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Research on Abnormal over-voltage of Substation

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Abstract：This paper starts from the analysis of the frequent occurrence of insulation breakdown accident in a substation in Northwest China.Through the calculation and simulation of over voltage,a government scheme of over voltage control is proposed.

Introduction

Upgrading and expansion of a power distribution system in the Northwest substation.After the transformation with two 35 kV power lines，two sets of new power transformer，S9-4000/35GY,the feeder circuit has 13 lines,and daily load of 60 thousand kWh.After put into operation a month began to frequent switch cabinet contact box, cable head loss insulation breakdown accidents, happen once a month on average.In sever cases,devices was breakdown two times in one day. Frequent tripping, switching system, power outage maintenance operations increased maintenance cost, serious threat to the safety and reliability of the driving power supply.The main wiring and fault parts of the substation are shown in Figure 1.

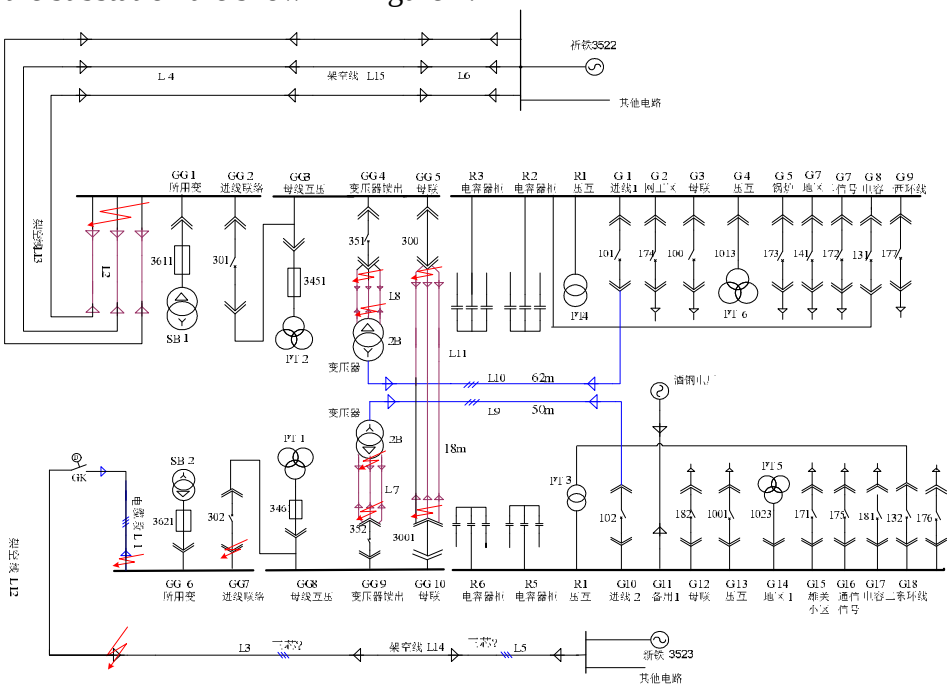

Fig. 1 Schematic diagram of the main wiring and fault location of a substation

In order to ensure the safe operation of the substation and the reliable power supply of railway transportation and driving power supply,needing to develop an integrated management device for abnormal over voltage of 35kV railway distribution substation.

Qualitative analysis of the causes

According to the basic experience of high voltage electrical equipment operation. In addition to external forces can directly cause damage to the equipment. The main cause of the electrical equipment insulation discharge or breakdown accident is nothing more than the following two points：First, aging, defective insulation, the device itself ability to withstand voltage decreases；Second, the over voltage problems,the voltage applied to electrical equipment much

more than capacity of the equipment.

From the theory of over voltage analysis，over-voltage is a kind of electromagnetic transient phenomenon. Occur over-voltage there must be an external electromagnetic interference，or the energy of system within a larger "incentive" (for example: the system of energy redistribution caused by internal operation mode change, etc.).Investigation and analysis of the insulation breakdown accidents of more than once occurs in substation.， every accident was found suddenly. When the accident happened，the weather is sunny and no thunderstorm, etc. Therefore，can rule out the possibility of aggrieve that caused by lightning over-voltage. Before the accident, the system runs normally and stably, there is no switching operation and no other short circuit faults in the system.. Thus，not a reason for operating over voltage. Because there is no change in the system operation mode，the load is small and basically remain uncharged. Hence，the system is stable，there is no large disturbance and disturbance in the system.and no possibility of generating an electromagnetic resonance with the system. Hence,it could be maintained:It is a result of abnormal over-voltage that the insulation and discharge accidents happened many times in this substation.

Causes of abnormal over-voltage

Can be seen from the main wiring diagram of the substation，the total length of Qi iron 3522 line is 3161m，the two sections has been inserted into the three core cable amount to 2080m，Cable terminal connector 4, intermediate joint 4; 3523 new rail lines with a total length of 6480m, which consists of 3 800m cable, 3 core cable joint, a total of 10 single core, 6 joints. Two 35kV high voltage power lines to the outside, are about 80m long cable into the high pressure chamber. Consequently，Consider 35 kv overhead lines, cable lines, high pressure chamber busbar and capacitance, the equivalent capacitance and line equivalent inductance, the transformer, the equivalent inductance of main transformer, voltage transformer, it is a more complex mesh L - C parameters of the circuit. According to the theory of electrical engineering, each L-C mesh has a natural resonant frequency and resonant structure. Due to the complexity of the L-C parameters, the resonant frequency can be high frequency, or low frequency, frequency division ratio, the cause of resonance occurs is depending on the electromagnetic disturbance of the crocodile system. The analysis shows that the high voltage power line circuit of the power distribution system has the possibility of resonance of high frequency, low frequency or frequency division.

Qi iron wires and new wires are from variable distribution of 35kV busbar is introduced. Bus with a plurality of other load line, including power supply circuit of the nearby iron and steel enterprises. Communication equipment and steel rolling impact of the Iron and Steel enterprises,there is a very wide range of frequency. These wide frequency electromagnetic shock or disturbance. For large capacity of the local 110kV variable distribution, the relative energy is small, not enough to cause over-voltage. However，for the power distribution system, which is connected to the same bus bar, due to its own light load,,the overhead lines and cable lines are connected alternately. Presenting a complex L-C network. from the power supply in the broadband rate electromagnetic impact or disturbance, there will be corresponding resonance, thus in no thunder and lightning.In the case of the variable power distribution system is not operated, the power supply system itself is running stable, resulting in abnormal over voltage.

Theoretical calculation and Simulation of abnormal over-voltage

Equipment and load conditions of power distribution substation

Main transformer capacity：4000KVA

Change in use：SC9—50/35GY

Current transformer：35KV：150/5 (LDJ1-35/300S)
10KV：300/5 (LZZB19-10C2)
Circuit breaker：35KV：ZN12—40.5/1250—25
10KV：ZN28—12/1250—25
Bus voltage transformer of 35KV：JDZX9—35
Peak load period：（9:00—11:00） 32A, cos *j* ：0.9
Minimum load period：（2.00—6.00） 21A, cos *j* ：0.93

The 35kV system of the power distribution system

The 35kV system of the power distribution system is composed of the new iron wire and the iron wire, and the related changes, circuit breaker, voltage transformer, bus bar and so on. The structure of the new iron wire and the iron wire is symmetrical, so the simulation of the new wire system is selected, as shown in Figure 2.

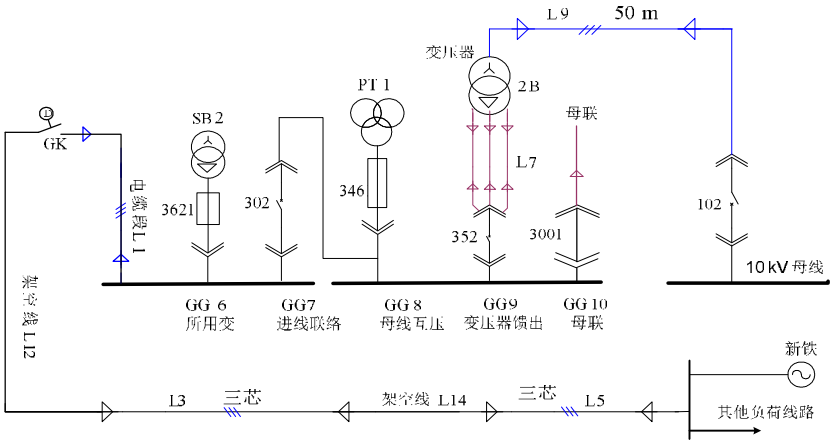

Fig.2 new line 35kV system diagram

Equivalent circuit of 35kV system (new line) in Substation

Because of the symmetry of the new iron wire and the wire of the prayer, the calculation should be considered. The equivalent circuit of the new subway system as shown in Figure 3, including: C0 denote per unit length of overhead lines and cables or switch cabinet bus capacitance to ground, for example: C06 said GG6 switch cabinet bus capacitance to ground; cm, respectively, which indicated that the mutual capacitance per unit length of the overhead line or a switch cabinet bus between, for example: Cm6 said the mutual capacitance between GG6 switch cabinet bus; m represents the mutual inductance per unit length between overhead lines; power system of infinite three-phase supply through the new railway substation 110kV/35kV to change the distribution of the power supply.

In the new railway substation, power supply to the power transformation and distribution of the same bus, other load (for example: Iron and steel enterprises in the variable current equipment, rolled steel, impact, etc.) is equivalent to amplitude and frequency are random shock disturbance, 3 with E (T) of the CJ said.

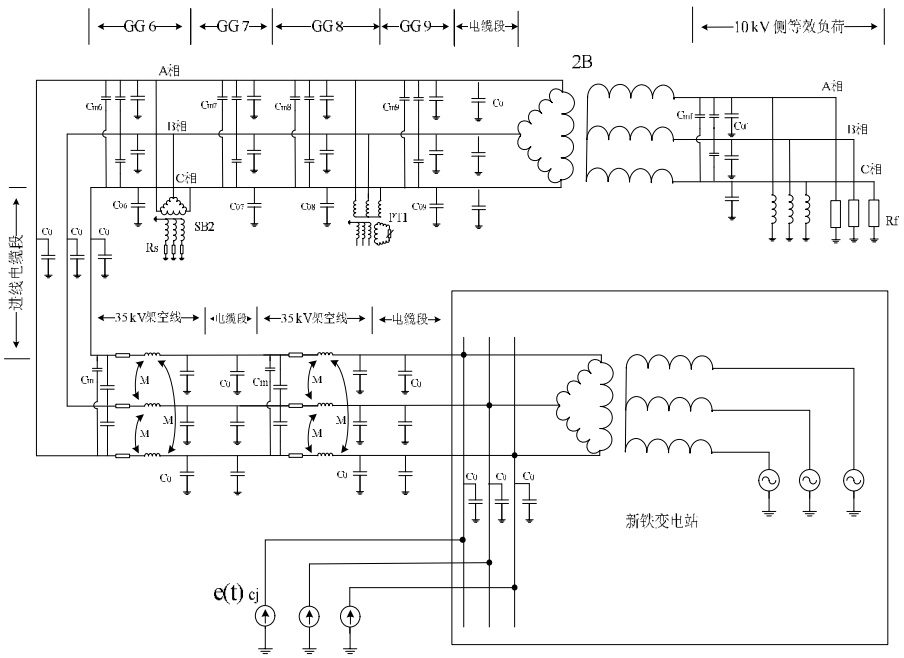

Fig.3 equivalent circuit of the new line 35kV system in the substation

Calculation method of abnormal over-voltage

Based on the above analysis, the source of the abnormal over-voltage in the power distribution system (new line system side) is caused by the harmonic impact or disturbance caused by the new line. In theory, one of the methods to calculate the over voltage caused by harmonic shock is to use the method of modal analysis.

The resonant voltage caused by the shock disturbance of the system is known as the F:

$$\boldsymbol{U}_f = \boldsymbol{Y}_f^{-1}\boldsymbol{I}_f \tag{1}$$

The admittance matrix of the system network at the frequency of F; and the node voltage and the node injection current matrix of the system network at the frequency of F. In order to simplify the notation, the following omitted the subscript F.

According to the characteristic root of the vector analysis, the matrix Y can be decomposed into the following form：

$$\boldsymbol{Y} = \boldsymbol{L\Lambda\ R} \tag{2}$$

In order to form a diagonal eigenvalue matrix, the left and right eigenvectors are respectively.

The type (2) into the equation (1) can be obtained.：

$$U = \mathbf{L}\boldsymbol{\Lambda}^{-1}RI \quad \text{or} \quad TU = \Lambda^{-1}RI \tag{3}$$

Defined as "mode voltage vector", as "mode current vector", then type

$$\boldsymbol{V} = \boldsymbol{\Lambda}^{-1}\boldsymbol{J} \tag{4}$$

The vector equation (4) is written in matrix form:

$$\begin{bmatrix} V_1 \\ V_2 \\ \mathrm{M} \\ V_n \end{bmatrix} = \begin{bmatrix} l_1^{-1} & 0 & 0 & 0 \\ 0 & l_2^{-1} & 0 & 0 \\ 0 & 0 & \mathbf{L} & 0 \\ 0 & 0 & 0 & l_n^{-1} \end{bmatrix} \begin{bmatrix} J_1 \\ J_2 \\ \mathrm{M} \\ J_n \end{bmatrix} \tag{5}$$

The reciprocal of the characteristic value of the upper admittance matrix is the unit of the impedance, and is named as the modal impedance ". From the formula (4) it can be seen that, if or very small, very small mode injection current will result in a large mode voltage V, i.e., the occurrence of overvoltage.

The mode voltage is obtained according to the above method, and the voltage of any node in the system can be obtained, and the relationship between the node voltage and the mode voltage is:

$$U = LV \tag{6}$$

The vector equation (6) is written in matrix form:

$$\begin{bmatrix} U_1 \\ U_2 \\ \vdots \\ U_n \end{bmatrix} = \begin{bmatrix} L_{11} \\ L_{12} \\ \vdots \\ L_{1n} \end{bmatrix} V_1 + \begin{bmatrix} L_{12} \\ L_{22} \\ \vdots \\ L_{nn} \end{bmatrix} V_2 + \mathbf{L} + \begin{bmatrix} L_{1n} \\ L_{2n} \\ \vdots \\ L_{nn} \end{bmatrix} V_n \approx \begin{bmatrix} L_{11} \\ L_{12} \\ \vdots \\ L_{1n} \end{bmatrix} V_1 \tag{7}$$

Abnormal over-voltage simulation

In accordance with the above modal resonance analysis method to calculate the workload is very large, must be completed by computer simulation. According to the actual situation of the substation 35 kV system structure and equipment, to establish the simulation model of three-phase, the single-phase simplified schematic model as shown in Figure 4, wherein said power supply system, new railway substation 110 / 35 kV transformer said said new railway substation busbar and the cable outlet total equivalent capacitance, represented with the new wire connected on the same bus harmonic impact source, line parameters, said variable Jiayuguan center distribution of 35 kV side of the transformer, voltage transformer, power transformer, switch cabinet, bus, etc. the total equivalent capacitance and reactance.

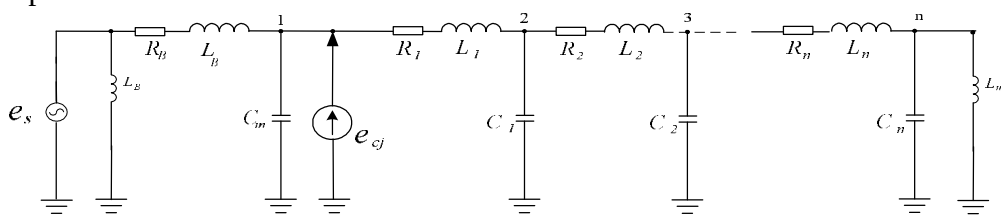

Fig.4 single phase simplified model of the new line 35kV system

Hypothesis and the new wire is connected on the same bus harmonic impact current source as shown in Figure 5, the maximum peak is 30a, equivalent effective value of about 21a; according to Fourier series decomposition method can calculate the harmonics percentage such as shown in Figure 6.

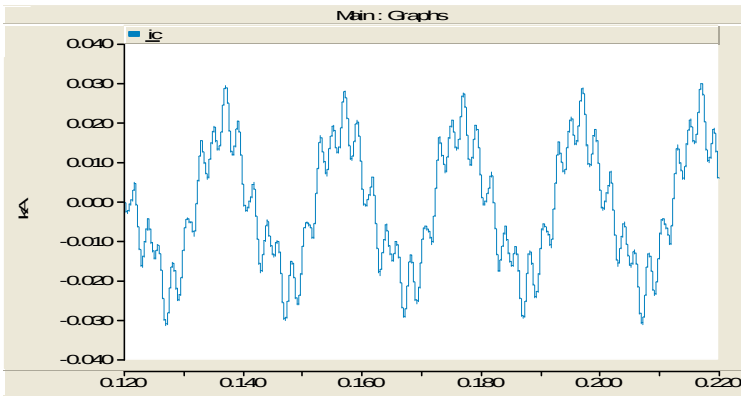

Fig. 5 harmonic current source e_{cj}

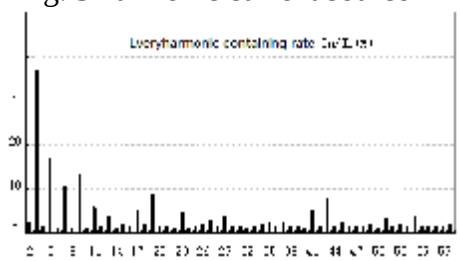

Fig. 6 percentage of harmonic content in harmonic

According to the analysis of the modal resonance method and apparatus actual parameters using computer programming, the figure 5 shows the assumption of harmonic current source, change the combination of different harmonic impact time harmonic content, drawn in accordance with the

superposition method of the distribution of the entrance of the harmonic resonance voltage distribution as shown in Figure 7. From the simulation results, we can see: with the increase of the harmonic content of the harmonic interference source and overvoltage general trend was increased, the harmonic content is 13% ~ 21%, over voltage close to 200 kV; harmonic content is 50%, peak voltage up to 380 kV. Such a high voltage is not able to withstand the insulation equipment, must be limited, to ensure the safety of the operation of the power distribution system.

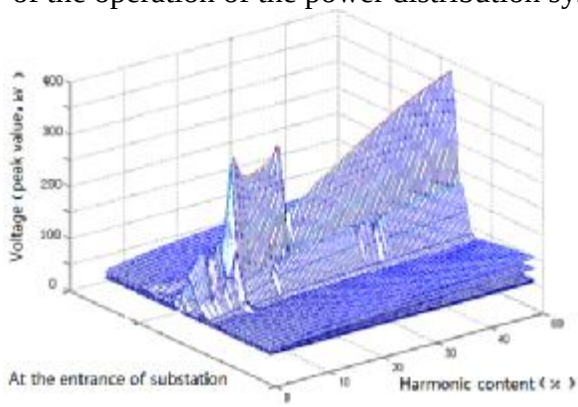

Fig. 7 the distribution of harmonic resonance over voltage

Over voltage comprehensive treatment plan

Principle and requirement of comprehensive control over voltage

According to the above analysis and calculation, it is needed to study and determine the over voltage comprehensive treatment plan, and follow the following principles and requirements：

1.The new 35kV line system, which is the most serious insulation accident, is selected as the test object.

2.Does not change the main wiring and relay protection setting value of the transformer substation.

3.The developed overvoltage control device can eliminate the resonance overvoltage of various frequencies caused by the power supply, namely, the integrated control of the overvoltage.

4.The over-voltage control device of the transformer and the power distribution substation can not cause the other switch trip of the transformer and the power supply to the load.

5.Due to the face of the resonant overvoltage is a continuous function of over-voltage, any lightning arrester can not withstand, once the sustained resonance over-voltage, will cause the bus on both the lightning arrester explosion and equipment damage. As a result, the overvoltage control device can control the trip of the 302 switch, and has the function of protecting the operation equipment.

6.Variable power distribution over the voltage comprehensive control device has the function of 35 kV bus power of real-time monitoring, voltage exceeds the national standard (38.5kV) of alarm function, alarm and the parameter can be adjusted in the field.

7.The installation and implementation of the integrated control device of the transformer and distribution substation, shall not affect the overall structure of the power distribution equipment, and the equipment is as simple as possible.

Development of voltage integrated control device

According to the principles and requirements of the comprehensive treatment plan of the above mentioned above, the integrated control device for over-voltage must be composed of the following equipment:

1.Substation over voltage harmonic suppressor - when the variable power distribution system in various frequency resonant, immediate anti phase oscillations, cancellation and over-voltage suppression；

2.The energy consumption of the 10Hz ~ 3500Hz in the wide frequency range of the wide frequency range (variable power distribution system) is the power consumption of the system, which is the amplitude of the damping off;

3.The voltage of the variable distribution substation is an indication of the anti phase offset, suppression and damping;

4.Distribution the voltage control cabinet, monitor - a hand finish the function of real time monitoring system voltage and also achieve reservation system sustained ferroresonance, control 302 switch trip to equipment protection function.

Effect of the combined action of the device: when the variable power distribution system in electromagnetic transient impact or disturbance, in the A, B, C phase of positive sequence, negative sequence and zero sequence, wide frequency range of anti phase offset, suppression and ultra damping overvoltage; the anti phase offset, anti ultra and damping, the existence of residual voltage energy release, thus removing the overvoltage. Therefore, the development of over voltage integrated control device, will greatly reduce the system from the power impulse or disturbance caused by the risk of over voltage.

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