

Analysis on Reason of Generator Set Complete Power Outage of a Hydropower Plant

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Abstract. There was a single-phase high resistance grounding fault on the outgoing line of a 110kV hydropower plant. As a result of the mismatch of protection setting values, misoperations happened outside of the main transformer protection area, which caused generator set complete power outage. This paper used RTDS to carry out simulation analysis on this fault, restored the development process of the fault and figured out the fault reason. Meanwhile, through the investigation and analysis on the configuration status of the main transformer backup protection from high voltage side and the neighborhood transformer protection of 110kV hydropower plants throughout the whole province, we concluded the irrationality of the protection configuration and proposed the solutions to it.

1. Introduction

Single-phase grounding faults can be classified into arc grounding, high resistance grounding and metallic grounding. According to the statistics of power systems, the majority of single-phase grounding faults are arc grounding and high resistance grounding^[1]. High resistance grounding is the most common single-phase grounding. As a result of its complex fault status and large variation range of its grounding resistance, the fault signals are weak, which often leads to neglect or misjudgement on the fault.

The main transformer backup protection generally has overcurrent protection, zero-sequence overcurrent protection and gap protection. Their calculations involve the configuration of protected sections, current and voltage values, weighing complex voltages and direction, time coordination, etc^[2]. So it is of significance to carry out comprehensive analysis combining primary polarity of CT and factors like directions of directional components in the instruction of protection devices when it comes to the setting calculation of power directional components; if not taking primary polarity of CT into account in directional components setting calculation, setting errors may appear, which will result in protection misoperations or refusing actions, turning out to be a severe threat to system security.

2. Process

2.1. Operation Mode before the Fault

NO.1 generator connects to NO.1 main transformer through switch 910, NO.2 generator connects to NO.2 main transformer through switch 920; switch 201 of NO.2 main transformer, switch 101 of



NO.1 main transformer and 110kV line 1 connects to 110kV busbar; 110kV bypass bus and 110kV line 2 work as cold spares. The main connection of the power plant is shown in Figure 1.

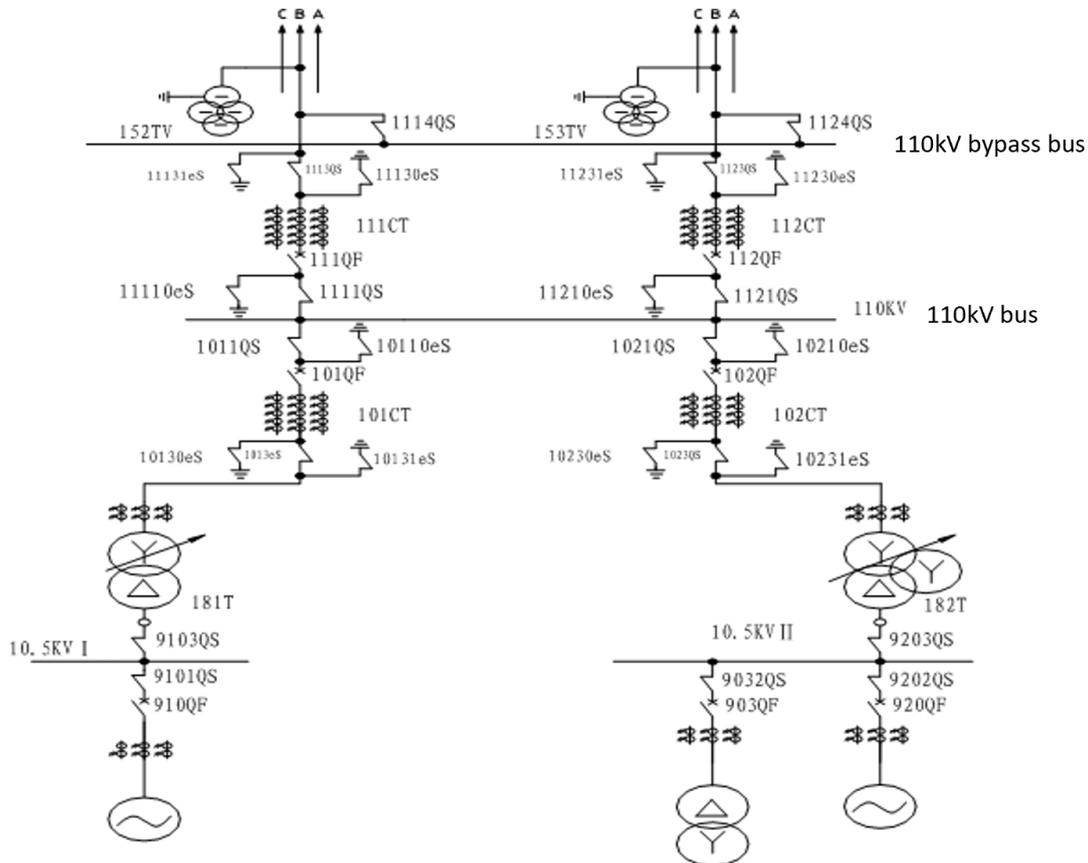


Fig. 1 Main connection diagram of the power plant

2.2. Description of the Fault

At 14:46:25:087, on April 29th, 2017, there was a grounding fault on phase A of 110kV line 1 of a hydropower plant. Zero sequence section IV of 110kV line 1 from the substation side sent out the trip signal, the line protection from the substation side started up without a trip signal; complex current section II of NO.2 main transformer backup protection from high voltage side actuated protection, cut out NO.2 generator, NO.2 main transformer tripped; zero sequence current protection of NO.1 main transformer backup protection gap from high voltage side sent out a signal, NO.1 main transformer tripped, NO.1 generator was cut out, which resulted in complete power outage. After line-tracking, the fault location was found to be near the power plant about 4km.

2.3. Time Sequence Diagram of Fault

As the time setting of protection devices GPS from both sides was inaccurate and duration of this fault was long, it is difficult to analyze the whole development of the fault directly through protection actions messages and fault wave-record charts. The action time and starting time of all the protections and fault wave recorders must be converted to a unified time coordinate point on the standard of starting time of protection of 110kV line 1 from the substation side. The following time points have been converted from which we could deduce the time sequence diagram of the fault (as shown in Figure 2).

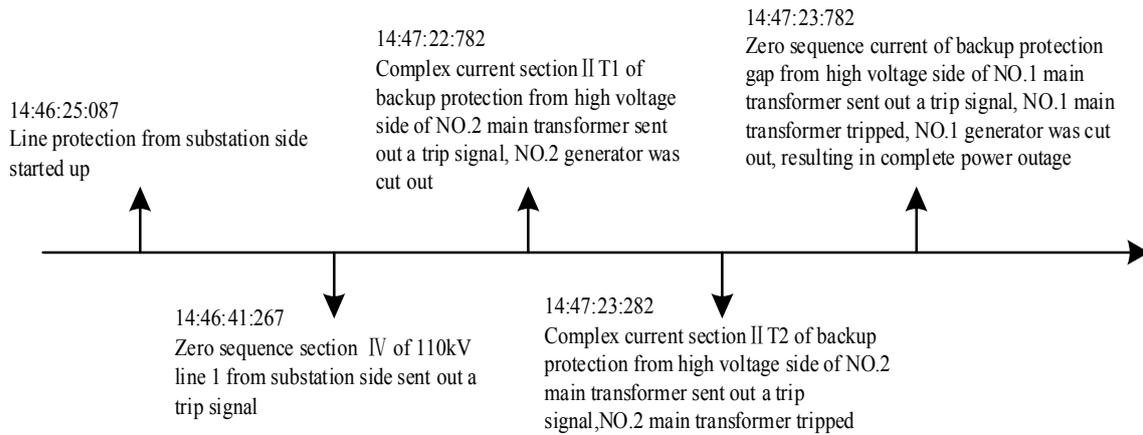


Fig. 2 Time sequence diagram of the fault

3. Analysis on Line Protection Actions

3.1. Analysis on Messages of Actions on Both Sides of Line and Wave-Record Chart

Actions messages of the protection of line 1 from the substation side said that there was a fault at phase A of the line, the protection from the power plant side started up and did not send a trip signal. As for normal single-phase grounding fault, voltage decreasing and current increasing are the fault characteristics of current and voltage waveforms. However, through the analysis on the current and voltage waveforms from the both sides of the line fault, fault waveforms from the substation side in Figure 3, current from phase A of the line was less than that from phase B and phase C, the bus voltage almost kept invariant; in Figure 4, fault waveforms from the power plant side, current from phase A of the line was larger than that from phase B and phase C, the bus voltage was also almost invariant.

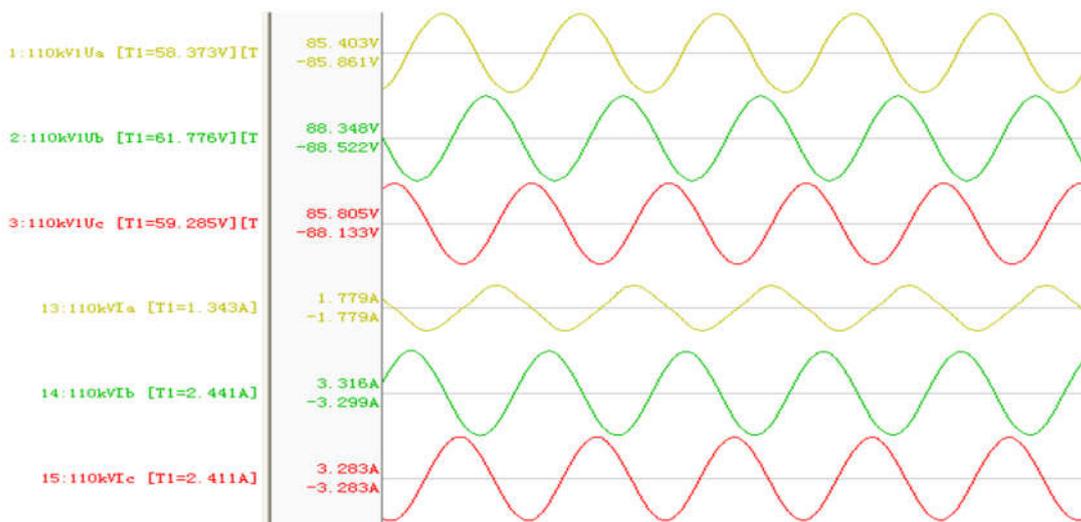


Fig. 3 Fault wave-record chart from the substation side

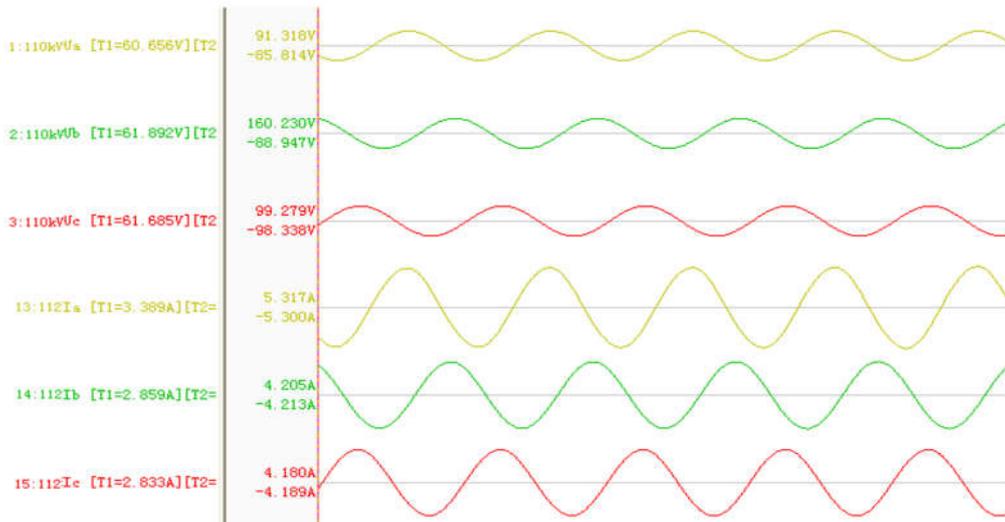


Fig. 4 Fault wave-record chart from the power plant side

3.2. Analysis on RTDS Simulation of High Resistance Grounding Fault

According to the parameters of the primary system and lines, we used RTDS to carry out simulation analysis on this high resistance grounding fault. Side M refers to the power plant side, side N refers to the substation side. After line-tracking, the fault was found to be near the power plant side, the distance between them was 4.3km.

According to the simulation results, when the single-phase high resistance grounding fault happened at phase A of 110kV line 1 from the power plant side about 4.3km with its grounding resistance more than 50Ω, the fault current of phase A from the substation side was less than that of non-fault-phases B and C.

4. Analysis on Main Transformer Protection Actions

4.1. Analysis on Main Transformer Protection Actions Messages and Wave-Record Chart

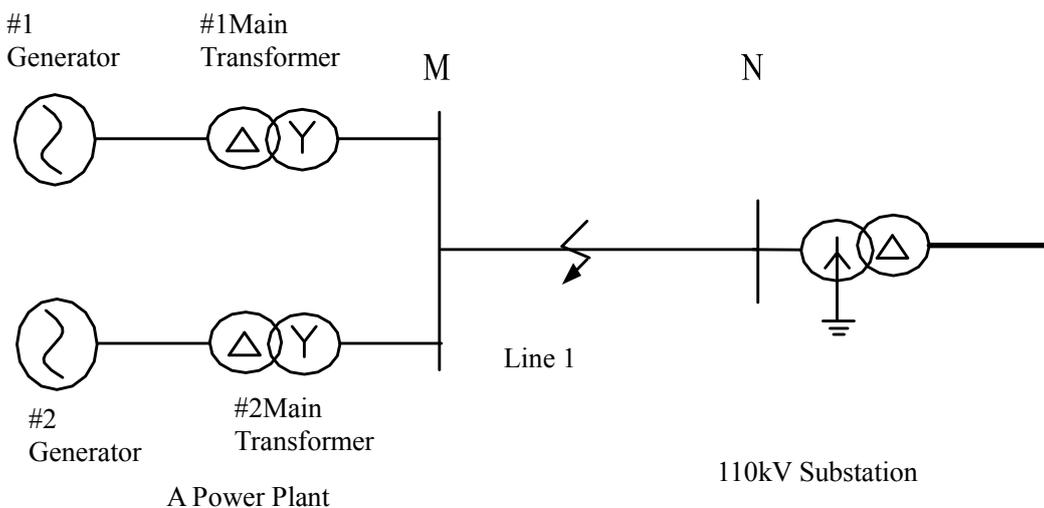


Fig. 5 Main wiring diagram

The main wiring between the power plant and substation is shown in Figure 5. As for the complex current section II of NO.2 main transformer, this fault was an external fault, so the action of complex current section II was a misoperation.

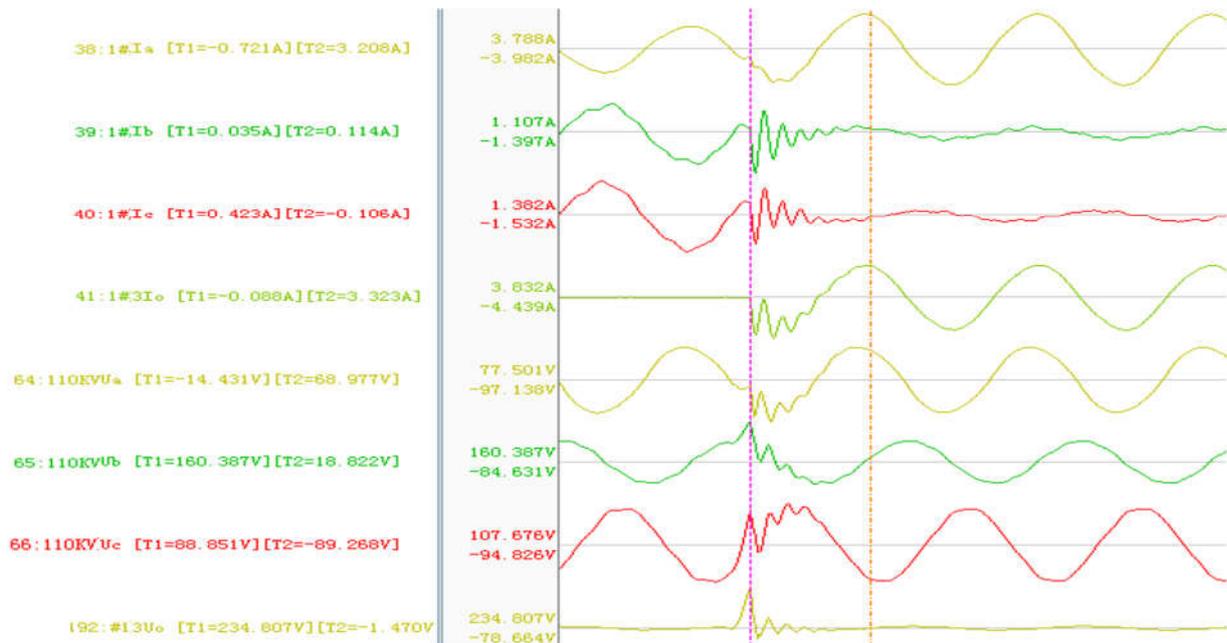
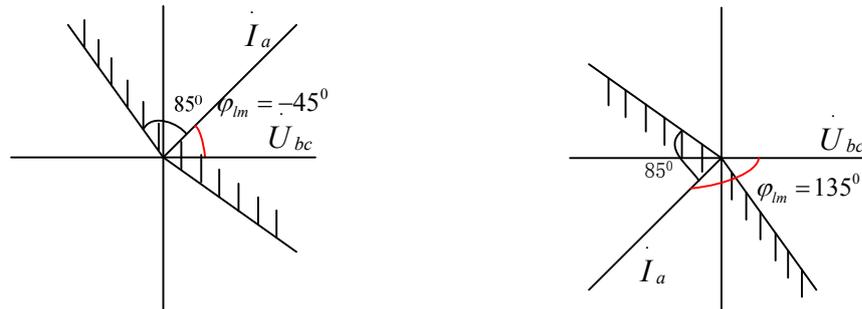


Fig. 6 Current and voltage waveforms of the high voltage side before NO.1 main transformer sent out the trip signal

When NO.2 main transformer tripped, NO.1 main transformer turned to have gap protection. The gap voltages are shown in Figure 6, the maximum instantaneous voltage was 234V, the gap was broken down. The zero sequence current RMS passing through the gap was 3.32A, larger than setting value 2.5 A. After 0.5s, gap zero sequence current protection started up, NO.1 main transformer tripped, NO.1 generator was cut out, the protection actions were correct.

4.2. Analysis on Reason of No.2 Main Transformer Protection Misoperation

High resistance grounding fault happened on phase A of line 1. Misoperation happened outside of complex voltage overcurrent section II of NO.2 main transformer backup protection from high voltage side, which could be related with the power directional components of complex voltage overcurrent section II. According to the principle of complex voltage locking overcurrent protection of CSC-326GH protection device [4], operation characteristics of interphase directional components in Figure 7 and Figure 8 were based on the conditions that the primary positive polarity end of main transformer CT was on the busbar side, the direction of directional components could be ordered to point to the busbar or transformers by control words.



a). The direction points to the transformer b) The direction points to the system

Fig. 7 Operation characteristics of interphase directional components

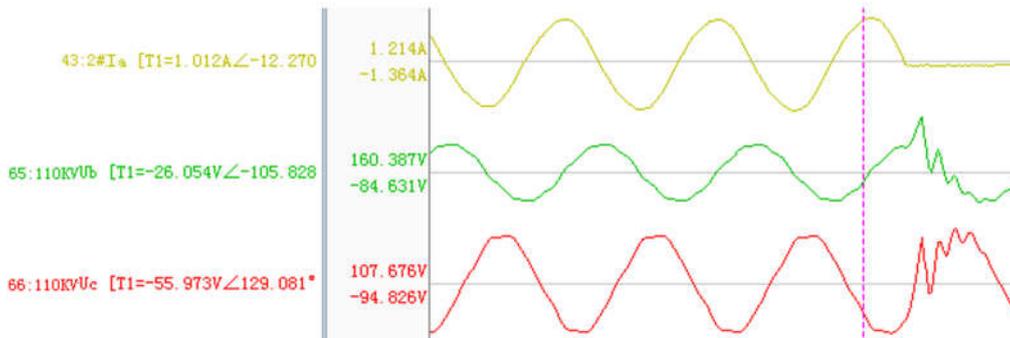


Fig. 8 Current and voltage waveforms of the high voltage side before NO.2 main transformer sent out the trip signal

Through the onsite verification and on-load tests of NO.2 main transformer backup protection from high voltage side, it was proved that the primary positive polarity end of NO.2 main transformer CT from the power plant side was on the high voltage side of the main transformer, which was contrary to the standard that primary positive polarity end of TA was on the busbar side as backup protection from high voltage side requested. Since the direction of fixed complex current section II pointed to the main transformer, the operation characteristics of directional components were the same as the specification said. According to the current and voltage waveforms, we could calculate the vector of power directional component of phase A as shown in Figure 9, which was consistent with the operation characteristics in the principle.

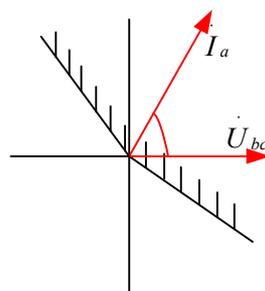


Fig. 9 Vector diagram of power directional component of phase A when the fault happened

The fixed value of current of complex current section II of NO.2 main transformer backup protection from high voltage side was 0.2A, the fixed voltage of negative sequence was 8V. When the

fault happened, the fault current RMS was 0.75A. When the negative sequence voltage of busbar was larger than 8V (the negative sequence voltage was 10.234V when the complex current section II sent out the trip signal), the complex current section II sent out the trip signal, which was a misoperation caused by setting.

The fault of line 1 wasn't enough to make the line trip, but it made the main transformer overcurrent protection actuated, so the current setting of complex current section II of main transformer was unreasonable.

4.3. Analysis on Coordination between Main Transformer Protection and Neighborhood Transformer Protection

Apart from not considering the primary polarity of the main transformer CT, that the fixed value of complex voltage overcurrent section II was too small also turned out to be a reason why the protection operation of complex current section II of backup protection of NO.2 main transformer from high voltage side was an overstepping action.

Therefore, a contradiction turned out: when the complex current section II worked as backup protection of the neighborhood transformer, the protection sensitivity was unable to meet the request, which was easy to cause misoperations; when the complex current section II did not work as backup protection of the neighborhood transformer, the neighborhood transformer would not have backup protection.

5. Present Situation Investigation

Through the information collection and analysis on eight 110kV hydropower plants including Luowan, Julongtan, Shangyoujiang, Baozishi, Jiangkou, Hongmen and Liaofang hydropower plants, Table 1 is as following:

Tab. 1 110kV hydropower plant protection configurations statistics of the whole province

Hydropower Plant	Neighborhood transformer backup protection configuration
Dongjin	No
Luowan	Yes
Julongtan	No
Shangyoujiang	No
Baozishi	No
Jiangkou	No
Hongmen	Yes
Liaofang	Yes

From the analysis on statistics results, we found that more than half of the neighborhood transformers of hydropower plants did not have backup protections, which would be a blind area of protection. Solutions to it must be proposed as soon as possible.

6. Conclusion and suggestions

We carried out simulation analysis on the high resistance grounding fault at phase A of 110kV line 1 according to the system actual parameters by using RTDS. We found that when the high resistance grounding fault happened at phase A, the fault current from the substation side would be larger than the current from non-fault-phases.

Through the analysis on the operating principles of NO.2 main transformer backup protection from high voltage side, fault wave-record charts of NO.2 main transformer protection and the report of the on-load tests of NO.2 main transformer, checking the direction of the primary polarity end of NO.2 main transformer CT, we concluded that the setting of directional components of complex current

section II of NO.2 main transformer backup protection from high voltage side did not take the primary polarity of CT into account, which caused the setting errors and misoperations.

Through the consideration on the rationality of taking the main transformer backup protection as the neighborhood transformer backup protection and statistical analysis on the neighborhood transformers of the 110kV hydropower plants from the whole province, we concluded that the directions of the directional components of main transformer backup protection should be consistent. And it is unreasonable to take complex current protection as line backup protection as well as neighborhood transformer backup protection, which may cause misoperations of protection devices due to the setting errors of directional components.

Suggestions upon the rectification of the power plant: 1) If the outdoor space allows, add a set of CT and protection devices on the branch side of the neighborhood transformer as the protection configuration of the neighborhood transformer. 2) Add a protection device for the neighborhood transformer as its protection, sharing the original protection winding of the neighborhood transformer.

References

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