Field analysis of switching transient process on the 35 kV side of a substation connecting to PV plant

Ge Wang¹, Yi Zhou¹*, Jingfeng Zhu¹, Shaoqing Chen¹², Tao Su¹, Jingwei Zhao¹ and Wei Liang¹

¹ State Grid Liangshan Electric Power Supply Company, Xichang, China
² State Grid Sichuan Electric Power Research Institute, Chengdu, China

*Corresponding author e-mail: zy863129@163.com

Abstract. To reveal the real causes of two explosion faults of potential transformer (PT) on a substation connecting to PV plant, an on-line monitoring equipment with a sampling rate of 40 MS/s for the transient voltage was installed on the secondary side of the PT. By switching the 35kV bus bar onto the main transformer, the switching transient processes on the PT were obtained. The field measured transient process indicated that the switching transient voltage caused by switch operation induced the resonance between the charging circuit and the PT and the resonance may be the direct cause of the PT explosion. The effective measures to suppress resonance in this substation are proposed.

1. Introduction

The booster power station of photovoltaic (PV) power station is the key hub of energy delivery of PV network and its stability tightly determines the generation income of photovoltaic power station. In China's Sichuan province, since 2015, a 2 MV photovoltaic power station has been unable to deliver its power because of two failures on the potential transformer (PT) on a booster plant.

For the first fault, thanks to the lightning location system, an obvious lightning strike was detected near the PV power station and the arrester installed on the 35 kV overhead transmission line acted. Thus, this fault can be identified as a lightning strike fault. The other fault happened during the operation of the switch which connects the 35 kV transmission line and the main transformer. As the consequence of the two faults, the explosion of 35 kV PT occurred.

In order to reveal the real cause of the fault, to propose the solutions, and to understand the transient process of the overhead line connected with the photovoltaic power station, a recording system of the transient process was arranged at the 35kV side. By reproducing the operation process prior to the faults, the recorded transient voltage oscillogram reveals the cause of the two faults. In addition, the recording system is kept operating to record the transient processes.

2. Field record of the transient process

The 2 MV PV plant is connected with the 35 kV bus bar of a booster substation via a 170 m overhead transmission line and this PV plant is the only power source of the 35 kV bus bar. Three single-phase electromagnetic potential transformers are connected to three-phase conductors of the bus.

The 35 kV bus bar is connected to the medium-voltage side of the main transformer via two parallel high-voltage cables. A switch is installed at the transformer end of the cables. The switching
fault occurred when the switch took an operation to connect the 35 kV side equipment through the cable.

A voltage recording system with a sampling rate of 40 MS/s was used to measure the voltage on the secondary output of the PT, which can be triggered by the mutation of input signals.

A field measured result of the recording system is shown in Fig.1. A transient voltage with a great amplitude appeared during the operation of the switch, which triggered the resonance of the circuit composed of the cable, the PT, the overhead transmission line, etc.

The frequency spectrum of the transient voltage is shown in Fig. 2. Besides power frequency voltage, there is a high dividing frequency voltage, which doesn't attenuate for a long time.

![Figure 1. Field result of the recording system](image1)

![Figure 2. Frequency spectrum of the transient voltage](image2)

3. Analysis of PT resonance suppression measures

According to analysis on potential transformer resonance oscillogram recorded by the overvoltage monitoring equipment, the process of potential transformer resonance can be divided into excitation processes and self-sustaining processes. The measures to suppress the resonance in potential transformer should be developed from these two ways.

3.1. Remove excitation process

Middle point of transformer high voltage winding grounds through zero sequence potential transformer, a connection method so-called ‘4PT’ [1-4], shown as Fig.3. With the access of zero sequence PT, zero sequence voltage and harmonic voltage will mainly fall in zero sequence PT, and those zero-sequence voltage and harmonic voltage of three-phase PT will be reduced effectively. The overall voltammetry of each phase of main PT is steeper than before, which can reduce amplitude of low frequency saturation current and prevent large oscillating currents. Three-phase PT is hardly to be re-excited to the core saturation state so that the ferro resonance problem of potential transformer is solved at the source.

‘4PT’ connection method consists of three single-phase fully insulated potential transformers and a semi-insulated (or fully insulated) single-phase potential transformer. The harmonic elimination principle is that when a transient voltage appears on the PT side, the primary voltage of the potential
The transformer has zero sequence and positive sequence voltages, the positive sequence voltage is applied to the main PT connected to the three-phase star, the phase voltages on the main PT do not change, the zero-sequence voltage (the zero-sequence voltage of each phase is the source phase voltage U0) is borne by the three-phase main PT and zero-sequence potential transformer, it is because the zero-sequence winding (open-angle loop) of the three-phase main PT is short-circuited, its zero sequence impedance is very small, it can be ignored compared with the impedance of zero sequence potential transformer so that the zero-sequence voltage is applied almost entirely to the zero-sequence potential transformer, and discharge current is suppressed by high impedance of zero-sequence PT and the large DC resistance will not cause transformer saturation and the resonance will not happen.

![Figure 3](image3.png)

**Figure 3.** Schematic wiring diagram of zero sequence PT for neutral point connection

3.2. Remove self-keeping process

The middle point of the potential transformer is grounded by resistance equals to increase the series resistance in the LC series resonance circuit to suppress the oscillation of the circuit[5-8]. When R is high enough, the RLC series circuit is under oscillation, and when the potential transformer is excited to saturation state, the circuit is not resonant, voltage at the end of the potential transformer cannot maintain the saturation state of the potential transformer, and then the circuit return to normal. Wiring diagram of potential transformer's high voltage midpoint grounding through resistance is shown in Fig.4, the resistance can be linear or non-linear. As for nonlinear resistance, the ground potential of mid-point can be kept to not exceeding the insulation level of PT’s N end to the ground when potential transformer works.

![Figure 4](image4.png)

**Figure 4.** Schematic wiring diagram of neutral point connection resistance

The selection of resistance is currently determined by test and calculation, the critical resistance is the inductive reactance of the transformer at phase voltage of 5.6%. There are also some gaps in the PT neutral point series resistance, that is, if the heat capacity of the resistance is not enough, the resistance will be damaged and loss the effect of harmonic elimination, and if the primary de-harmonic
resistance is too large, it will endanger the voltage level of the n-terminal to the ground. Generally, voltage withstand level of transformer N end to ground is 3kV, 1min, therefore, it is required that the voltage drop generated on the de-harmonic resistance should be less than 3kV, we should give attention to the resistance while choosing the resistance. In addition, the measure brings about a drawback that the voltage drop in the resistance produced by third harmonic current, makes third harmonic voltage filtered from the open angle circuit affect the normal operation and leads to three-phase source voltage unbalanced.

The photoelectric substation analysed in the text will expand so that the parameters of resonance circuit will change with the increase of line length and the number of line PT. According to the principle analysis of eliminating PT resonance self-retaining process by series resistance at neutral point on the high voltage side of PT, the resistance value of the neutral point at the PT high voltage side of the process of removing self-keeping needs to be modified with the change of the resonant circuit parameters, therefore, the de-harmonic method of PT high voltage side neutral connection resistance is not suitable for this photovoltaic substation. According to the principle analysis of eliminating PT resonance excitation process by means of series zero-sequence potential transformers at neutral points on PT high voltage side, considering the fact of photovoltaic substation usually runs a large harmonic voltage, it is necessary to raise the excitation threshold of its PT resonance, and the de-harmonic method of PT high voltage side neutral series zero sequence potential transformer is suitable for this photovoltaic substation.

4. Conclusion

A necessary condition for PT resonance is the presence of transient voltage perturbations, which causes saturation of PT core and decrease of inductance, then forms with circuit capacitance. But until recently, the sampling rate of fault recording devices in substation keeps low, which only record the resonance processes and do not record excitation processes so that it is difficult to analyze the resonance mechanism. To solve this problem, a transient voltage recording device with a sampling rate of 40MS/s is used to accurately record the resonant excitation processes and the resonant self-maintaining processes of potential transformers caused by the overvoltage during the process of switch operation.

According to the specific situation of this photovoltaic substation, we propose a resonant suppression measure to restrain the resonance excitation process of PT by means of series zero-sequence potential transformers at neutral points on the high voltage side of PT.

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