chart of power plant power plant.

### 3.1. Short circuit current calculation

Assume that the upper part of the transformer used in the factory is an infinite system,  $S = \infty$ ,  $X_j^* = 0$ , generally take the reference power:  $S_j = 100MVA$ , the reference voltage is the average voltage  $V_j = V_p$ . The maximum operating mode and the minimum operating mode are selected from all possible operating modes including the self-injection. 10.5kV needs to calculate the minimum short-circuit current at the end of segment of the feeder  $I_{d\_10.5kV}^{\min}$ , for the 10.5kV feeder switch and the bus-coupled switch over-current I segment sensitivity check. Similarly, 400V needs to calculate the maximum short-circuit current  $I_{d\_400V}^{\max}$ , and minimum short-circuit current  $I_{d\_400V}^{\min}$ , and calculate the value converted to 10.5kV  $I_{d\_10.5kV}^{\text{eq max}}$  and  $I_{d\_10.5kV}^{\text{eq min}}$ .

### 3.2. 400V protection setting calculation

#### 1) Overload protection (L)

Since the overcurrent II segment avoids the maximum starting current of the motor connected to the 0.4kV bus, the overload protection acts only as a severe overload protection for the transformer and acts as a trip.

Setting principle: Avoid the normal overload current and allowable running time of the low-voltage factory transformer[14].

$$I_{setI} = K_{rel} I_e / K_{re} / I_n$$

$$= K_{rel} S_n / (\sqrt{3} U_n) / K_{re} / I_n \quad (1)$$

In the formula:  $K_{rel}$  — the reliability factor, taken as 1.2;

$K_{re}$  — return coefficient, taken as 0.85;

$I_e$  — rated current of low voltage transformer used in factory;

$I_n$  — The rated current of the circuit breaker.

## 2) Time-limited overcurrent II segment protection (S)

Since the protection object belongs to the end of the load, it is only necessary to avoid the maximum load current and the motor is self-starting<sup>[14]</sup>.

The maximum motor self-starting current is:  $I_{ss.max} = \sum K_{ss} I$ ;

Setting value:  $I_{set}^{II} = K_{rel} \times I_{ss.max}$

$$n = I_{set}^{II} / I_n$$

Among them,  $I_n$  is the rated current of the switch,  $K_{rel}$  is the reliability factor, which is 1.2.

Sensitivity check:

$$K_{sen} = I_{d-400V}^{\min} / (n I_n) > 2 \quad (2)$$

Where:  $I_{d-400V}^{\min}$  — 400V minimum short-circuit current, calculated from short-circuit current.

## 3) Current quick-break protection (I)

Two-phase short circuit with 400V busbar has 2 times sensitivity calculation  $I_{set}^I = I_{d-400V}^{\min} / 2$

Setting value  $n = I_{set}^I / I_n$

$I_n$  is the rated current of the switch.

## 400V factory power contact switch protection setting calculation

According to the operation mode of the 400 V system, that is, during normal operation, each segment runs independently. When one of the power failures occurs, the communication switch is closed by the self-injection device, and the power supply continues to be supplied to the power failure segment. According to the protection tuning selectivity principle, when a short-circuit fault occurs in the power failure section, the contact switch should be tripped first. Therefore, the protection setting calculation of the tie switch is set according to the minimum short-circuit current of each segment.

### 3.3. 10.5kV protection setting calculation

#### 1) Overcurrent I

The overcurrent I segment, quick-break, is calculated according to the following principles<sup>[14]</sup>:

a) Maximum short-circuit current flowing through the protective installation when avoiding an external short circuit:

$$I_{set}^I = K_{rel} I_{d-400V}^{\max} / n_{TA} \quad (3)$$

Where:  $K_{rel}$  - the reliability factor, taken as 1.1;

$I_{d-400V}^{\max}$  — In the maximum mode, the short-circuit current of the three-phase short circuit occurs on the low-voltage side of the low-voltage transformer of the factory;

$n_{TA}$  - CT ratio.

b) Avoid the magnetizing inrush current of the transformer:

$$I_{set}^I = (3 \sim 5) I_n / n_{TA} \quad (4)$$

In the formula:  $I_n$  - the rated current of the high voltage side of the low voltage transformer used in the factory  $I_n = S_n / (\sqrt{3} \times U_n)$ .

c) Sensitivity check:

$$K_{sen} = I_{d\_10.5kV}^{\min} / (n_{TA} I_{set}^I) > 2 \quad (5)$$

Where:  $I_{d\_10.5kV}^{\min}$  - Minimum short-circuit current of 10.5kV bus.

2) Overcurrent section II

a) The overcurrent II section, quick-break, is matched with the maximum starting current of the motor that needs to be self-starting on the low-voltage transformer used in the factory, and cooperates with the 400V incoming timing definite current protection [14]. Available:

$$I_{set}^{II} = K_{rel} I_{set,400V}^{II} \quad (6)$$

Where:  $K_{rel}$  - the coefficient of cooperation, take 1.1;

$I_{set,400V}^{II}$  - 400V incoming line timing limit overcurrent protection setting.

b) The action delay matches the overcurrent protection of the low side branch.

c) Sensitivity check

$$K_{sen} = I_{d\_10.5kV}^{eq \min} / I_{set}^{II} > 2 \quad (7)$$

In the formula:  $I_{d\_10.5kV}^{eq \min}$  - The minimum short-circuit current of the two phases occurs on the low-voltage and low-voltage side busbars of the plant (returned to the 10.5kV side).

3) Overload protection

Operating current  $I_{set,I} = K_{rel} I_{nH2} / K_{re}$

In the formula:  $K_{rel}$  - the reliability factor, generally takes 1.05 when acting on the signal;

$K_{re}$  - return coefficient, generally 0.95

$I_{nH2}$  - Maximum load current,  $I_{nH2} = S_n / (\sqrt{3} \times U_n) / n_{TA}$ .

4) Low-voltage and low-voltage side zero-sequence overcurrent protection

Calculated by avoiding the normal maximum unbalance current:

Operating current  $I_{set,0} = 25\% I_{nL2} / n_{TA0}$

In the formula:  $I_{nL}$  - rated current of low voltage side of low voltage transformer used in factory  $I_{nL} = S_n / (\sqrt{3} \times U_{nL})$  ;

$n_{TA0}$  - Low-voltage side zero-sequence CT ratio.

### 3.4. Protection coordination check

According to the setting result, in the same level, the protection setting values of the same switch with different time limits are checked; the matching of the bus coupling switch and the incoming line switch and the feeder switch is checked. In different levels, check the matching of the protection of each level of protection. The inspection of the protection cooperation mainly includes the following points:

1) The sensitivity of 10.5kv feeder switch over current I section, 10.5kv feeder switch over current II section, 400V inlet switch speed break protection, 400V inlet switch over current II section is greater than or equal to 2;

2) Check the coordination of 10.5kv feeder switch over current section I, II and overload; Check the 400V current break, over current section II and over load.

3) 10.5kV feeder switch over-current I section and 400V incoming line switch quick-break protection cooperate with each other, the former is larger than the latter;

4) 10.5kV feeder switch overcurrent II segment and 400V inlet switch overcurrent II cooperate with each other, the former is greater than the latter;

5) 10.5kV feeder switch overload and 400V line switch overload cooperate with each other, the former is greater than the latter;

6) The protection coordination time difference satisfies  $\Delta t=0.2\sim 0.5$  seconds;

7) The 10.5kV feeder switch overcurrent I and II sections must also be matched with the factory high voltage transformer backup protection.

#### 4. Instance verification

In order to verify the feasibility of the above-mentioned plant power setting method, the method is used to set the power setting value of a power plant in Yunnan. The setting results and the coordination check of protection are shown in Table 1.

Obviously, using the tuning method of this paper, the accuracy of the setting from the depth and the breadth is effectively ensured, and the protection of the leap-level trip situation is avoided. The actual engineering application shows that the improved setting value by using this method greatly improves the reliability of the plant power protection action and is conducive to the safe and stable operation of the power grid.

**Table 1.** Consolidation results and coordination check of protection.



Circuit breaker name	Remarks	10kV incoming feeder switch Overcurrent I section (T=0.05S)	10kV incoming line feeder switch overcurrent I section sensitivity check	10kV incoming feeder switch overload protection (T=20S, alarm)	Low-voltage side zero-sequence overcurrent (T=1S, trip)	400kV incoming current fast-break Idmin/2 (sensitivity is 2)
011	Unit 2 self-use b segment	7.49	2.93	0.51	2.26	3.35
012	The first group of public electricity a segment	6.96	2.36	0.48	2.84	4.03
021	Unit 3 self-use electricity a segment + 5 machine self-use electricity b segment	7.53	2.91	0.51	3.01	3.35
022	Unit 4 self-use electricity a segment + 6 machine self-use electricity b segment	10.52	2.09	0.51	3.01	4.45
023	The first group of public electricity b segments	7.07	2.33	0.48	2.84	4.06
026	The second group of public electricity a segment	7.07	2.33	0.48	2.84	4.06
027	Unit 1 self-use a segment	8.23	2	1.22	7.22	6.91
031	Unit 2 self-use a segment	7.57	5.71	0.51	2.26	3.81
032	Unit 6 self-use electricity a segment + 4 machine self-use electricity b segment	7.57	5.71	0.51	3.01	3.81

033	Unit 5 self-use electricity a section + 3 machine self-use electricity b section	10.56	4.09	0.51	3.01	5.28
089	Unit 1 self-use electricity b segment	8.85	2	1.62	7.22	6.17
045	The second group of public electric b segments	6.63	2	0.48	2.84	3.8

**Continued Table 1.** Consolidation results and coordination check of protection.

Circuit breaker name	Quick break test		400kV incoming line overcurre nt II segment setting (T=0.5)	400kV incoming line overcurre nt II section sensitivity	10kV overcur rent II section (T=0.7S )	10kV overcur rent II segment sensitivi ty	Factory high change backup test (T=3.5S)		400V overload setting		
	10kV incomin g line feeder switch overcur rent I section current value	400kV incoming current quick-brea k current value (10kV side)					10kV incomin g line feeder switch overcurr ent II section current	10kV incomin g line feeder switch overcurr ent I section current			
011	449.4	159.5238	<div></div>	2	<div></div>	3.3 5	1.75	3.03	105	449.4	0.82
012	556.8	191.9048	<div></div>	2.5	<div></div>	3.2 2	1.64	2.93	131.2	556.8	1.03
021	451.8	159.5238	2	1.5	3.35	4.4 6	3.06	1.74	183.6	451.8	0.82
022	631.2	211.9048	1.5	1.5	5.93	5.9 3	2.62	2.7	157.2	631.2	0.82
023	565.6	193.3333	<div></div>	2.5	<div></div>	3.2 5	1.64	2.94	131.2	565.6	1.03
026	565.6	193.3333	<div></div>	2.5	<div></div>	3.2 5	1.64	2.94	131.2	565.6	1.03
027	658.4	329.0476	<div></div>	5.5	<div></div>	2.5 1	3.6	2.58	288	658.4	2.61
031	454.2	181.4286	<div></div>	2	<div></div>	3.8 1	1.75	3.45	105	454.2	0.82
032	454.2	181.4286	2	1.5	3.81	5.0 7	3.06	1.97	183.6	454.2	0.82
033	633.6	251.4286	1.5	1.5	7.05	7.0 5	2.62	3.2	157.2	633.6	0.82
089	531	293.8095	<div></div>	3	<div></div>	4.1 1	2.62	4.22	157.2	531	2.61



045	530.4	180.9524		2		3.8	1.31	3.45	104.8	530.4	1.03
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## 5. Conclusion

This paper describes in detail a calculation method for the power setting of large hydropower plants. The system adopts the calculation method of the sub-module, and points out that it should cooperate with the logic of the self-injection, list all possible operation modes, select the maximum operation mode and the minimum operation mode to prevent the protection setting value from being incorrect due to the omission of the operation mode. . For the case where the sensitivity requirements and the protection coordination requirements conflict, a treatment method that satisfies the compatibility requirements by sacrificing the selectivity of the lower protection is proposed. The problem of protection coordination is checked from both depth and breadth, which effectively avoids the occurrence of protection overstepping trips. The power-setting method proposed in this paper is of great significance to the stable operation of the power plant. It is also conducive to the establishment of the plant power setting and professional inspection system, laying the foundation for the programmatic realization of the plant power setting and protection coordination check.

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