Analysis of fire failure of wind turbine in a wind farm in Northwest China

Huai-xiang Wang, Dang-guo Ma, Zhou chun and Niu bin
Huadian Electric Power Research Institute Co., Ltd, 2 Xiyuan 9th Road, Xihu District, Hangzhou, China.
Email: 278436257@qq.com

Abstract. The accident fan is the first-stage wind farm unit. From 2011 to 2019, the transformation of low-voltage crossing, lightning protection, grid switch, engine room grid cabinet and frequency converter cabinet are gradually carried out, and the original main control system is updated. One day in 2019, a fire accident happened to the generator, most of the engine room covers were burnt, the top section of the tower tube had traces of oil overflow after combustion, and a large area of combustion damaged parts scattered around the tower base. The cause of the accident is that the two phases of the stator contactor are not completely disconnected when the network is disconnected, and the main circuit breaker of the tower base is not tripped when the stator contactor is in fault, and the fault current is not cut off in time, which is a design defect.

1. Introduction
The wind turbine in this accident is a phase I unit of a wind farm, with the model of sl1500 / 82 of a company. The unit is equipped with yffs450-4 generator, imported pm3000w frequency converter, and a ppsc1290 main shaft built-in gearbox in Dalian. The gearbox adopts the transmission mode of "two-stage planetary wheel and one-stage parallel shaft", with the transmission ratio of 1 / 104.25.

After the wind turbine was put into operation, the transformation of low-voltage crossing, lightning protection and grid switch was gradually carried out from 2011 to 2019. The grid breaker was replaced by vacuum contactor. Ncc300 grid cabinet and ncc320 frequency converter cabinet (the ignition source) in the engine room were equipped with fire-extinguishing bombs. One fire-extinguishing bomb was installed for each. The fire-proof blocking transformation and high-voltage crossing transformation of tower cable were carried out [1-2].

One day in 2019, a fire accident happened to the generator. It was found through field investigation that hr26 wind turbine was in shutdown state and there was a warning line around it. Most of the engine hood was burnt, and the root of one blade was burnt and broken. There are traces of grease overflow after combustion in the top section of tower drum, and large area of scattered combustion damaged parts around the tower base, including lightning rod, anemometer, frequency converter water-cooling device, etc.

Then, after the engine room, impeller and upper tower are hoisted to the ground, it is found that the engine room cover, hub cover, electric control cabinet, battery cabinet and gearbox radiator are burnt, the generator, generator coupling, brake, gearbox and main shaft are over fire, there are smoke marks on the top of the tower, one blade is broken, and the hub is smoke marks; the door of 320 cabinet (frequency conversion cabinet) falls to the ground, bending The radiator of gearbox, IGBT module of
frequency converter, chopper resistance and anemometer bracket are scattered on the ground. Lift the engine room to the ground after it catches fire as shown in Figure 1.

Figure 1. Situation after engine room fire

2. Event passing
On a certain day in 2019, at 18:42, the personnel on duty found that hr26 wind turbine reported 767 (abnormal stator contactor), 806 (low grid voltage), 536 (general fault of frequency converter) fault through SCADA system, and then arranged the maintenance personnel of wind turbine to check the stand. In the process of maintenance preparation, open fire was found in the engine room of hr26 wind turbine in front of the building door of booster station, then all wind turbines of 311 collecting line where hr26 is located were manually and remotely stopped, and 311 collecting line switch was opened to prevent the expansion of the accident. At 19:29, the open fire in the engine room of the wind turbine was out, the engine room was basically burned, and the root of one blade was burned and bent. Then, the second level data of hr26 wind turbine failure period is exported and analyzed through the SCADA backstage server of wind turbine. The failure information is as follows:

- At 18:42:54, 767 fault (stator contactor breaking timeout fault) is reported.
- At 18:42:55, 806 fault (grid voltage is lower than the limit value of 621v) is reported.
- At 18:42:57, 536 fault is reported (additional fault: general fault of frequency converter).
- At 18:43:00, 535 fault is reported (communication between converter and CANBUS is interrupted).
- At 18:43:04, 537 fault was reported (the required power is different from the measured power).
- At 18:43:08, 659 fault was reported (400V power supply interruption was detected by the system).
- At 18:43:22, 681 fault (power consumption > 30 kW) was reported.
- At 18:43:28, 525 fault (excessive change rate of generator speed) was reported.

In the morning of the next day, the wind farm organized personnel to inspect the accident wind turbine as follows:

- The phase B drop fuse at the high voltage side of the unit transformer is blown, and the fuse at the low voltage side of the unit transformer is normal.
- It is found that 690V circuit breaker of wind turbine tower base is not tripped.
- It is found that the 400V power supply air switch of the wind turbine tower base is not tripped.

3. Event analysis
From 18:00 to 42:00 on a certain day in 2019, hr26 wind turbine will generate normal power before reporting failure. The wind speed will change in the range of 4-8M / s. The angle between the engine room and the wind direction will be 661 ° and the instantaneous angle between the engine room and the wind direction will be 29.9 ° at 18:42:36. According to the main control logic of the wind turbine: when the sum of the position angle of the engine room plus the angle between the engine room and the wind direction is greater than 680 ° of the yaw cable removal limit (661 ° + 29.9 ° > 680 °), the wind
turbine will stop and cable removal. SCADA data of wind turbine shutdown and cable removal are shown in Table 1.

Table 1. SCADA data of wind turbine shutdown and cable removal

| Time   | State | Power generation | Wind speed | Wind direction | Engine room location | Active power | Reactive power | Blade angle |
|--------|-------|------------------|------------|---------------|----------------------|--------------|----------------|-------------|
| 18:42:36 | 7     | 318.1            | 817        | 67            | 661                  | 318.1        | -1             | -0.6        |
| 18:42:37 | 10    | 314.1            | 819        | 67            | 661.2                | 314.1        | 0              | 0.18        |

At 18:42:36, the wind turbine was in power generation state (wind turbine state 7) and yaw state 15, and the unit performed normal shutdown and cable release actions according to the main control logic. At 18:42:37, the wind turbine was in 10 (setting state), the wind turbine was shut down, the blade angle was changed from -0.6 ° to 89 °, and the wind turbine performed the yaw cable release action. The blade angle record during the shutdown of the wind turbine is shown in Figure 2.

Normal shutdown logic: the speed of the wind turbine is gradually reduced (and the output power is reduced at the same time). When the speed is less than 1150rpm and the output power of the wind turbine is less than 20kW or the speed is less than 1050rpm, the unit is ready to be off grid, and the main control sends the off grid command to the frequency converter. The frequency converter enters the generator side closing state (S9) from the generation state (S8), the main control of the wind turbine sends out the tripping signal of the stator contactor, and the generator stator and the grid are disconnected. After the master control sends out the opening command of stator contactor for 500ms, it can judge whether the opening of stator contactor is successful by detecting whether the current value of main circuit of stator is less than 50A or the feedback signal of auxiliary contact of stator contactor. When the frequency converter receives the disconnection signal of the stator contactor, the frequency converter enters the arm state (S6). After a delay of 5ms, the frequency converter enters the disconnection state (S10) of the contactor on the rotor network side. The main control sends out the tripping command of the contactor on the rotor network side. After the frequency converter judges that the contactor on the rotor network side is normally disconnected, the frequency converter enters the initial reset state (S0). If there is no fault in the frequency converter, the frequency converter enters the Enter standby mode (S1) and wait for starting.

From 18:42:36 to 53 seconds, the rotating speed changed from 1406rpm to 1088rpm, and the power changed from 318kw to -48.7kw. According to the main control logic: when the rotating speed is less than 1150rpm and the output power of the wind turbine is less than 20kW or the rotating speed is less than 1050rpm, the unit enters the ready to be off grid state, and the main control sends the off grid command to the frequency converter. The WTG status changes from 10 (set state) to 1 (fault state). At this time, the current value is shown in Table 2.
Table 2. SCADA records current and voltage values

| Time       | VoltageA | VoltageB | VoltageC | CurrentA | CurrentB | CurrentC |
|------------|----------|----------|----------|----------|----------|----------|
| 6:2 18:42:53 | 493      | 602.2    | 684.2    | 1767     | 1758     | 73       |
| 6:2 18:42:54 | 437.8    | 603.4    | 657.5    | 1704     | 1682     | 5        |

At 18:42:54, the wind turbine generator reported 767 fault (main contactor / grid contactor breaking timeout fault). After the main control sent out the opening command of the stator contactor, it detected three-phase current $i_a = 1704a$, $i_B = 1682a$, $i_c = 5A$. According to the main control logic, it judged the stator main contactor breaking failure and reported 767 fault (main contactor / grid contactor breaking timeout fault), which is wind power generation. The current value is as shown in Fig. 3 at this time.

![Figure 3. Record of current when the contact of stator contactor is disconnected](image)

According to the main control logic, in the process of wind turbine off grid, the main control and the frequency converter will send out the disconnection command of the contactor at the rotor network side only after receiving the feedback signal of the stator contactor disconnection (auxiliary contact of the contactor). According to figure 4, the contactor at the rotor network side is judged to be disconnected, so it can be judged that the contactor is mechanically disconnected after the main control sends out the disconnection command of the stator contactor, but according to the fault current recording, the electric circuits of phase A and phase B are not completely disconnected. It can be determined that arcing occurs in phase A and phase B during the opening process of the stator contactor. See Figure 5 for the transition of the generator from the generation state to the lack of phase electric state.

![Figure 4. State feedback of contactor at rotor network side](image)
Figure 5. Generator power status diagram

In case of fault, the stator current is IA = 1704a, IB = 1682a, IC = 5A. The converter starts crowbar protection (the maximum allowable absorption energy of crowbar is 1080kJ). After crowbar is damaged, the open circuit of generator rotor causes the DC bus voltage of converter to rise (Umax = 1362v). The arc generated by phase A and phase B of the stator contactor is not completely broken, the power grid continues to supply power to the stator of the generator, the maximum negative power of the generator is 598.4kw, the generator is in the state of motor, the tower base circuit breaker does not act in case of fault (short delay setting value 2500A, 0.4s action tripping, long delay setting value 1500A, 15s action tripping, the current does not reach the short delay action value in case of fault), and the generator rotor is in the state of In the open circuit operation state, the high potential feedback generated by the rotor causes a sudden rise in the voltage of the DC bus. At this time, the IGBT module and the capacitance of the inverter cabinet are in the over-voltage state (the maximum DC voltage that the capacitance can bear is 1200V).

In normal operation, the DC bus voltage is 1050V, and the maximum withstand voltage of the bus support capacitor is 1200V. Through fault recording, it can be seen that the maximum bus voltage is 1362v, as shown in Figure 6.

Figure 6. Converter DC bus voltage

The DC bus voltage of frequency converter is far higher than the normal working voltage, and the rate of change is large. IGBT module and capacitor explode.
Figure 7. Frequency converter module explosion

After the explosion of IGBT module and capacitor, the accumulated heat of inverter cabinet fault and IGBT module and capacitor residue after the explosion of inverter cause fire, as shown in Figure 7. At 18:42:53, the wind turbine reported 806 fault (the grid voltage is lower than the limit value of 621v), and the stator contactors A and B phases were not completely disconnected, as shown in Figure 8.

Figure 8. Three phase current of wind turbine in case of fault

At 18:43, 535 (the communication between the frequency converter and CANbus was interrupted), the communication between the main control PLC and the frequency converter was interrupted, and then the data of the main control PLC was interrupted. It is speculated that the fire of 310 cabinet caused the burning of the main control PLC at this time. According to the data interruption of PLC later than the data interruption time of the frequency converter, combined with the results of the field survey, the fire point of this event can be determined as 320 cabinet.

At 18:43, communication between frequency converter and CANBUS is interrupted, communication between main control PLC and frequency converter is interrupted, and then data of main control PLC is interrupted. It is speculated that at this time, 310 cabinet fire causes main control PLC to burn down. According to PLC data interruption later than data interruption time of frequency converter, combined with field investigation results, it can be determined that the ignition point of this event is 320 cabinet.

According to the above analysis, the main causes of the accident are as follows:

a) The direct cause of this accident is that the stator contactor is not completely disconnected. After disassembling the contactor on site, it can be seen that there are obvious arcing traces on the dynamic and static contacts of phase A and B of the stator contactor.

- Mechanical problem of stator contactor, poor synchronization, resulting in incomplete cut-off of phase A and phase B.
• The decrease of vacuum degree of stator contactor results in arcing of dynamic and static contacts.
• The breaking capacity of vacuum contactor is weak.
• The installation method of the stator contactor is different from that of the manufacturer (the manufacturer requires vertical installation with a maximum allowable angle of 30°, but the emergency wind turbine is installed horizontally with an angle of 90° with the vertical surface).

b) The failure of tower based circuit breaker is an important cause of this accident. Check the protection setting of the circuit breaker: the short delay setting of tower based circuit breaker is 2696a, 0.3s acts on tripping, the long delay setting is 1468a, 27s acts on tripping, the maximum fault current does not reach the short delay action value, and the short delay action value is reached, resulting in long fault duration, extended fault range and wind power generation The motor frequency converter protection did not design the converter double fault trip tower base circuit breaker, which resulted in the converter failing to trip tower base circuit breaker in time when it was in serious fault, and the interlock protection function design of the wind turbine generator was defective.
c) The reason why the fire-extinguishing bomb didn't work

| Table 3. Technical parameters of fire extinguisher |
|-----------------------------------------------|
| Working principle                            |
| The fire-extinguishing bomb is started by the electric initiator or the heat sensitive line, and the blue aerosol is ejected to the protection area to inhibit the oxidation-reduction reaction in the combustion process, absorb heat and rapidly reduce the temperature of the fire area |
| technical parameter                          |
| Protection volume: 2 m³, hot start temperature: 170±10°C. |

According to the analysis of the working principle and technical parameters of the fire-extinguishing bomb in Table 3, the volume of the 320 cabinet in the engine room is 1.25m³ and it is a sealed space. If the control cabinet is always in a closed state when the fire starts, the fire-extinguishing bomb should be able to put out the fire normally. Through field inspection, it is known that 320 cabinets exploded at the time of the accident, which formed an open space between the cabinet and the engine room, resulting in exceeding the protection volume of the fire-extinguishing bomb and unable to achieve the fire-extinguishing effect [3].

4. Conclusion
a) The direct cause of the fire accident is that the phase A and phase B of the stator contactor are not completely disconnected (the contactor at the rotor network side is normally disconnected according to the main control logic, the generator is lack of phase electric operation and the rotor is open circuit);
b) The failure of stator contactor to trip the main circuit breaker of tower base (failure to cut off the fault current, which is a design defect) is an important cause of the accident.

5. Existing problems and suggestions
First of all, it was not found in the operation and maintenance stage that the design of the grid connected circuit of the wind turbine was unreasonable in protection, and there was no defect in the function of the main circuit breaker of the tower base when the stator contactor failed. Secondly, the arc extinguishing ability of the selected stator contactor in the design phase was not evaluated carefully in the operation and maintenance phase, and the effective protection measures were not taken in time for the problem that the action times of the stator contactor were close to the life limit and the arc extinguishing ability was insufficient. Moreover, through the inspection records and patrol inspection records, only the no-load closing test of the unit stator contactor and the grid side contactor was carried out, and no corresponding measures were formulated for the arc extinguishing capacity attenuation of the stator contactor in the operation and maintenance stage [4].
To sum up, first of all, it is necessary to reconstruct the circuit of the tower base circuit breaker with heavy fault of the frequency converter cabinet of the wind turbine in the whole site, add the function of the tower base circuit breaker with heavy fault of the frequency converter, timely disconnect the wind turbine from the power grid, narrow the fault range and reduce the economic loss. Secondly, we should immediately carry out the troubleshooting of unit hidden dangers, focusing on the comprehensive troubleshooting of safety chain protection circuit, electrical protection and backup power supply of wind turbine. Finally, the temperature parts of main circuit breaker, stator contactor and generator shall be inspected and rectified, and the SCADA operation statistics and analysis of wind turbine shall be carried out regularly.

References
[1] Niu Chunping, Xiong Qian, Xu Dan, Wu Yi, Li Zhongxiang, He Hailong. Experimental study on arc breaking characteristics of high power DC contactor in different media [J]. High voltage technology, 2019, 45 (11) p 3481-3484
[2] Yang Wenying, Liu Lanxiang, Zhai Guofu. Study on the spring characteristics of contactors for new energy under the influence of thermal field [J]. Journal of electrical technology, 2019, 34 (22) p 4687-4688
[3] Zhuang Jierong, Xu Zhihong. Auto disturbance rejection current model predictive control of intelligent electromagnetic contactor [J]. Journal of electrical technology, 2018, 33 (23) p 5449-5452
[4] Liu Yugen, Mi Hongwei, Wang Jianan, Ma Jinpei. Study on transient recovery voltage of small capacity generator outlet circuit breaker [J]. High voltage technology, 2015, 41 (06) p 1943-1946