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Analysis of Backup Protection Action of a Transformer Caused by Improper Implementation of Voltage Regulation Measures

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Abstract. It is an effective measure for power enterprises to improve the voltage level of the system by raising and lowering the tap position of the main transformer. For the parallel operation of the main transformer, the whole process of adjusting the tap must strictly meet the conditions of parallel operation. Aiming at a case of backup protection action of main transformer caused by improper implementation of voltage regulation measures, this paper analyzes the uneven load distribution and increase of reactive power loss caused by improper adjustment of tap, and the analysis results are verified by PSCAD.

1 Introduction

Parallel operation of main transformers has the advantages of improving power supply reliability and facilitating system expansion, which has been widely used in power grid operation. However, the parallel operation of two main transformers must strictly meet the conditions of the same connection group, the same transformation ratio (allowable error of 0.5%) and equal short-circuit voltage (10%). Otherwise, there will be circulating current between the two main transformers in parallel operation, affecting the power supply capacity of the main transformer, causing overload of the main transformer and threatening the safe and stable operation of the system [1-5]. Based on an accident case, this paper analyzes in detail the mechanism of backup protection action for high voltage side of main transformer caused by the destruction of parallel operation conditions of main transformer when the system voltage level is improved by adjusting the tap position of transformer, and the analysis results are verified by simulations. The conclusion of correlation analysis has strong warning significance for engineering operation.

2 Case analysis

2.1 System operation mode before the accident

The main electrical connection of the substation in the case is shown in Fig.1. The substation consists of two main transformers of SSZ11-10000/110 with capacity of 10000/10000/10000 kVA, and voltage combination of 110±8×1.25%/38.5±2×2.5%/10.5 kV. Before the accident, 110kV 041 and 042 lines were in operation, 012 circuit breaker was in operation; 35kV 544 line was in operation, 541-543 line interval was cold standby, 512 circuit breaker was in operation; 10kV 142 line was in operation, 141, 143-148 line intervals were out of service, 171, 173, 174 interval low-voltage reactors were in operation state, 172 interval reactors were not put into operation, 4011 station transformer bay was in operation, and 112 circuit breaker was in operation. In addition, the tap position on the high voltage side of No. 1 main transformer is 10, and that of No. 2 main transformer is 8; the neutral points of 110kV and 35kV of the two main transformers are not grounded.

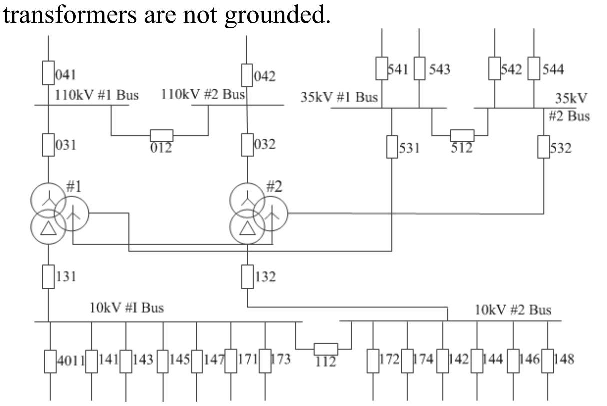

Fig. 1. Case related main electrical connection of Substation

2.2 Brief description of the accident

At 12:55 on a certain day in 2020, the voltage of 110kV Bus in the substation jumps to 120.23kV, which is beyond the allowable range of normal voltage operation; meanwhile, the voltage of 10kV Bus in the substation is low, which is 10.1kV. In order to control the voltage of 10kV bus within the normal operation range, the dispatcher on duty selects to increase the transformer tap position, so as to put the No.2 low-voltage reactor into operation after increasing the voltage of 10kV bus. At 12:58, the dispatcher adjusted the tap position of No.1 main transformer from 10 to 16. At 13:01, the multiple

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voltage overcurrent section III for the high voltage side of No.1 Main Transformer acted to trip off the three sides of No.1 main transformer. On-site inspection, the main transformer body has no fault, and the line inspection results show that there is no fault in the medium and low voltage side lines.

2.3 Accident cause analysis

The main transformer protection of the station is the main and rear split protection device. The model of differential protection device is IPAC-5741, and the model of backup protection device at high, medium and low voltage sides is IPAC-5742. When the accident occurred, the fault recorder in the station was damaged and the waveform at fault time was not grasped. The wave recording function of the backup protection device for the high voltage side of the main transformer was abnormal, and the action waveform was not recorded, only the start-up waveform was recorded, as shown in Fig.2. The waveform was not recorded in the medium and low backup protection of the main transformer either. Fig. 2 shows that the three-phase current at the high-voltage side of the main transformer is symmetrical, and the three-phase voltage is normal, showing overload characteristics. Due to the limited basis of accident analysis, the fault process can only be qualitatively deduced based on SCADA, WAMS and protection action message, but the rationality of the deduction is verified by the electromagnetic transient simulation results.

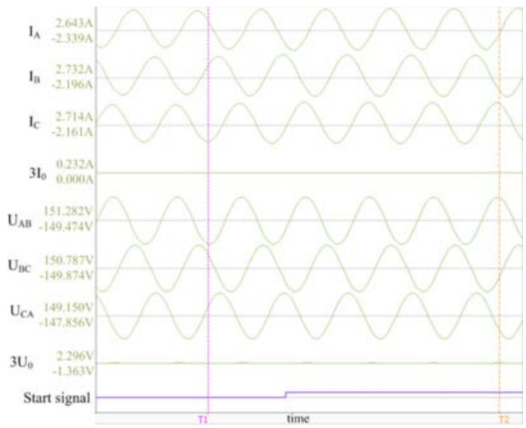

Fig. 2. Starting wave recording of backup protection of main transformer before tripping

Before the accident, the load of 544 and 142 lines was light, and the load of main transformer was the inductive reactive load of 171, 173 and 174 low-voltage reactors, and the capacity of each low-voltage reactor was 4.2MVar. According to the SCADA system, the reactive power distribution of the two main transformers before the shift adjustment of No.1 main transformer is unbalanced, and the reactive power consumption of No.1 main transformer is higher than that of No.2 main transformer. Before the shift adjustment, the tap position of No.1 main transformer is higher than that of No.2 main transformer, and the voltage of medium voltage side of No.1 main transformer is higher than that of No.2 main transformer. Current is then formed in the closed circuit of medium voltage side and two sections of bus bar of two main transformers. After induction of high voltage side, circulating current will be generated between two main transformers and high and medium voltage side buses, as shown in Fig.3. In the figure, I_1 and I_2 are the circulation on the high and medium voltage sides respectively, and I_3 is the total circulation. The circulating current does not flow to the load and only flows in the parallel circuit between the two main transformers, so it mainly shows reactive current.

Due to the high tap position of No.1 main transformer, the circulating current flows from No.1 main transformer to No.2 main transformer, and the current direction is the same as that of No.1 main transformer and opposite to that of No.2 main transformer, resulting in the reactive power of No.1 main transformer higher than that of No.2 main transformer. It should be noted that there is no power point in I_3 circuit simply from Fig.3, and according to Kirchhoff voltage law I_3 should be zero. However, in fact, I_3 circuit is composed of a part of two large power grid systems in parallel. Two main transformers are supported by system power supply voltage and become power points in I_3 circuit, which is the basis of circulating current generation. In the same principle, there will be circulation between the high-voltage side of the main transformer and the low-voltage side of the main transformer, that is, there will be circulating current in the three sides of the main transformer, and the high-voltage side circulation is the sum of the middle and low-voltage sides.

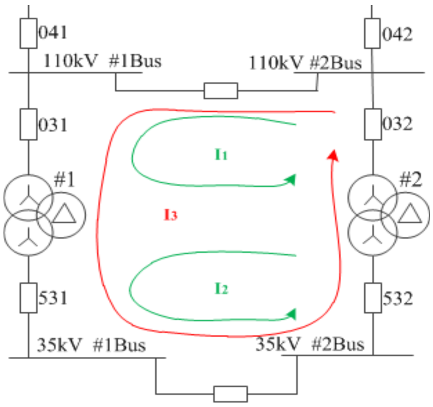

Fig. 3. Circulation flow chart

Further analysis the data of SCADA shows that after the shift adjustment, the reactive power at the high and medium voltage sides of No.1 Main Transformer increases suddenly, the reactive power at the high and medium voltage sides of No.2 main transformer suddenly decreases, and the reactive power at the low voltage side of the two main transformers does not change suddenly. The reason is that the dispatchers only adjusted the No.1 main transformer, resulting in the further widening of the tap position difference and voltage ratio difference of the two main transformers, and the circulation current at the high and medium voltage sides increased accordingly. After the adjustment, the reactive power direction at the high voltage side of No.2 main transformer is still in the

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positive direction, while the reactive power direction at the medium voltage side is in the opposite direction, which indicates that the circulating current is less than the load current at the high voltage side and larger than the load current at the medium voltage side, which is consistent with the light load on the 35kV side and heavy load on the 10kV side.

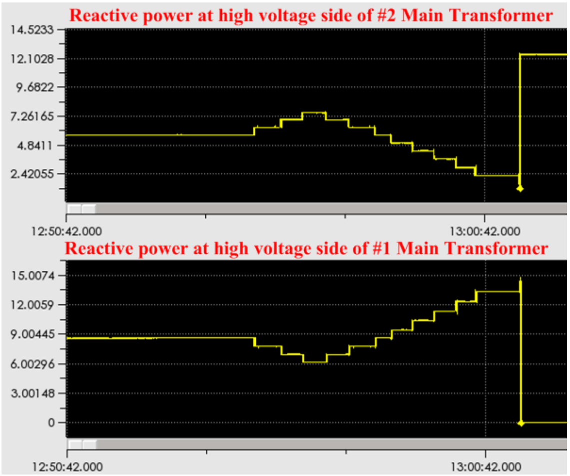

Fig. 4. Main transformer reactive power diagram of WAMS system

The high backup protection of main transformer is equipped with three section over-current protection, section I and section II are equipped with multiple voltage locking, and section III is not with multiple voltage locking, and the operation value of section III is 1.73A, that is 1.378 times of rated current; the middle backup protection is equipped with four sections of over-current protection, I, II and III are all locked by multiple voltage, Section IV is not provided with multiple voltage locking, and the operation value of Section IV is 1.65A. It is 1.32 times of the rated current; the low voltage side is equipped with four section over-current protection, the first three sections are locked by multiple voltage, and IV is not locked by multiple voltage. The action value of IV is 3.0A, that is 1.31 times of rated current. As there is no wave recording file support, WAMS fault data with relatively higher data accuracy is further retrieved, as shown in Fig.4. Fig.4 shows that with the tap adjustment, the reactive power distribution of the two main transformers changes gradually. When the tap changer is adjusted to the last tap, the reactive power consumption of No.1 Main Transformer suddenly rises to slightly higher than 14MVar, which is 1.4 times of the main transformer capacity, resulting in the action of section III of high backup protection of No.1 main transformer. It should be noted that, according to the unit value, the setting value of low backup overcurrent Section IV is lower than that of high backup overcurrent section III, but the low backup overcurrent IV does not act because the high voltage side reactive power is the sum of the low voltage side reactive load, main transformer reactive power, high and medium voltage side circulating current reactive power, and the high and low voltage side circulating current reactive power. After adjusting the tap, the circulating current at the high and medium voltage side suddenly increases, and the current does not flow through the low voltage side of the main transformer, and the main transformer low backup protection did not act. At the same time, the load on the medium voltage side of the main transformer is light, and the circulating current flowing through the main transformer fails to reach the action value, so it does not act. In addition, due to the normal three-phase voltage, the over-current protection function with multiple voltage blocking will not operate.

To sum up, the high backup protection action of No.1 main transformer is due to improper implementation of voltage regulation measures, which seriously damages the parallel operation conditions of main transformer, resulting in circulating current at high, high and low voltage sides of parallel main transformer, resulting in uneven load distribution of two main transformers and small transformation ratio, and increased reactive power loss of main transformer, resulting in high backup protection action of No.1 main transformer and correct protection action behavior.

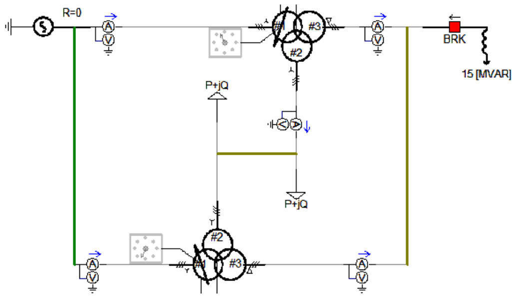

Fig. 5. simulation model

3 Simulation verification

The simulation model shown in Fig.5 is constructed based on PSCAD simulation platform. The figure includes two 110kV main transformers with on load voltage regulation in parallel operation, No.1 Main Transformer corresponding to voltage regulation 1 and No.2 main transformer corresponding to voltage regulation 2. Winding No.1 is the high-voltage side, winding No.2 is the medium voltage side, and winding 3 is the low-voltage side. The rated short circuit impedances of each transformer are 10.24%, 17.91% and 6.29% respectively, which are consistent with the actual case. There are 9 taps in total, and the voltage regulation ratio of each tap is 2.5%, which is twice of the voltage regulation ratio of one tap of the actual main transformer. In the above accident case, the tap of No.1 main transformer was adjusted to 6 taps, but the taps of the two main transformers were not consistent before the shift. In the initial state of the simulation, the taps of the two main transformers were the same, so four taps should be adjusted accordingly. The simulation results based on the model are shown in Fig.6. P1, Q1, P2 and Q2 are active and reactive power of high voltage side and low voltage side of No. 1 main transformer, P3 and Q3 are active and reactive power of high voltage side of No. 2 main transformer, P4 and Q4 are active and reactive power of low voltage side of No. 2 main transformer, and P5 and

Q5 are active and reactive power from medium voltage side of No.1 main transformer to medium voltage side of No.2 main transformer. Fig.6 shows that the active and reactive power of the two main transformers are completely the same before the shift adjustment, and no current is generated between the medium voltage sides of the two main transformers; with the gradual increase of the tap position of No.1 main transformer, under the condition that other conditions remain unchanged, the reactive and active power output of the two main transformers are different, and the difference gradually increases, and the output of No.1 main transformer is higher than that of No.2 main transformer; the comparison shows that the high and medium voltage sides and high and low voltage sides are the same The circulation in the voltage side is higher than that in the low voltage side.

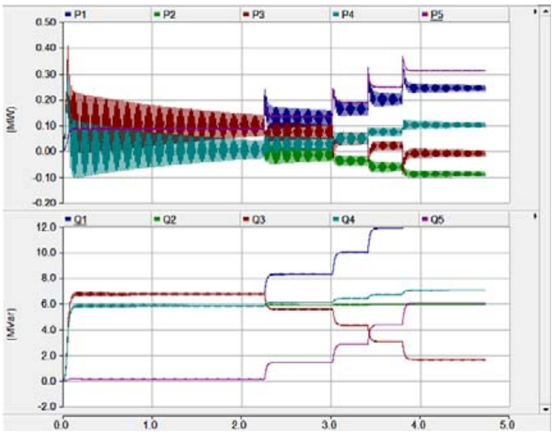

Fig. 6. Simulation waveform when the tap of No.1 and No.2 main transformer are 9 and 5 respectively

On the basis of Fig.6, the tap of No.2 main transformer is reduced to the first tap, and the simulation results are shown in Fig.7. In Fig.7, the reactive power at the high voltage side of No.2 main transformer is in the opposite direction, the reactive power flowing from the medium voltage side of No.1 main transformer to the No.2 main transformer is larger, and the reactive power at the low voltage side of the two main transformers is in the positive direction. The figure shows that the main cause of Q3 reverse is the increase of Q5. The reverse reactive power at the high voltage side of No.2 main transformer is more reliable to confirm the existence of circulating current between the two main transformers.

The simulation results in Fig.6 and Fig.7 show that when two main transformers operates in parallel, only adjusting the tap position of one of the main transformers will generate circulating current between the two main transformers, and the circulating current will increase with the increase of the shift difference, which may cause overload or even over-current protection action of the main transformer with small transformation ratio. In addition, under the condition of impedance parameters of each side of the main transformer used in the simulation, the circulating current in the high and middle voltage side is larger than that in the high and low voltage side, which is consistent with the actual case.

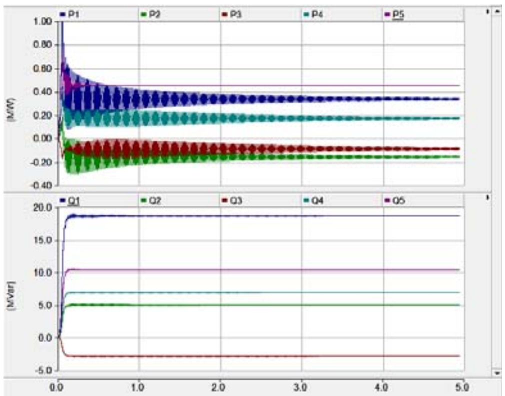

Fig. 7. Simulation waveform when the tap of No.1 and No.2 main transformer are 9 and 1 respectively

4 Conclusions

Based on accident case analysis and electromagnetic transient simulation, this paper shows that circulating current will occur when two main transformers do not meet the conditions of parallel operation. Especially when the difference of transformer ratio is large, it will not only cause uneven load distribution of main transformer in parallel operation, but also bring additional reactive power loss to main transformer, which may lead to mal-operation of backup protection of main transformer with small transformation ratio, which must be alerted sufficiently. Power grid operation enterprises should strengthen personnel training and reasonably arrange the operation tap of main transformer in each substation. Two main transformers should be adjusted step by step in turn to ensure that the main transformers always meet the conditions of parallel operation.

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