Research on External Fault of Salient Pole Synchronous Motor at Rated Load

Yubo Shen *, Hongyi Zhou, Zhibin Li, Siwei Han, Minhu Xu, Shulei Shang, Meng Zhou and Xuyang Yao
State Grid Heilongjiang Electric Power Co., Ltd. Electric Power Research Institute, Harbin, Heilongjiang, China

*Corresponding author e-mail: shenyubo@hepri.hl.sgcc.com.cn

Abstract. The pumped storage power station is an inevitable product of the power system structure and power supply demand development to a certain stage, and it is a necessary management tool to ensure the safe and stable operation of the power system. Pumped storage power plants have the ability to improve and balance the load of the power system, which can improve the quality of power supply to the power grid and improve overall economic benefits. With the development of high-tech industries such as informatization and digitization and the improvement of people's living standards, society has higher and higher requirements for pumped storage power stations. Pumped storage motor is a three-phase salient-pole synchronous motor used in pumped storage power stations. This paper simulates and analyzes the stator voltage, current, and electromagnetic torque when single-phase grounding short circuit, inter-phase short circuit, and two-phase grounding short circuit occur in pumped-storage motors, and the law of change is obtained.

Keywords: Pumped storage motor, salient pole synchronous motor, short circuit, change rule.

1. Introduction
With the continuous expansion of the single-unit capacity of hydro-generators in various countries, professors and scholars all over the world are paying more and more attention to the study of motor short-circuit faults. When the motor is in a short-circuit fault state, the short-circuit current value is far greater than its rated value, and the electromagnetic force generated is far beyond the tolerance of the motor. Its destructive force can make the rotor eccentric, the motor generates severe mechanical vibration, and the excitation winding is deformed [1- 3]. It can be concluded from the accidents in the power system that most of the external short circuits in the power grid are asymmetric short circuits, which can cause the internal temperature of the motor to rise sharply, burn the motor windings, and break down the motor insulation, resulting in extremely efficient motor operation. Therefore, it is particularly important to study the external short-circuit transition process of pumped storage motors. This paper simulates and analyzes the stator voltage, current, and electromagnetic torque when single-phase grounding short-circuit, phase-to-phase short-circuit, and two-phase grounding short-circuit occur in pumped-storage motors, and finds its changing law, which has good practical significance [4- 6].
2. Analysis of Electrical Parameters of External Short Circuit at Rated Load

2.1. Electrical Parameters Change When a Single-phase Grounding Short Circuit Occurs.

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When the motor is under rated load conditions, set the stator side of the motor and a single-phase grounding short-circuit fault occurs on the phase A winding. The change curve is shown in Figure 1, Figure 2, and Figure 3.

![Fig. 1 Single phase grounding short circuit current variation curve under rated load operation](image1)

![Fig. 2 Single phase grounding short circuit voltage variation curve under rated load operation](image2)

![Fig. 3 Single phase grounding short circuit torque variation curve under rated load operation](image3)
It can be seen from the above figure that when the motor is under load operation under abnormal power generation conditions, the load current and back-EMF will have a jump, which far exceeds the rated value of the motor, posing a serious threat to the operation of the motor.

2.2. Electrical Parameters Change When a Phase-to-phase Short Circuit Occurs.
When the motor is under rated load conditions, set the stator side of the motor, A and B two-phase windings will have a phase-to-phase short-circuit fault. The change curve is shown in Figure 4, Figure 5, and Figure 6.

![Figure 4](image1.png)  
**Fig. 4** Interphase short circuit current variation curve under rated load operation

![Figure 5](image2.png)  
**Fig. 5** Interphase short circuit voltage variation curve under rated load operation

![Figure 6](image3.png)  
**Fig. 6** Interphase short circuit torque variation curve under rated load operation
It can be seen from the above figure that when the motor is operating under abnormal power generation conditions, such as a phase-to-phase short-circuit fault, the load current and back EMF surge, and its value is the highest under the three short-circuit faults.

2.3. Electrical Parameters Change When a Two-phase Grounding Short Circuit Occurs.
When the motor is in the rated load condition, set the stator side of the motor, A and B two-phase windings have a two-phase grounding short-circuit fault. The change curve is shown in Figure 7, Figure 8, and Figure 9.

**Fig. 7** Two phase grounding short circuit current variation curve under rated load operation

**Fig. 8** Two phase grounding short circuit voltage variation curve under rated load operation

**Fig. 9** Two phase grounding short circuit torque variation curve under rated load operation
In order to compare and analyze the calculation results more intuitively, when the motor is operating under rated load conditions, when an external short-circuit fault such as single-phase grounding short-circuit, inter-phase short-circuit, two-phase grounding short-circuit occurs, short-circuit voltage, short-circuit current and electromagnetic The maximum values of torque parameters are shown in Table 1, and the effective values of electrical parameters after a stable fault are shown in Table 2.

Table 1. Comparison of maximum value of parameters of external short-circuit fault of generator/motor under rated load operation

| Failure form       | Single phase to ground short circuit | Short circuit | Two phases to ground short circuit |
|-------------------|-----------------------------|--------------|----------------------------------|
| $I_{\text{max}}$ / kA | 40                          | 130          | 125                              |
| $E_{\text{max}}$ / kV  | 19                          | 12           | 7.1                               |
| $T_{e\text{max}}$ / MNm | 65                          | 60           | 65                                |

Table 2. Instantaneous values of parameters for generation/motor under no load operation after fault stabilization

| Failure form     | Single phase to ground short circuit | Short circuit | Two phases to ground short circuit |
|------------------|-------------------------------------|--------------|----------------------------------|
| $I_A$ / kA      | 30.11                               | 15.40        | 27.80                            |
| $I_B$ / kA      | 6                                   | 15.35        | 27.84                            |
| $I_C$ / kA      | 5                                   | 4            | 1                                 |
| $E_A$ / kV      | 1.11                                | 5.50         | 0.82                             |
| $E_B$ / kV      | 10.15                               | 5.44         | 0.90                             |
| $E_C$ / kV      | 7.62                                | 9.20         | 7.21                             |
| $T_e$ / MNm     | 6                                   | 7            | 5                                |

When the pumped-storage motor is running under rated load conditions and an external short-circuit fault occurs, the back EMF, current, torque, etc. will change over time. After the transient state of the transition process, it will eventually turn to a steady state. The values of back EMF, stator current, and electromagnetic torque will eventually approach a constant value over time.

Comparing Table 1 and Table 2 with the simulation results one by one, the simulation results are consistent with the actual operating conditions, verifying the correctness of the establishment of the field-circuit coupled time-step finite element model.

From the data in the table, it can be concluded that when the motor has an external short-circuit fault, the effective value of the electrical parameters far exceeds its rated value. Excessive electromagnetic torque can easily cause the motor to vibrate, and the stator side current and voltage are too large, which can easily cause overheating, Hazards such as breakdown insulation have a serious impact on the safe and stable operation of the motor.

When a single-phase short circuit occurs under the rated load of the pumped storage motor, the maximum current is 40 times the rated value, the maximum voltage is 13.32 times the rated value, and the maximum electromagnetic torque is 8.95 times the rated value. Give the rotor core The rotor shaft brings a serious burden, and it is easy to cause serious faults such as rotor eccentricity, which affects the normal operation of the motor; in the case of a phase-to-phase short circuit, the maximum current of the Xiangshuijian motor is 130 times the rated state, if the neutral point is not considered for grounding The influence of resistance can easily cause the stator side temperature to be too high, which will cause the stator windings to be burned and the insulation layer to be destroyed. The maximum voltage is 8.65
times in the rated state, and the maximum torque is 8.33 times in the rated state; a two-phase grounding short circuit occurs in the motor In the case of a fault, the maximum current is 125 times in the rated state, the maximum voltage is 5.2 times in the rated state, and the maximum torque is 8.96 times in the rated state. The phase-to-phase short-circuit fault still has the most serious impact on the motor. From the table data, it can be concluded that no matter the motor is in no-load or load conditions, when an external short-circuit fault occurs, no matter in terms of electromagnetic force or current and voltage, it will affect the motor. The impact on the operating performance cannot be ignored.

3. Summary
This paper conducts a simulation analysis on the short-circuit fault of pumped storage motor load operation, and draws the following conclusions:

The magnetic field distortion of the motor running under the rated load condition is severe after an external short-circuit fault occurs. When a fault occurs, not only does the current on the stator side increase, the temperature of the stator winding on the stator side rises, and the winding is easily burned. For the rotor side, the electromagnetic force of the damping bar is also several times higher than that under the rated load operation, which easily makes the rotor eccentric. And produce great mechanical vibration, threaten the safe and stable operation of the motor. The phase-to-phase short circuit of the motor A and B is particularly obvious. The rotor side eddy current is the largest relative to the single-phase grounding short-circuit and the two-phase grounding short-circuit. The electromagnetic force of the damping bar is the highest under the three types of faults. The interphase short-circuit fault is harmful to the motor. The most serious.

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