Research on obtaining method of rotor moment of inertia of synchronous generator set suitable for different rated speed

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Abstract. Aiming at the problem that the moment of inertia of the rotor of the generator set is different from that of the generator set under different load rejection, according to the energy conversion characteristics of the generator set during the rotor rotation, the energy conversion balance equation of the rotor rotation process is put forward, which is applied to the load rejection process of the generator set under different load and calculated and analyzed, and the accurate moment of inertia of the rotor of the generator set is obtained, this method improves the accuracy of kinetic energy of generator, which is one of the parameters of generator model in power grid stability analysis.

1. Introduction
The calculation and analysis of power grid stability need accurate generator model and parameters. The kinetic energy of generator is one of the parameters of generator model, which is determined by the moment of inertia of generator rotor. The moment of inertia of rotor can be obtained by conventional load rejection test [1-3], which is generally based on the measured data of unit load rejection and calculated by energy conversion formula [3-5]. Because the traditional calculation method ignores the resistance of the speed rising process [6-8], the moment of inertia calculated by the load rejection of the unit under different power is inconsistent. According to the characteristics of energy conversion in the process of rotor rotation, this paper puts forward the balance equation of energy conversion in the process of rotor rotation. Through the simultaneous equations, the calculated value of the moment of inertia is accurately obtained, which ensures the accuracy of the power parameters.

2. Traditional calculation method of moment of inertia
Load rejection of a 700MW unit at 100%, 75%, 50% and 25% of the active power respectively, and wave recording during rotor flying is shown in Figure 1.

During the load rejection test, all mechanical power is converted into kinetic energy and stored in the rotor shafting. Through the dynamic derivation, the energy conversion formula of the unit is obtained:

\[ \frac{1}{2} J (\omega_2^2 - \omega_1^2) = \int_0^T P_0 dt \]  

(1)

Formula: \( J \) Is the moment of inertia of the generator rotor, kg.m\(^2\); \( \omega_1 \) It is the speed of the generator rotor exceeding the initial angle, rad/s, \( \omega_1 = \frac{\pi}{60} \); and \( r_i \) is the initial speed after
load rejection, \( r \cdot \text{min}^{-1} \); \( \omega_2 \) refers to the speed at \( T \) time of generator rotor speed flying up, \( \text{rad/s} \), \( \omega_2 = \frac{\omega_p}{2\pi} \), and \( r_2 \) is the speed at \( T \) time after load rejection, \( r \cdot \text{min}^{-1} \); \( P_0 \) refers to the active power of generator before load rejection, \( \text{W} \); \( T \) refers to the time when all load rejection power of generator unit is converted to the kinetic energy of generator rotor after the generator outlet switch is disconnected, \( \text{s} \).

![Figure 1. Oscillogram of rotor speed during load rejection.](image)

According to the oscillogram of the load rejection rotor flying up process, the starting speed \( r_1 \), the speed \( r_2 \) at time \( T \) and the speed flying up time of the load rejection of 25%, 50%, 75% and 100% can be obtained. The moment of inertia of the starting motor rotor can be calculated from Equation (1). See Table 1 for load rejection test data and rotor moment of inertia.

**Table 1. Load rejection test data and rotor moment of inertia.**

| Load rejection/\% | Starting speed/(r.min\(^{-1}\)) | T time speed/(r.min\(^{-1}\)) | Speed flying time/s | Rotor moment of inertia/(kg.M\(^2\)) |
|------------------|-------------------------------|-------------------------------|---------------------|-------------------------------------|
| 25               | 107.377                       | 109.140                       | 0.759               | 65422694                           |
| 50               | 107.978                       | 112.119                       | 0.895               | 62692142                           |
| 75               | 108.054                       | 118.677                       | 1.525               | 60986327                           |
| 100              | 107.935                       | 120.903                       | 1.408               | 59885220                           |

From the data in Table 1, it can be seen that with the increase of load rejection power value, the moment of inertia decreases gradually, and it is closer to the factory design value (55 000 000 kg \cdot m\(^2\)) of the rotor moment of inertia of the generator set; the difference of the moment of inertia of the rotor obtained by load rejection at different power points is large, the difference between the maximum value and the minimum value is 5537474 kg.M\(^2\), and the moment of inertia of the rotor of the generator set is the minimum when the load is 100%. However, there is still 8.88% deviation from the factory design value.

**3. Improved algorithm of moment of inertia**

Due to the resistance of the generator rotor in the process of speed rising after load rejection, the mechanical power acting on the generator rotor after load rejection of the unit is not only converted into the kinetic energy of the rotor, but also part of the power needs to be used to overcome the resistance and work, which is equivalent to the negative work of the resistance on the generator rotor, so that the speed rising acceleration of the generator rotor is significantly lower than the ideal working condition without resistance. The traditional calculation method of rotor moment of inertia just ignores
the resistance factor, which leads to the big deviation of calculation results. In the process of load rejection, the maximum value of runaway of speed is within 10% of rated speed, and the work of resistance of load rejection under different power is basically the same in unit time. Therefore, it can be assumed that the work rate of resistance in the process of speed runaway of load rejection rotor is the same. In order to make the balance equation of energy conversion closer to the reality after load rejection, this paper introduces the Formula (1) as follows:

$$\frac{1}{2} J (\omega_k^2 - \omega_0^2) + P_k T = \int_0^T P_0 dt$$

(2)

The test data of 25%, 50%, 75% and 100% load rejection are substituted into Equation (2), and the following four equations are obtained:

1. $2.0926748 J + 0.759 P_k = 136908420$ (3)
2. $4.9970695 J + 0.895 P_k = 313272375$ (4)
3. $11.7163566 J + 1.346 P_k = 714537560$ (5)
4. $16.2714452 J + 1.408 P_k = 974419072$ (6)

For Equation (3) to Equation (6), the moment of inertia and resistance power of the rotor can be solved by the simultaneous two-dimensional first-order equation. See Table 2 for the calculation results. The proportion in Table 2 is defined as Proportion=$100P_k/ P_{min}$. If the load rejection value of the simultaneous equation is $P_1$ and $P_2$, $P_{min}=$min($P_1$, $P_2$).

Table 2. Calculated values of rotor moment of inertia and resistance power.

| Equation (6) | Equation (5) | Equation (4) |
|--------------|--------------|--------------|
| $J/(kg.M^2)$ | 58150119     | 58929687     | 60028200 |
| $P_k/MW$     | 20.051558    | 17.902174    | 14.873413 |
| Proportion/% | 11.12        | 9.92         | 8.25     |
| $J/kg.M^2$   | 57262333     | 57935084     |
| $P_k/MW$     | 30.311193    | 30.311193    |
| Proportion/% | 8.66         | 7.59         |
| $J/kg.M^2$   | 56524359     |
| $P_k/MW$     | 38.839532    |
| Proportion/% | 7.32         |

It can be seen from the data in Table 2 that: (a) the larger the load rejection power value of the unit is, the smaller the moment of inertia of the generator rotor calculated by the simultaneous equations is, and the closer it is to the factory design value. For example, if Equation (5) and Equation (6) are combined to establish the binary primary equation, the calculated value of rotor moment of inertia is 56524358.98 kg.M^2, which is only 2.77% deviation from the factory design value; (b) the calculated value of resistance power is 14.8 ~ 38.9 MW, which basically belongs to the same order of magnitude, and the higher the value of load rejection power is, the greater the calculated value of resistance power is, which indicates the resistance of the unit during high load rejection; (c) the lower the load rejection power is, the higher the ratio of resistance power is.

4. Verification example

In order to test the effectiveness and applicability of the improved algorithm proposed in this paper, the traditional calculation method and the improved algorithm proposed in this paper are used to
calculate the rotor moment of inertia based on the load rejection data of a nuclear power turbine generator unit with rated speed of 1500r/min and rated power of 1000 MW.

According to the test requirements, adjust the load of the unit, carry out load rejection test under 50% and 100% active power respectively, and use the traditional calculation method to obtain the rotor moment of inertia, the results are shown in Table 3.

| Load rejection% | 50    | 100      |
|----------------|-------|----------|
| Starting speed/(r.min⁻¹) | 1499.7 | 1502.262 |
| T time speed/(r.min⁻¹) | 1514.478 | 1538.412 |
| Speed flying time/S | 0.306  | 0.324    |
| Rotor moment of inertia test value/(kg.M²) | 595118.21 | 577893.85 |
| Design value of rotor moment of inertia/(kg. M²) | 566758     |
| Rotor moment of inertia deviation value/% | 5       | 1.96     |

Substituting the load rejection test data in Table 3 into Equation (2), the following two equations are obtained:

\[ 244.2371914J + 0.306 P_k = 145350000 \]  \( (7) \)
\[ 602.7058426J + 0.324 P_k = 348300000 \]  \( (8) \)

The moment of inertia of the rotor is 564949.16 kg.M², which is only 0.32% deviation from the design value. It can be seen that the improved algorithm proposed in this paper can accurately obtain the rotor moment of inertia, and is suitable for different rated speed units.

5. Conclusions
In this paper, an improved algorithm of the moment of inertia is proposed, which considers the influence of the resistance in the process of load rejection and greatly improves the accuracy of the rotor moment of inertia. The results show that the larger the load rejection power is, the more accurate the moment of inertia calculated by the simultaneous equations is. In order to obtain the moment of inertia of the rotor of the generator set, the traditional calculation method which ignores the resistance and the improved calculation proposed in this paper should adopt the high load rejection test data. However, it should be noted that for the speed rise time T, it is the time when the load rejection power of the unit is completely converted into the kinetic energy of the generator rotor after the generator outlet switch is turned off so that the rotor angular speed can accelerate the rise evenly. For the speed rise curve of the rotor, it is the time span of the linear section with the largest slope; improper selection of the speed rise time will lead to errors.

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