Analysis and preventive measures of excitation system failure leading to two downtime accidents

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Abstract. For the fault of rectifier bridge filter of excitation system and fault of 24V power supply of excitation system, the unit was shut down twice, by analyzing the causes, the preventive measures for excitation system operation are formulated, meanwhile, it is found that the equipment management of excitation system is not deep enough and the training of excitation system is not in place. It is proposed to carry out in-depth equipment operation and maintenance control, strengthen the excitation system knowledge training, increasing the excitation system inspection frequency and other improvement measures, such as deal with the similar problems to the scene and engineering technical personnel to provide useful experience and processing basis.

1. Introduction
Excitation system generally consists of excitation power unit and excitation regulator. The excitation power unit provides excitation current to the synchronous generator rotor. The excitation regulator controls the output of the excitation power unit according to the input signal and the given regulation criterion. The automatic excitation regulator of the excitation system plays an important role in improving the stability of the parallel power system. In particular, the development of modern power system leads to the tendency of reducing the stability limit of the unit, and also promotes the continuous development of excitation technology[1].

The excitation system maintains the generator terminal voltage at a given value. When the generator load changes, the terminal voltage is kept constant by adjusting the strength of the magnetic field, and the reactive power distribution among parallel running units is reasonably distributed to improve the static and transient stability of parallel running generators. In case of internal failure of the generator, the excitation system shall conduct demagnetization to reduce the degree of failure loss, and the maximum excitation limit and minimum excitation limit shall be imposed on the generator according to the operating requirements.

2. Overview of accident
2.1. Unit 3 accident overview
(1) On May 30, 2018, no. 1, no. 2 and no. 3 generating units were in operation, and no. 4 generating units were in operation. 500kV four-string 5041/5042 switch cold standby state, no. 3 generator set through the 5043 switch grid-connected operation, no. 3 unit load of 245MW, reactive power 0.64mvar. Section 3A/3B for 6kV plant is supplied from no.3 high plant. The 6kV desulfurization...
section 3 and 4 are supplied by no.3 high voltage desulfurization transformer, the 3A operation is changed to the power supply of 0.4kV working section 3A, and the 3B operation is changed to the power supply of 0.4kV working section 3B. The working section 3A of 0.4kV is operated with no. 3 MCC1, and the working section 3B of 0.4kV is operated with no. 3 MCC1 and no. 3 MCC2. Section 3A and section 3B of 0.4kV dust removal are respectively powered by 3A/3B dust removal. Boiler primary fan A, B, induced fan A, B, coal mill A/B/C/D are in operation. The turbine stator cooling water pump A is in operation state, and the stator cooling water pump B is in standby state.

09:59 on May 30, 2018, no. 3 generator set tripping, the first "generator failure", "generator loss of magnetism", "generator cut off water" light brand alarm, checking the normal linkage equipment is normal, Factory power switching is normal. The MCC2 section of the turbine is automatically switched to the power supply of the operating section 3A of 0.4kV. The fixed cooling pump B runs after the trip of the fixed cooling pump A. The excitation current decreased from 1239.09A to 824.15A. The reactive power of the generator decreased from 0.64mvar to -415.69mvar. The stator three-phase current Ia suddenly increased from 7174A to 15788A. The operation personnel contact the maintenance personnel for handling.11:47 there is no obvious abnormality in the maintenance check, and the zero-start booster check for no.3 generator is normal. At 12:10, With the approval of shandong electric power dispatch and control center, no.3 machine is connected to the network.13:10 the load is increased to 200MW, all oil guns are removed, the unit resumes normal operation.

2.2. Unit 2 accident overview
On August 28, 2017, The active power of unit 2 is 320MW, and the reactive power of unit 2 is 38MVar, the stator voltage is 19.56kV, the stator current is 9348A, the rotor voltage is 190V, the rotor current is 2094A; At 11:29, no. 2 generator set trip, no. 2 main transformer 220kV switch, no. 2 high power transformer 6kV 2A/2B switch, no. 2 high voltage desulfurization switch is tripped, ETS first sends out the signal of "generator trip", and the protection action signal of "excitation variable over velocity fault, excitation winding over load with fixed/inverse time limit, excitation variable over load" is sent out by the protection panel A2 and B2. The excitation regulator information is shown in figure 1.

Figure 1. Excitation regulator information.

3. Site investigation of unit 3
3.1. Basic information of unit 3
The excitation system of unit 1-4 of the company adopts ABB Unitrol 5000 system, and the excitation regulators A and B of Unitrol 5000 system are supplied by the same 24V dc bus. The 24V dc busbar is simultaneously supplied by the double-circuit power supply, one is taken from the dc control 220V power supply of the unit, and the other is supplied by the switching power supply after the excitation
change and voltage reduction. The excitation system of unit 3 was put into operation in June 2007 and has been in good condition since then[2].

3.2. On-site inspection of unit 3
After the disassembly of the generator set, after on-site inspection, the generator transformer protection cabinet of no. 3 has the phase II of loss of magnetic field and loss of step protection, the excitation system failure (external reanimation 3) action exit, the generator excitation system local control panel shows the "146" alarm signal. According to the protection action, the first and second circuits of the generator outlet PT are checked, and the fuse of the rectifying bridge of the excitation system, the fan motor, the excitation transformer, the external power supply and the first and second circuits of the system are checked. No obvious abnormality is found. After that, according to the Suggestions of the manufacturer, the system and circuit are inspected by means of zero voltage boost. After the first voltage boost to 13.5kv, no further boost is possible. After the inspection, there is no abnormality. 12:10 units connected to the network operation.

3.3. Operation status of operation personnel of unit 3
Within half an hour before the disassembly of the generator set, the operator shall have no other major adjustment operation, and the machine, furnace, electricity and its auxiliary equipment shall operate normally.

3.4. Historical data access of unit 3
(a) DCS accident recall records and historical trend curve data are as follows:
09:59:03 to 09:59:04 the excitation system of no.3 generator sent the excitation failure alarm to DCS for 2 times successively;
From 09:59:06 to 09:59:14, the excitation voltage of no. 3 generator decreased from 214.86V to 0V, and the excitation current gradually decreased from 1239A to 772A, and then rose to 824A. Stator current Ia increased from 7173.86A to 15788.45A, Ib increased from 7281.43A to 15588.19A, Ic increased from 7078.88A to 15357.03A, reactive power of the generator decreased from 0.64Mvar to -415.69Mvar and then to -257Mvar, active power of the generator decreased from 245MW to 222MW and then to 262MW.
09:59:15, No.3 machine DCS electric optical brand "generator loss of magnetism", "generator cut off water (external rework 2)" optical brand alarm, disengage the disconnection of magnetism, jump 5043 switch, jump off the magnetic switch, jump plant for 6kV 630A/630B switch and desulfurization 6T30A switch, start quick cutting, 6kV plant with 3A/3B cut to no.02 start standby transformer power supply. 09:59:06, the current of the no. 3 generator stator cooling water pump A increased from 34.28a to 43.63a, and 09:59:14, the no.3 generator stator cooling water pump B is successfully started, the actual water cut-off time is 2s.
09:59:23 no.3 Generator protection reports excitation failure (external reactivity 3) signal, the fault stop command of generator group is issued by DCS, the joint jump engine, boiler, no. 3 generator set is completely shut down.
09:59:34 the excitation failure general alarm signal is issued again from the excitation system of generator no.3.
(b) Consulting the transmitter protection action message.
09:59:15 (10:01:18:301) : the second phase of the generator's magnetic loss protection is operated to disassemble the magnetic loss.
09:59:14 to 09:59:16 (10:01:20:050 to 10:01:20:1750) : the generator's water cut protection (external rework 2) is dislocated, and dislocated after about 2s.
09:59:23 (10:01:27.275) : external reanimation 3 (excitation system failure) stops.
(note: the difference between the protection time of mutants and DCS is about 2 minutes and 3 seconds, which has been corrected.)

(c) Access to the excitation system accident records
Before the unit was unassembled, the same packets of 141 (+Aux. AC fail), 146 (+ start-up BLKD extrn), -119 (-standby alarm), 1 (COB power fail), 54 (MUB fault/power fail), 110 (+System restart) and so on appeared on the excitation system channel A/B, indicating that the 24V power supply of the excitation system had disappeared instantaneously.

3.5. The check of the control logic of unit 3
(a) Phase II of the deactivation protection of the generator group was performed, demagnetization was performed, and the interlock operation was correct.
(b) External rework 3 (excitation system failure) action was outlet, the unit all stopped, interlock action was correct.
(c) The logic of generator and boiler is normal, the protection input is normal and the interlock action is correct.

4. Field investigation of unit 2
(1) No. 2 machine excitation system 1-4 rectifier bridge, the electrical components such as control panel power supply board is burning in different level. 1-3 excitation regulator rectifier cabinet communication into line knife all have obvious traces of three-phase short-circuit, the capacitor of rectifier bridge filter in no. 1-2 rectifier cabinet are exploded. 1, 3, 4 traces of pulse rectifier cabinet board has obvious burning, Part of the thyristor circuit in the no. 1-4 rectifier cabinet are fused off [3].

(2) Excitation transformer protection configuration and trip logic: excitation transformer capacity is 6.6MW, rated current of high voltage side is 191A, CT ratio 1000/5 (low voltage side 6000/5). Setting principle of excitation variable speed fault protection (hereinafter referred to as fast break protection, taking the current of the high-voltage side of the transformer): in the case of two-phase short-circuit on the low-voltage side, the sensitivity coefficient should not be less than 2 to set, the action value is 1.71A, 0s; Protection trip logic is the unit all stop[4]. The condition of no.1 rectifier cabinet is shown in figure 2.

![Figure 2. No.1 rectifier cabinet.](image)

(2) Protection actions: on August 28, 29 points at 11, a short circuit fault occurred in the excitation system of unit 2, 109.7ms after the fault, excitation variable speed protection is acted, lateral excitation transformer hv current secondary value: A phase (2100A) A current with 10.5 A, B phase (2160 A) A current with 10.8 A, C 9.8 A (A current 1960 A), decided to speed values, the protection action, 141.6ms, no. 2 main transformer of 220kV switch 212 switch trip, 299.1ms, MK brake, the fault duration of 1102ms.

Conclusion: the protection action of the system is correct, and the switch trip logic is correct.
5. Tripping cause analysis of unit no.3  

(1) Causes of unit disassembly: before unit disassembly, the DCS system receives two excitation failure alarms from the excitation system. Refer to the history records of the excitation system, the excitation device A/B channel is restarted at the same time, because the excitation regulator loses power, triggering the pulse latching, resulting in the protection of the excitation loss section II of the generator group, and demagnetization. 

By the further inspection, it is found that the 24V power supply of the excitation system disappeared instantly, resulting in the instantaneous power loss of the COB and MUB plates of the two channels, which was the main reason for the simultaneous restart of the excitation device A/B channel. After consulting the drawings, it is suspected that the reason for the disappearance of 24V power supply of the excitation system is as follows:

(a) The aging of the power supply module of the equipment causes the high level of the 24V busbar power of the excitation system to be immediately grounded, and the low 24V voltage is pulled, resulting in the instantaneous power failure and restart of two excitation devices.

(b) ABB Unitrol 5000 system design adopts 24V high level input to be effective, DCS system adopts 48V low level input to be effective, doing not rule out that because the excitation system sent DCS contact closure or cable insulation aging, the excitation system 24V bus high level potential was immediately pulled down, resulting in the excitation device restart.

(2) Reasons for the failure of the first zero-start booster of the unit: there is no relevant historical fault record of the excitation system. According to the analysis of the manufacturer, the failure of the excitation system for the first zero-start booster is caused by the instantaneous power failure and restarts of the excitation system, which leads to the failure of the system program to be completely reset and the abnormal operation of some programs[5].

(3) Causes of generator water cut-off protection alarm: in the process of generator excitation device power failure and restart, as the excitation system is in the process of continuous current de-excitation, the terminal voltage continues to drop, and the bus voltage in the working section of 0.4kV decreases accordingly, resulting in the over-current trip of the stator cooling pump A and the connection of the stator cooling pump B. Then the 6kV quick cutting device was switched successfully, the 0.4kV bus voltage returned to normal, and the output of the stator cooling pump B gradually returned to normal. During this period, the generator's water cut time was about 2 seconds, and the water cut protection alarm was issued (because the water cut protection was delayed for 30 seconds due to the fixed value of the water cut protection, so the water cut protection did not operate at the outlet).

6. Cause analysis of unit 2 trip  

(1) Partial discharge exists in the capacitor of the rectifier bridge filter circuit in the excitation no.1 rectifier cabinet, when the degree of discharge is serious enough to severe perfoliate insulating oil gas discharge, when the ionization of high temperature and high pressure oil mist spraying to connect in rectifier cabinet, triggered communication bus interphase short circuit, leading to a variable set of actions of protection downtime. However, due to the long demagnetic time of the excitation system, even after the demagnetic switch is switched off, the anode voltage of the rectifier cabinet still remains under pressure for a long time, so each rectifier cabinet continues to discharge for a long time. The spray of the first rectifier capacitor is the fundamental cause of the large area discharge on the ac and dc sides.

(2) The capacitor inside the filter circuit of the rectifier bridge is double-sided thickened polypropylene film, benzyl toluene impregnation agent is used as the medium (France C101), the aluminum foil used for power capacitor is used as the electrode, the element outside is used as the ground oxide cylindrical aluminum shell, the internal benzyl toluene impregnation agent is filled to the junction post position, not all filled; And the level of capacitor installation (the number of capacitance nameplate for vertical installation), capacitance inside the upper part of the film, the electrode is not full of benzyl toluene impregnant, at close range and distance heat resistance (below 5 cm), due to the resistance of filter circuits run normally when temperature is 100 degrees temperature gun test, making
the upper capacitance affected by high temperature for a long time, it is more than the manufacturer's specifications, caused ageing of capacitance.

7. Major problems exposed
(1) The original 24V power supply design is not reasonable, and the power supply reliability is poor.
(2) Long-term operation of equipment, aging of insulation of electronic components and circuits, and decreased reliability of equipment.
(3) The technical strength of operation and maintenance personnel of the excitation system is relatively weak, and the technical training of personnel needs to be strengthened.
(4) During routine equipment inspection, it is not found that the operating temperature of the upper part of the capacitor has exceeded the requirements of the capacitor manufacturer;
(5) After the equipment is out of service, the capacitor has not been checked and relevant tests have not been conducted, and the problems of the capacitor cannot be found in time[6].

8. Handling and preventive measures
(1) Because no. 3 generator set is currently in operation, it is impossible to conduct investigation on the above reasons that may cause power loss of 24V bus of excitation system, and the final cause can be determined only after the unit is shut down. During operation, relevant measures should be formulated and issued to strengthen the operation and maintenance of equipment and the purchase management of spare parts.
(2) The clocks of all devices are checked and corrected to ensure the unification of equipment clocks and facilitate the tracing of abnormal faults.
(3) Thermal SOE records are combed to ensure that important equipment signals are included in SOE records.
(4) In view of this incident and similar cases related to the same type of power plant, other units were investigated based on the results of unit maintenance.
(5) Checked the similar equipment of unit 1, the temperature of the capacitor regularly is monitored according to the requirements of the manufacturer's manual, and the capacitor is replaced when it is stopped.

9. The conclusion
The power plant excitation system equipment management is not deep enough, although daily maintenance and regular maintenance work can be carried out, but the failure of the excitation system components analysis is insufficient; The training work of excitation system is not in place, the three measures and two cases do not reflect the attention of operation personnel and the emergency response measures, the excitation system fault treatment special emergency plan is lacked.

References
[1] Li, C. (2009) Design and application of modern synchronous generator excitation system [M].2 Version. China electric power press, Beijing.
[2] Zhang, W. (2003) Overview of operation mode of digital excitation regulator [J]. Hydro-power plant automation, 4: 33-37.
[3] Zhao, H. (2018) Local electromagnetic force distribution study on giant nuclear turbo-generators with stator short-circuit fault[J]. Transactions of china electrotechnical Society, 33: 1497-1507.
[4] Sun, Y. (2014) Calculation of stator winding inter-turn short circuit in 12-phase synchronous generators with rectifier load system[J]. Transactions of china electrotechnical Society, 3: 57-64.
[5] Yang, J. (2012) Study on the excitation system based on full-controlled-devices for improving power system damping characteristics[J]. Big motor technology, 3: 63–67.
[6] Mao, C. (2013) Multivariable feedback linearization scheme for new excitation systems based on full controlled devices[J]. Proceedings of the csee, 22: 53–60.