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Production and Suppression of Resonance Overvoltage for a Type of DC De-icer Installation

HE Zhaoxia¹, WU Chuanqi², CHEN Jun², WAN Tao², XIA Tian², LI Jingbin²

1, Yangtze University College of Technology & Engineering, Jingzhou, 434023, China

2, State Grid Hubei Electric Power Research Institute, Wuhan 430077, China

HE Zhaoxia: 13617257427@163.com

Abstract. The DC de-icer installation has been widely used in the ice protection of power system. Because of the difference between the design and the actual operation of the installation, the resonance overvoltage has been threatening the device body from the distribution parameters of the de-icer transmissions. In this paper, based on the analysis on the mechanism of the resonance overvoltage, the estimate expression of the resonant length of the transmission has been derived. Through the simulation modeling by PSCAD/EMTDC, the effectiveness of the estimate expression has been verified. The suppression measures of the resonance overvoltage have been proposed.

Index Terms: DC de-icer, Resonance Overvoltage, mechanism, simulation modeling, effectiveness, suppression measures

1. Introduction

The large-scale icing of the power grid will seriously affect the safe operation of the power system. Icing of transmission lines is one of the most serious hazards, and the DC de-icer installation is the most effective measure to resist the icing of wires [1]-[5]. The first 500kV fixed DC de-icer installation in Hubei Power Grid has been put into operation at Enshi, which can effectively defend extreme weather and major natural disasters of the Yu-E Power Grid. As an electrical equipment that has only been widely used in recent years, the DC de-icer installation will face various problems that were not foreseen in the initial stage of the design during the actual operation [6]-[8]. When the line is melting, the resonance overvoltage generated by the DC de-icer installation is a special problem. The fixed DC de-icer installation installed by China Southern Power Grid Corporation in Liping Substation has experienced damage to the device due to resonance overvoltage [9]. So it is necessary to analyse the mechanism of resonant overvoltage in the DC de-icer installation, and propose measures for the overvoltage fault.

Based on the characteristics of the distribution parameters in a fixed DC de-icer installation with a typical structure when the transmission line is melting ice, the cause and resonance characteristics of the resonance overvoltage fault are analyzed. A DC harmonic power supply simulation model is used to study of the resonance overvoltage. In the meantime, the measure for this type of resonance overvoltage is proposed in combination with the structural characteristics of the DC de-icer installation.

2. Analysis of ice melting method of DC de-icer installation

At present, most of the fixed DC de-icer installation operating in China adopt a twelve-pulse rectification structure, as shown in Figure 1. Between the device and the ice-melting line, the



ice-melting line and the ice-melting mode are switched through six isolated switches G1-G6, and the three-phase short-circuiting ends of the ice-melting line are short-circuited. Corresponding to the above installation settings, there are "1 + 1" and "1 + 2" ice melting methods for the ice melting line [8].

The "1 + 1" ice melting method refers to the simultaneous melting of two phases and the non-connection of the other phase. Take Figure 1 as an example, that is, the operation mode after closing the G1 and G6 switches.

The "1 + 2" ice melting method refers to simultaneous ice melting of three phases and two of them are connected in parallel. Take Figure 1 as an example, that is, the operation mode after closing the G1, G5, and G6 switches.

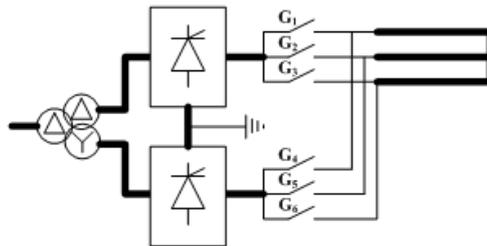


Figure. 1 The typical operation method of DC de-icer installation

Because the de-icer installation usually does not need to operate at full load, the "1 + 1" de-icer method can perform full load ice melting on two-phase lines at the same time, and the three-phase lines need only be switched one time. Therefore, the proportion used in actual production runs is higher. But at this time, the disconnecter side of the unmelted ice phase is a floating phase with voltage operation, and its voltage changes with the voltage change at the end of the de-icer line, that is, the fractures of G2 and G5 and the relative ground both endure the line end voltage. In the "1 + 2" de-icer mode, the disconnect switch only withstands positive and negative outlet voltages.

3. Mechanism of overvoltage in DC de-icer installation

3.1. Analysis of resonant overvoltage loop

The quality of the DC voltage waveform of the DC de-icer installation is lower than that of the DC transmission line, and the harmonic content in the DC voltage is higher. In the "1 + 1" method of de-icer, the harmonic components in the DC voltage form a resonance loop between the line distribution parameters, and the resonance overvoltage is amplified from the floating phase line to the exit of the de-icer installation, posing a threat to the device.

It can be known from the operating conditions of the three-phase circuit that there is ice melting current in phases A and C, and no ice melting current at the open end of phase B. The ice melting distance of the DC de-icer installation is usually within 100 km, so it can be equivalent to a single π -type concentrated parameter circuit[10]. It can be obtained that the mutual inductance L_m between the A phase and the C phase needs to be considered, and the direction of the harmonic current flowing through the two phases is the same. Referring to the calculation model of the zero sequence parameter of the line, the inductance of the A phase and the C phase can be expressed as (L_0 is Self-inductance):

$$L_a = L_c = L_0 + L_m \quad (1)$$

Because the head end is connected to the power supply and the end is short-circuited, the mutual capacitance has little effect in this equivalent circuit, so it can be ignored. The resonant overvoltage equivalent circuit of a typical DC de-icer installation is shown in Figure2.

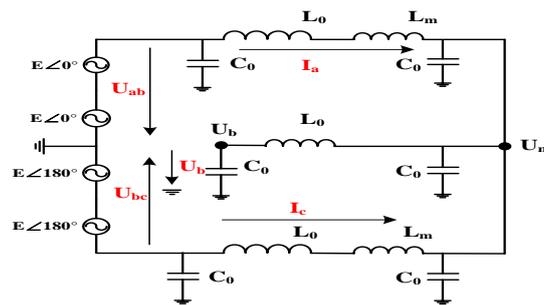


Figure. 2 Equivalent circuit of the π parameters in the de-icer method

3.2. Calculation method of resonance point of transmission line

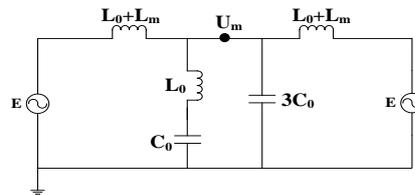


Figure. 3 Equivalent circuit of the resonance overvoltage

The equivalent circuit of resonant overvoltage analysis is obtained by simplifying the equivalent circuit of Figure 2, as shown in Figure 3. According to Kirchhoff's law, the expression of the equivalent circuit can be derived as:

$$\frac{2(U_m - E)}{j\omega(L_0 + L_m)} + \frac{U_m}{j\omega L_0 + \frac{1}{j\omega C_0}} + \frac{U_m}{\frac{1}{j\omega 3C_0}} = 0 \quad (2)$$

Simplifying the above formula gives:

$$U_m = \frac{2(1 - \omega^2 L_0 C_0)E}{3.72(\omega^2 L_0 C_0)^2 - 6.96\omega^2 L_0 C_0 + 2} \quad (3)$$

According to this formula, the conditions under which the circuit reaches the resonance point is:

$$3.72(\omega^2 L_0 C_0)^2 - 6.96\omega^2 L_0 C_0 + 2 = 0 \quad (4)$$

The inductance per unit length of the transmission line is dL ; The capacitance to ground per unit length is dC ; The line length is l . The capacitance C_0 to ground of the transmission line under the π -type equivalent circuit is $dCl / 2$. Solve the formula (4), get the line length l of the two resonance points in the equivalent circuit as shown in formula (5), where the frequency of the equivalent circuit is f .

$$l = \frac{1.51}{\omega\sqrt{dLdC}} = \frac{1.51}{2\pi f\sqrt{dLdC}} \quad (5)$$

$$l = \frac{0.36}{\omega\sqrt{dLdC}} = \frac{0.36}{2\pi f\sqrt{dLdC}}$$

4. Simulation research on resonant overvoltage of DC de-icer installation

4.1. Establishment of simulation model

With PSCAD / EMTDC, a resonant overvoltage simulation model of a twelve-pulse DC de-icer installation is established based on the three-pulse DC harmonic model. The model is shown in Figure 4. Where V_{ac} is the output voltage of the DC de-icer installation, V_{end} is the phase-to-ground voltage of the floating phase isolating switch, V_{end_U} is the breaking voltage of the isolating switch, and V_{post} is the end voltage of the transmission line. Phase B is a suspended phase, and the de-icer installation performs phase A and C melting.

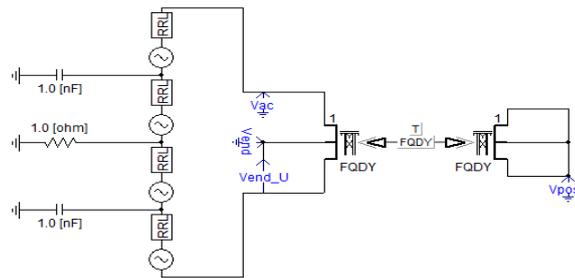


Figure. 4 The simulation modeling of the resonance overvoltage for DC de-icer installation

The upper and lower six pulsating bridges are regarded as two harmonic power sources, and the harmonic frequency of 300 Hz is the characteristic harmonic of the six pulsating bridges. The phases of the upper and lower six-pulsating bridges of the power supply model differ by 180 degrees[7]. The 6th harmonic content of the six-pulsation bridge can be up to about 30%. The AC measurement voltage of the DC de-icer installation is 10kV, so its harmonic voltage can reach 3kV, and each power supply is set to 1.5kV. Because only the impedance and capacitance of the line need to be considered, the transmission line model uses the Bergeron model with distributed parameters.

4.2. Comparison between analysis and simulation

The typical 220kV transmission line impedance parameters are used in the calculation. The typical parameters at the reference frequencies of 50Hz and 300Hz are shown in Table 1. Because the harmonic characteristic frequency has a great influence on the distribution parameters of the transmission line, the inductive and capacitive reactances directly affect the calculation of the resonance overvoltage.

Table. 1 Parameters of typical 220kV transmission-line

Impedance Parameters	Frequency 50Hz	Frequency 300Hz
Positive Resistance R	$0.058 \cdot 10^{-3} \Omega / m$	$0.058 \cdot 10^{-3} \Omega / m$
Positive Inductive Reactance XL	$0.41 \cdot 10^{-3} \Omega / m$	$2.44 \cdot 10^{-3} \Omega / m$
Positive Capacitive Reactance XC	$185.94 M \Omega \cdot m$	$31 M \Omega \cdot m$
Zero-sequence Resistance R	$0.198 \cdot 10^{-3} \Omega / m$	$0.198 \cdot 10^{-3} \Omega / m$
Zero-sequence Inductive Reactance XL	$0.64 \cdot 10^{-3} \Omega / m$	$3.86 \cdot 10^{-3} \Omega / m$
Zero-sequence Inductive Reactance XC	$357.55 M \Omega \cdot m$	$59.59 M \Omega \cdot m$

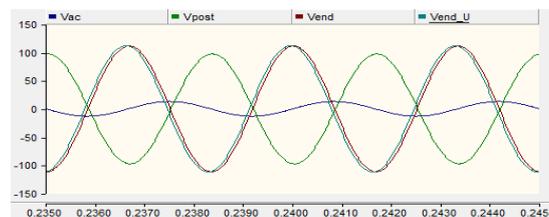


Figure. 5 Typical simulation waveform of the resonance overvoltage for DC de-icer installation (l=215km)

Based on the above parameters, the ice melting resonance lengths of 220kV lines are 215km and 68.8km by comparing the overvoltage amplitudes under different transmission line lengths. The typical resonance overvoltage waveform of the obtained ice-melting line is 215km as shown in Figure 5. The relative ground overvoltage of the B-phase isolating switch is close to the breaking voltage of the isolating switch, exceeding 100kV, which is slightly higher than the overvoltage at the short-circuit end of the transmission line. The amplitude of the terminal overvoltage exceeds the rated output voltage of the DC de-icer installation by 30p.u., which is far greater than the insulation design level of the commonly used 10kV DC de-icer installation.

Substituting the line parameters of 300 Hz in Table 1 into equation (5), the resonance point length of this transmission line is 234.1 km and 58.8 km. Comparing with the results of simulation calculation,

it can be seen that the difference between the resonance point lengths of the two methods is about 10% ~ 15%. Therefore, the simplified analytical expression of equation (5) can effectively estimate the length of the transmission line resonance point of the resonance overvoltage of the DC de-icer installation.

5. Treatment measures of resonant overvoltage fault in DC de-icer installation

The above results indicate that the resonant overvoltage of the floating phase isolation switch at the outlet of the DC de-icer installation in the above operating mode exceeds 30p.u. However, the disconnection and relative ground insulation level of the isolating switch is designed according to the rated voltage insulation level of the DC de-icer installation, so there is a high possibility of explosion and arcing of the arrester. It is recommended that the following measures should be taken for resonant overvoltage faults when different ice melting methods are used:

- (1) When the DC de-icer installation adopts the method of "1 + 2" de-icer, try to avoid the non-ice melting phase conductors from being charged and floating.
- (2) Install a flat wave reactor at the exit of the DC de-icer installation to reduce the harmonic content in the ice melting current and improve the voltage waveform quality.
- (3) When the DC de-icer installation adopts the method of "1 + 1" de-icer, formula (5) should be used to effectively estimate the resonance point of the de-icer line. The line length near the resonance point causes excessive resonance overvoltage.
- (4) A lightning arrester with a parallel gap can be installed at the exit of the DC de-icer installation to avoid damage to the body of the ice-melting device after the disconnection of the disconnecter. Because the resonance overvoltage is much higher than the insulation level of the DC de-icer installation, the surge voltage absorbed by the surge arrester alone can easily cause an explosion. Increasing the parallel clearance can effectively increase the safety margin of the overvoltage energy release.

6. Conclusion

Based on the above analysis, the following conclusions can be obtained:

- (1) With analyzing the mechanism of a resonance overvoltage fault generated by a typical DC de-icer installation in actual ice-melting conditions and effectively simplifying the ice-melting circuit, an analytical expression for estimating the resonance length of the transmission line is obtained.
- (2) A simulation calculation model of the resonance overvoltage of the DC de-icer installation is built. Comparing it with the estimated expression of the unloading of the transmission line resonance length, the validity of the formula is demonstrated.
- (3) Based on the generation mechanism and waveform characteristics of the resonance overvoltage, some suggestions on suppression measures are proposed.

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