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Analysis of converter insulation characteristics and selection of restraint resistors

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Abstract. The commutation structure is a composite insulation structure composed of oil, paper and cardboard. The converter transformer usually adopts positive and negative adjustment, and the polarity selector generates a recovery voltage and a breaking circuit between the opened contacts during the switching process. It is usually necessary to use a tie resistor to make a potential connection to the voltage regulating winding to limit the recovery voltage. At the same time, in order to shorten the time of the potential resistance access and reduce the no-load loss of the transformer, a potential switch is required to be used in conjunction with the tie resistor. In this paper, the characteristics of the floating potential and the capacitor current during the switching of the positive and negative voltage-regulating windings are analysed. The relationship between the arrangement of the commutating windings and the recovery voltage is given. The positive and negative floating suspension breaking capabilities of the contacts are analysed by examples. The calculation basis for the selection of the binding resistor is given, and relevant conclusions are given.

1. Introduction

The commutation structure is a composite insulation structure composed of oil, paper and cardboard. The valve side winding needs to withstand the effects of AC voltage, lightning impulse voltage, and operating surge voltage, and also withstands the DC voltage, the combined voltage of DC and AC, and the polarity reversal voltage generated by the system reversal (grid side). The winding is subjected to various tests such as AC voltage, power frequency AC induction and external test voltage, lightning impulse voltage and operating overvoltage. The main and longitudinal insulation structure of the side winding of the converter transformer is similar to the conventional DC. The key to the insulation design is the main and longitudinal insulation structure of the valve side winding.

Affected by the impact voltage and the AC voltage, the distribution of the relevant voltage in the insulation structure of the converter transformer is usually determined by the dielectric constant. Because paper and oil have similar dielectric constants, the electric field distribution is also present in the paper and the oil. Influenced by the steady-state DC voltage, the electric field distribution in the



paper insulation and the oil insulation is significantly different from the electric field distribution under the influence of the impact voltage and the alternating current, and is directly determined by the electrical resistivity of the insulating material. At this time, the resistivity of the oil is several orders of magnitude lower than that of the paper, so most of the DC electric field is distributed in the insulating paper. In the state of polarity reversal, a relatively complex insulation change is produced. Not only is the electric field strength of the oil insulation increased several times more securely, but the electric field distribution of the other medium is also significantly improved [1].

Generally, the windings in the commutation change are generally divided into the network windings connected to the AC system and the voltage regulating windings, and the valve windings of the converter valves are connected according to the system to which they are connected. There are two ways to connect in a typical way. The first one is iron core column → voltage regulating winding → mesh side winding → valve side winding. The second type is iron core column → ground screen → valve side winding → mesh side winding → voltage regulating winding arrangement. There are also references in the literature: iron core → voltage regulating winding → horizontal winding in the middle of the grid side winding → valve side winding and iron core → valve side winding → net side winding → voltage regulating winding, net valve winding are end vertical outlet and other connection methods, but it is not feasible to be considered uneconomic.

The OLTC uses the polarity selector to switch the positive and negative connection of the regulating winding. During the process of switching the polarity selector from "+" to "-" to "+", the positive and negative regulating windings will be short-lived. Instantaneous suspension potential. At this time, the switching process will cut off the capacitor current, and the recovery voltage will appear after the cut-off. The phase of the capacitor current relative to the recovery voltage is -90° , that is, when the capacitor current crosses zero, the recovery voltage reaches a peak value. If the peak voltage is too high, the polarity selector will not be able to complete the polarity change. For this purpose, the calculation of the breaking current and the recovery voltage should be calculated. When the corresponding limit value is exceeded, the binding resistor should be added to prevent the floating potential.

When the voltage regulating windings are arranged differently, the recovery voltage is also different.

2. Winding sequence

2.1 Converter structure

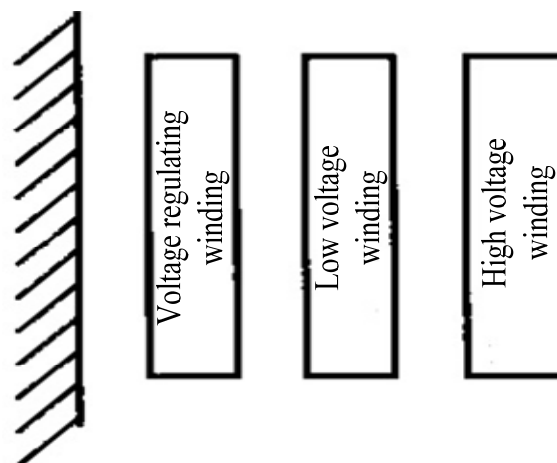


Figure 1. First arrangement

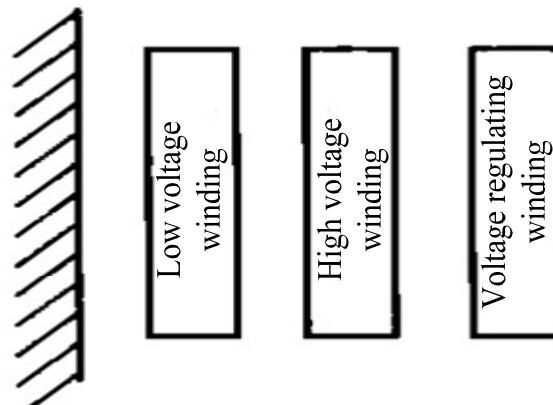


Figure 2. Second arrangement

In Fig. 1, the voltage regulating winding is separated from the high voltage basic winding by one winding, so the recovery voltage is low. In Figure 2, the voltage regulating winding is close to the high voltage basic winding, and the outside is the fuel tank, so the recovery voltage is high [2].

The arrangement of the commutating typical coil is: iron core → pressure regulating coil → net side coil → valve side coil → fuel tank, which is the first middle connection method above, because the winding insulation resistance level is increased, it is necessary to increase the coil between And the main insulation distance of the end insulation, by increasing the number of angle rings, paper tubes and coils, and reasonable arrangement, to ensure the reasonable distribution of the electric field under the action of AC, DC and polarity reversal voltage, effectively improve The insulation strength of the oil and paper insulation structure ensures that the insulation structure has sufficient insulation margin under various effects.

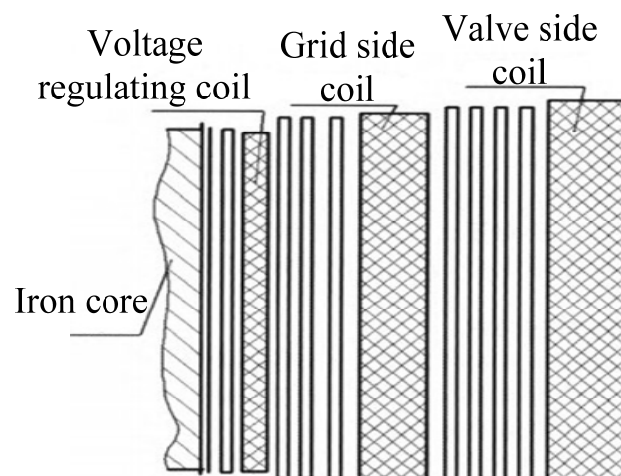


Figure 3. Main insulation structure of converter transformer

3. Main insulation structure of converter transformer

For the insulation structure of the converter transformer consisting of oil, paper and cardboard, the electric field distribution of alternating current, lightning impulse and operating surge voltage is basically the same as that of the conventional transformer electric field, mainly depending on the dielectric constant of different materials. When DC voltage is applied, the distribution of electric field depends on the resistivity of different materials [3]. From the above analysis, the dielectric constant of the transformer oil is relatively low. Therefore, when the AC voltage is high, the electric field strength is relatively large, and the insulation is relatively low. The solid insulation of paper and paperboard has a large electrical resistivity, and under the action of DC voltage, it is a region with relatively low

insulation. At the same time, the position of the winding end is subjected to various voltages, and is also a region with relatively low insulation.

Document 3 points out that the transformer oil is $2.2 \times 10^{-11} \text{F/m}$, oil-impregnated insulation paper is $3.5 \times 10^{-11} \text{F/m}$, oil-immersed insulating cardboard is $4.4 \times 10^{-11} \text{F/m}$.

When the polarity is reversed, it is necessary to consider the effects of alternating current and direct current. At the moment of polarity reversal, a large amount of electric charge is accumulated at the oil-paper interface, and a higher radial electric field stress is formed in the oil passage after the reversal. For this reason, the thickness ratio of oil and solid insulation material should be adjusted. This should be determined by the calculation and analysis results of the power plant to enhance the reliability of the main insulation, and the reasonable distribution of the ratio will seriously affect the safety of the insulation.

The longitudinal insulation of the commutating winding refers to the insulation between the winding coils and the insulation between the segments. With the increase of the working voltage of the commutation, the influence of the surge voltage and the long-term working voltage on the insulation between the coils becomes more and more important. For the long-term working voltage, the voltage per mm is less than 3kV, so that the insulation of the crucible is not free phenomenon. The effect of the impulse voltage on the insulation between the coils depends mainly on the winding structure. By adjusting the winding structure, the purpose of reducing the gradient voltage between the coils and increasing the impact strength between the turns is achieved [5], [8].

Under the working condition, when the polarity reversal occurs, the DC polarity changes and the positive and negative polarity changes abruptly. At this time, the abrupt voltage distribution is characterized by a capacitive distribution, and the oil gap with a small dielectric constant is subjected to the oil gap. Most of the voltage, plus the binding charge, the voltage mainly acts on the oil, so improving the oil resistance in the oil gap is the main target, and the voltage component acting on the paper is small [6].

4. Recovery voltage calculation

4.1 Recovery voltage calculation

An island station converter type ZZDFPZ-176700/230-330, $(230 \pm 8 \times 1.25\%) \sqrt{3}/166.57 \text{kV}$ adopts ABB Sweden's on-load tap changer model, UCLRE380/1800/III, voltage regulating winding the positive or negative direction is linked with the high voltage basic winding, which is a positive and negative voltage regulation. A garden converter station adopts mode 1 arrangement, and the commutation of a certain island station becomes the second mode arrangement, so the relative recovery voltage is higher.

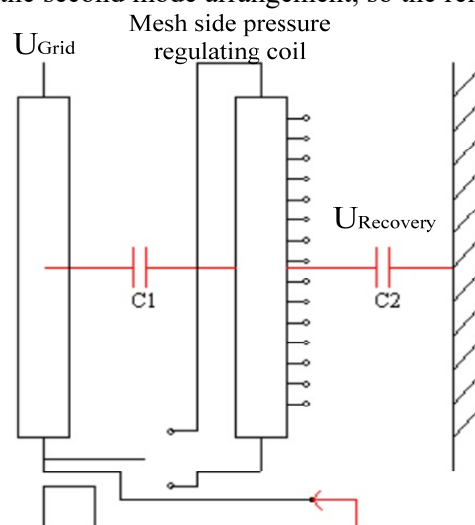


Figure 4. Equivalent capacitance distribution of commutation in an island station

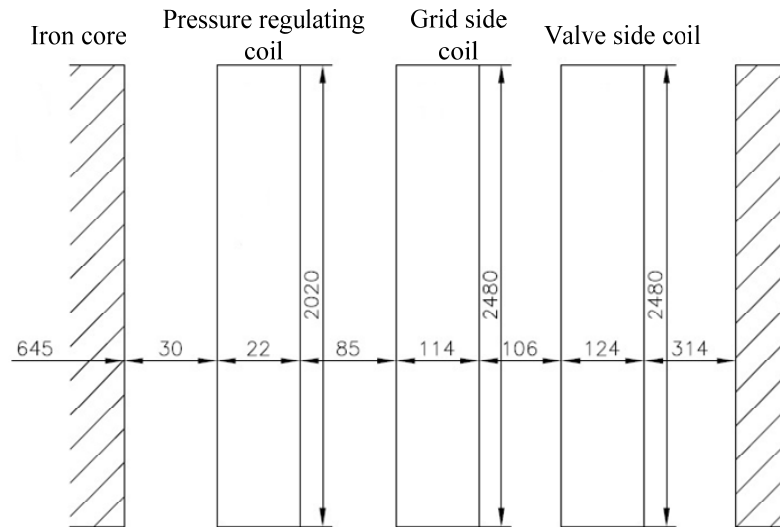


Figure 5. Coil arrangement of commutation in an island station

Table 1 provides the distribution of the capacitance of the two different types of commutation. From literature [2], [7], it is possible to calculate the + contact voltage and the contact voltage when the Y or YN positive and negative regulation windings are suspended. From the distribution of Table 1, it can be concluded that the recovery voltage of the second case is 116.6kV, which is much larger than the first case of 25.8kV, so it is necessary to increase the binding resistance to limit it.

Table 1. Calculation of breaking capacity during forward and reverse polarity suspension

Model		$(230 \pm 8 \times 1.25\%) / \sqrt{3} / 166.57 \text{ kV}$	$535 \pm (+28 / -4 \times 1.25\%) / \sqrt{3} / 210 / \sqrt{3} \text{ kV}$
Grid side voltage (kV)	U_1	230	535
Voltage regulator coil voltage (kV)	U_t	23	107
Capacitance (nF)	C_1	2.685	3.462
Capacitance (nF)	C_2	6.627	2.773
Angular frequency	ω	314	
+contact recovery voltage (kV)	U_{w+}	25.8	116.6
-contact recovery voltage (kV)	U_{w-}	12.5	54.9
\pm Contact voltage difference (kV)	U_{Δ}	13.3	61.8
+ Contact breaking current (mA)	I_{s+}	75.4	228.4
- Contact breaking current (mA)	I_{s-}	36.6	107.4

4.2 Selection of tie-in resistors

The load voltage of each type of on-load tap-changer and the capacitive current of the breaking have limits [1] [8]. When the binding resistor R_p is connected, the voltage can be restored on the polarity switch, but the breaking current is Due to the additional current flowing through the tie-up resistor, the latching resistance is much smaller than the capacitive reactance of the capacitor because the polarity switch operates, so the capacitive current flowing through the tie-up resistor is approximately

$I_s = \frac{U_1}{2\sqrt{3}} \times \omega C_1$, the phase voltage after adding the tie-in resistor is calculated as $U_R = I_s \times R_p$, power

consumption $P=U_R^2/R_p$. Select the number of binding resistors as $n=\frac{U_t}{2\sqrt{3}} \div U_m$. The single tie-in

resistance must not exceed the long-term voltage U_{rn} and must not exceed the long-term allowable power of the tie-in resistor. If the second type of commutating on-load tap-changer is added to the 92.4k Ω tie-in resistor, the recovery voltage on the contact will be reduced to 21kV, which does not exceed the relevant allowable limit [2].

5. Conclusion

At the moment of the polarity switching action, the induced voltage of the tap winding is completely determined by the capacitance distribution. For example, the voltage regulation stage and the voltage are high, and the recovery voltage is necessarily high. Due to the recovery voltage, when the polarity switching switch is separated and closed, a discharge is generated. Of course, the higher the recovery voltage, the more severe the discharge.

Both the recovery voltage of the on-load tap-changer and the capacitive current of the open-circuit are limited. When the limit is exceeded, tie-in resistors or other measures must be added. It can be seen that the smaller the main insulation distance of the transformer is, the larger the C1 is, that is, the distance between the voltage regulating coil and the main coil. The larger the tapping range is, the smaller C2 is (referring to the pressure regulating coil away from the tank wall). The larger the main insulation distance of the transformer, the smaller the C1 is, the smaller the US+- and IS+- are affected, but the relationship with the connection is relatively close.

Usually, when the calculated recovery voltage is greater than 35kV, to limit this voltage, the on-load tap-changer switch needs to be connected to a tie-in resistor and a tie-off switch before the polarity switch is activated. It can effectively reduce the discharge at the polarity switch when the polarity switch is switched, and limit the recovery voltage to a lower straight to reduce the effect of the recovery voltage, but it is impossible to eliminate.

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