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Electric braking method in hydroturbine generating unit and transformation scheme

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Abstract. The purpose of this paper is to study the electrical control and reconstruction of hydroelectric generating units. In general, there are two kinds of braking methods for hydraulic turbines: mechanical braking and electrical braking. The mechanical braking method has the disadvantage of low automation. Through the research and analysis of practical examples, a modified scheme of the combination of electric and mechanical braking water turbine generator sets is put forward. First of all, from the aspects of moment control and the design scheme, a detailed explanation on the electric braking method is introduced. The range and scope of application of various schemes concerning the advantages and disadvantages of different design schemes on the electric braking system is discussed. Secondly, based on the existing situation and transformation requisition of the generating unit electric braking system in Pingban hydropower station, this research is conducted. It is also the necessity and availability of the transformation. Finally, the concrete transformation scheme on the electric braking system in Pingban hydropower station is expressed in detail. The results show that the scheme improves the operating efficiency of hydroelectric generating units. Therefore, it is concluded that electrical control has important significance for hydroelectric generating units.

Key words. Hydroturbine generating unit, electric braking, mechanical braking, transformation scheme.

1. Introduction

During the working of electric system, the hydropower station generating unit is in the functions of peak load regulation of power grid and emergency standby [1–2]. Hydroturbine generating unit has two kinds of braking methods: electric braking and mechanical braking [3]. In general, the mechanical braking method creates the braking effect through the fraction drag generated by the touching of brake valve and

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brake ring, whereas the electric braking works through consuming the main power in a form of electricity and generating reverse electromagnetic force in the motor [4].

The generating unit employs traditional braking method: mechanical braking method, which is reliable, convenient and widely applicable, with low energy consumption [5]. Its braking effect will not be influenced by faults like power interruption or short-circuit of line owing to its high reliability and safety [6]. However, this mechanical braking method also has some shortcomings, for example, the powder generated during the braking process may enter the ventilation ducts, and powder accumulation during long periods of time will downsize the cross-section area of ventilation ducts and result in loss in cooling effect. During the process of braking, the surface temperature of the braking ring will increase rapidly, leading to thermal distortion and even crack. The airlock sometimes cannot fall itself, so our personnel will inspect the wind tunnel at every stop of it, which also lowers its level of automation [7].

To resolve the problems in mechanical braking, we conduct electric braking on hydroturbine generating unit here. Electric braking refers to a non-contact braking method based on synchronous motors electromagnetic induction principle, whose advantages lie in the high level of automation, high reliability and efficiency, as well as low abrasion and pollution [8]. On account of this, we analyze the electric braking moment control of generating unit and the influence on relay protection. We also design the transformation scheme for the electric braking system in Pingban hydropower station generating unit concerning the setbacks.

2. State of the art

During the practicing process of hydroturbine generating unit, the electric braking moment changes a lot, which is much more obvious especially when the generating unit speed decreases to be in a low statue [9]. In general, the electric braking moment is larger than the ultimate moment of the principal axis system [10]. So, there is some kind of danger. To ensure the safe operating of the generating unit, the electric braking system will be installed on the generating units that are frequently switched on and off, in order to better control the braking moment around rated torsion moment M_{e}. The ultimate moment of principal axis system T [11–12] can be expressed as:

$$T = KM_{\mathrm{e}} \,. \tag{1}$$

In this formula, K refers to the safety factor (often being 2.5). And the torsion moment of the principal axis system in generating unit M can be identified as:

$$M = \frac{60 * P_{\mathrm{M}}}{2\pi n}, \quad P_{\mathrm{M}} = P_2 - P_{\mathrm{Cu}} \,. \tag{2}$$

In this formula, P_{M} is the generator electromagnetic power, P_2 is the electric load power. When the hydroturbine generating unit is under the rated speed (N_{e}), the rated power(P_e) is in the condition of ($P_e = P_2$), then M_e can be identified as

$$M_e = \frac{60(P_e - P_{Cu})}{2\pi N_e} P_e = \sqrt{3} U_e I_e \cos\phi \,. \tag{3}$$

Here, ϕ is generator power factor, and I_e is the excitation current. If the copper loss of the stator winding is omitted, then

$$M_e = \frac{60 P_e}{2\pi N_e} = \frac{60(\sqrt{3} U_e I_e \cos\varphi)}{2\pi N_e} \,. \tag{4}$$

If the electric braking moment M_E is not larger than M_e, then

$$\frac{60 \cdot 3 I_k^2 R}{2\pi n} \leq \frac{60(\sqrt{3} U_e I_e \cos\varphi)}{2\pi N_e} \,. \tag{5}$$

In this formula, I_k is the braking current. During the process of electric braking, $M_E < M_e$ at first. If $I_k = I_e$, and remains constant, there is no need to modulate I_e to change I_k. This is the braking phase I. If the speed of generating unit keeps decreasing, $M_E = M_e$, until the generating unit stop completely. This is braking phase II.

If $I_k = I_e$ and remains constant, and also $M_E < M_e$ and n is the variable, then

$$\frac{60 \cdot 3 I_k^2 R}{2\pi n} < \frac{60 \cdot 3(\sqrt{3} U_e I_e \cos\varphi)}{2\pi N_e} \quad \to \quad \frac{\sqrt{3} I_e R}{U_e \cos\varphi} < \frac{n}{N_e} \,. \tag{6}$$

The critical rotating speed value is

$$n_1^* = \frac{\sqrt{3} I_e R}{U_e \cos\varphi} \,. \tag{7}$$

In this phase, the excitement current must be regulated, and keeping M_E around M_e. That is

$$\frac{60 \cdot 3 I_k^2 R}{2\pi n} = \frac{60 \cdot (\sqrt{3} U_e I_e \cos\varphi)}{2\pi N_e} \,. \tag{8}$$

Because I_k and n are all variables, then

$$I_k^2 = \frac{n}{N_e} \cdot \frac{U_e I_e \cos\phi}{\sqrt{3} R} \,. \tag{9}$$

From this, we can see that if keeping the value of M_E around M_e, we just need to regulate I_e and n, ensuring that they satisfy the relationships in formula (9).

3. Methodology

Hydroturbine generating unit is often equipped with independent electric braking device, as shown in Fig. 1.

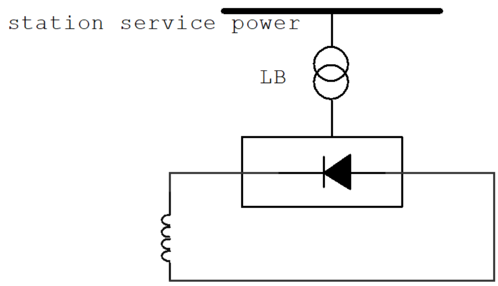

Fig. 1. Structure of independent electric braking device (note: LB—excitation transformer)

his device is applicable for all hydroturbine generating units. But it requires to set panel additionally, adding to the cost and difficulty in setting. However, to overcome the setbacks of independent electric braking method, some foreign researchers proposed a new mode of combining the electric braking of the generating unit with the excitation system [13–15], as shown in Figure 2.

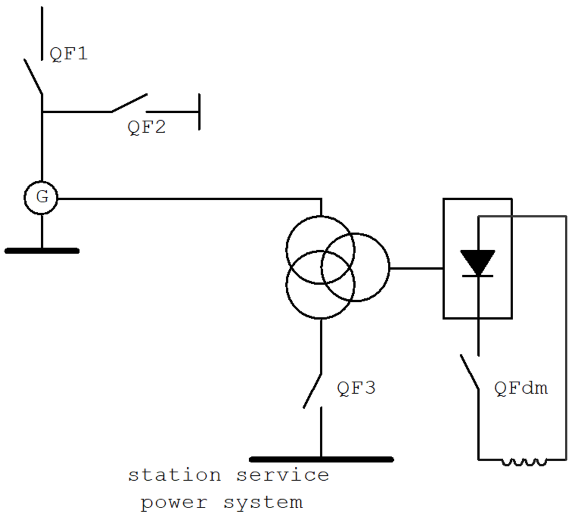

Fig. 2. System block diagram of combining electric braking with excitation system in generating unit (notes: QF1—circuit breakers, QF2—short circuiting switch, QF3—braking switch, QFdm—magnetic blow-out switch)

After analysis of Fig. 2, we can see that this mode can decrease costs to a large extent and also downsize the floor space. It belongs to an economic mode, deserving to be put into use.

In the practical process of operating, however, the mechanical braking of the generating unit is also an indispensable part, because electric braking only applies to the normal shutdown of generating unit or the emergency shutdown of nonmechanical generating unit [16]. Therefore, to improve the operating situation of thrust-bearing liner at low rpm, most manufacturers employ composite braking of electricity and mechanics at low rpm. The braking effect is better when starting the mechanical braking system at 10 % of the rated rotation speed [17].

4. Result analysis and discussion

4.1. About the hydropower station

We conduct this research with pingban hydropower station as an example. There are 3 hydroturbine generating units with 135 MWh in this station. The area of reservoir-controlled basins is 56000 km^2, the average annual flow rate is 616 m^3/s, the average annual volume of runoff is 1.94×10^{10} m^3. The normal storage level is 440 m, and the total reservoir storage is 2.78×10^{8} m^3.

4.2. Analysis on the necessity and availability of transformation

The braking method that Pingban hydroturbine generating unit employs is mechanical braking. The operating time and braking time is a bit long. The braking method combining electricity and mechanics refers to decreasing the rotating speed of the generating unit by conducting mechanical braking fraction moment rather than electric braking moment on the generator during stop [2], thus to realize its braking effect. Furthermore, the hydroturbine generating unit in Pingban hydropower station is switched on or off frequently. So, to avoid intensifying the system abrasion and improving mechanical durability, it is necessary to transform the mechanical braking method to the method of combining electric braking and mechanical braking.

Based on the above analysis on operation process and other aspects of electric braking moment, we can work out the decelerated curve of the generating unit (Fig. 3). The following is about the calculation on the basic parameters of 4 hydroturbine generating units. The original computed parameters of generating unit are expressed in Table 1.

From Fig. 3, we can see that it needs 290 s for the generating unit to stop from the rated rotating speed, among which, the time length from the start of electric braking to stop is 230 s.

According to the development and construct situation of Pingban hrdropower station in recent years, we choose the electric braking point of short circuit at the generator outlet. From the generator outlet to the low voltage side of main transformer, the main circuits are PT cabinet (set at the middle level of the main power house), generator outlet CT, excitation transformer, and generator circuit-breaker respectively. In addition, the equipment needed additionally involves [18] an electric braking switch and braking transformer.

Table 1. Original computed parameter of generating unit

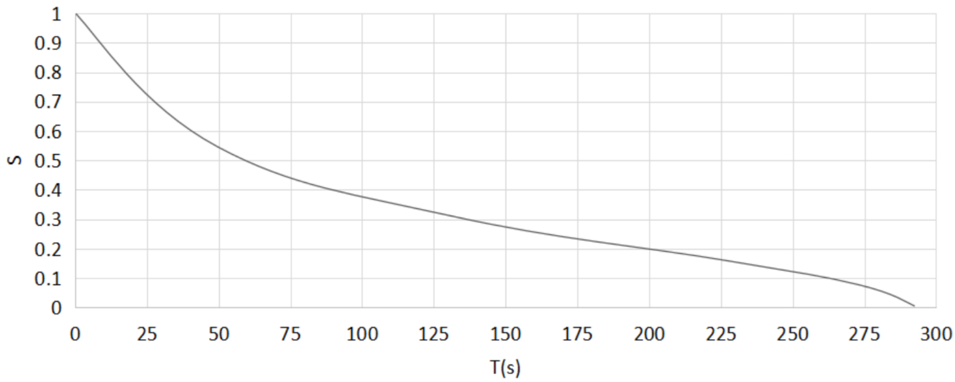

Fig. 3. Decelerated curve of the hrdroturbine generating unit (notes: $S = n/n_{\mathrm{N}}$, the rotating speed of electric braking is $0.05n_{\mathrm{N}}$, which is 100 rpm and braking current $I = I_{\mathrm{n}}$

Parameter	Value	Parameter	Value
Rated powerP_{N}	220 MW	Specific rotating speed n_x	150 rpm
Rated voltage U_{N}	18 kV	Stator core inside diameter D_{i}	8.06 m
Rated power factor $\cos\theta$	0.9	Stator core length L_{i}	2.70m
Rated current I_{N}	7857 A	Stator direct axis relative synchronous reactance X_{d}	1.057
Rated rotating speed of the generating unit n_{e}	200 rpm	Stator winding phase resistance R	0.00156 Ω
Flywheel moment GD_2	21250 t m^2	Weight of rotating part of generating unit FR	690 t
Runner diameter D	4.5 m	Unit pressure of trust bearing	42.13 kg/cm^2
Design head H_{d}	185 m	Mechanical time constant T_{mec}	9.487 s

4.3. Design on the transformation scheme

The core concept of this transformation scheme can be generalized as follows:

If setting the electric braking switch on the generator outlet, when the generating unit splits with the system, and the water distributor is closed, the rotating speed will decrease rapidly under the concerted effect of different moments [19]. When the speeding rate decreased to 50 % of the rated rotating speed, make the electric switch working. At the same time, decrease the rotating speed of the generating unit rapidly by adding excitation in the generator via electric braking transformer. When the rotating speed increase to 5 % or 6 % of the rated rotating speed, set the mechanical system to work, and the braking effect can be realized by decreasing the rotating speed to 0.

The relative parameters designed based on the designing principle of electric braking system are shown in Table 2.

Table 2. Relative parameters of electric braking system

Parameter	Value	Parameter	Value
Rated power	220 MW	Excitation transformer ratio	18 kV/670 V(676 V)
Rated terminal voltage	18 kV	Excitation transformer capacity	3×600 kVA
Rated excitation voltage	301 V	No-load excitation current	850 A
Rated excitation current	1565 A	No-load excitation voltage	122 V

Thepreliminary plan of this research is that: based on the general design mode for the electric braking system in the hydroturbine generating station, the electric braking system can adopt excitation system and share the same rectifying and controlling system with the electric braking system, and it is also possible to have two systems independents to each other. However, in sight of the practical operation of Pingban secondary power station, the primary excitation system has not concerned the practical situation of the electric braking function. The following text is about the detailed scheme of electric braking excitation and the controlling system and the allocation plan.

Without changing the preliminary excitation system, add a braking transformer, switch of low voltage side of excitation transformer, switch of direct current side of excitation and electric braking switch. What is more, add a set of independent rectifying device and electric braking controlling system.

The main circuit of the electric braking system employs independent electric braking device. To decrease the investment in this transformation scheme, the rectifying system uses the full bridge diode rectification. The schematic wiring diagram of this scheme is in Fig. 4.

Based on the above transformation scheme, considering the insulation of electric braking system and excitation device of the generating unit, an electric braking device completely independent from the former excitation system can be chose to ensure the operation of generating unit even when the electric braking device has faults, without influencing the normal on-load operation of the generating unit. Based on this, we designed the wiring diagram of primary electric braking equipment (seeing Fig. 5), which also increase the safety of the system.

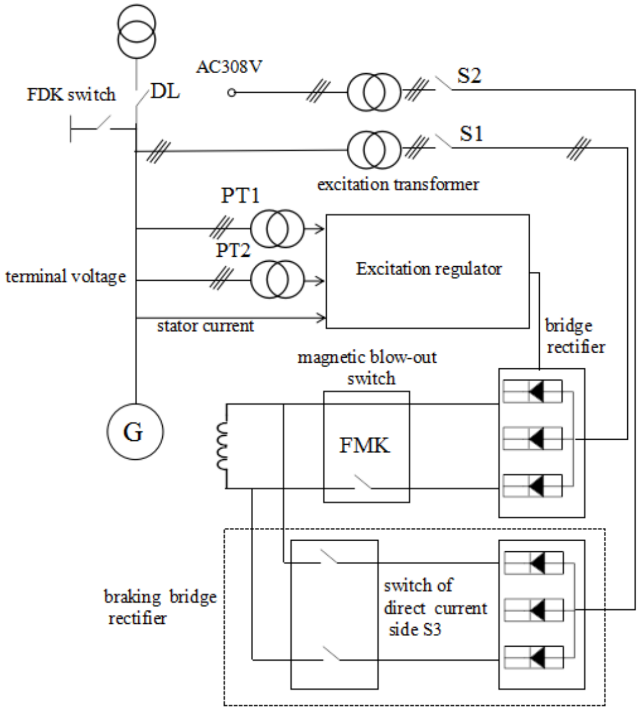

Fig. 4. Schematic wiring diagram

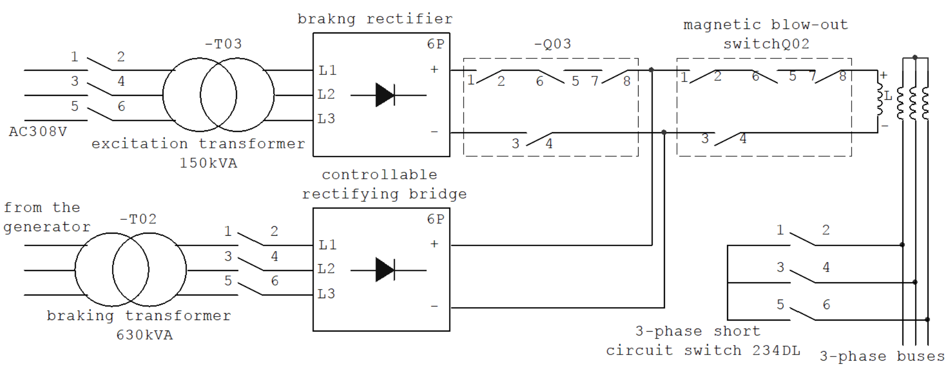

Fig. 5. Wiring diagram of electric braking primary equipment

5. Conclusion

Most large-scale hydropower generating units employ traditional mechanical braking method. To shortcut the operation time of the generating unit at low rpm, it must go into a penalty brake continuously. Using the mechanical braking system at high rotating speed may abrade the braking panel. Therefore, considering the safety of the system, we should choose the electric braking method. We conduct a detailed study on electric braking and its transformation scheme form the following aspects: first, we analyze the principle of electric braking and divide the electric braking moment control of hydroturbine generating unit into 2 phases, and also construct the modules of these phases concerning their different features. The demarcation point of the two phases is critical speed of rotation. Second, in addition, we discussed those three schemes of the electric braking of generating unit respectively, and analyzed the applicable range and environment of different schemes, providing the theoretical support for the following transformation scheme. Third, concerning the transformation requirement of the braking system of generating unit in Pingban hydropower station, we analyzed and discussed the necessity and availability of the braking method transformation. Involving the practical engineering example, we designed the transformation plan for the electric braking system of Pingban hydropower station, and also express the possible safety issues of the system after transformation.

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