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Analysis of Voltage Regulation Methods and Principles of UHV Transformers

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Abstract. The autotransformer voltage regulation is divided into two types: on-load voltage regulation and non-excitation voltage regulation. According to the position, it can be divided into medium voltage side line end voltage regulation, neutral point voltage regulation, and series winding end voltage regulation. This paper describes that a certain ODFPS-1000000/1000 transformer uses neutral point voltage regulation to change the magnetic flux for voltage regulation, and gives the magnetic flux, the coil zeta potential and the linear variation of the three-phase voltage, especially the formula for the compensation principle. Derivation and principle analysis.

1. Introduction

Ultra-high voltage AC power grid transformers are generally autotransformers, most of which use single-phase three-column iron core, single-column or two-column coil structure, single-phase or three-phase integrated. The UHV AC grid transformer is generally arranged for the main transformer and the variable sub-box. It adopts single-phase four-column or single-phase five-column iron core, two-column or three-column coil structure. At present, the ultra-high voltage transformer has a single-phase capacity ranging from 250 MVA to 1000 MVA. According to the voltage regulation method, it can be divided into on-load voltage regulation and no-load voltage regulation. According to the position of the voltage regulation winding, it can be divided into three types: medium voltage side line voltage regulation, neutral point voltage regulation and series winding end voltage regulation [1]. The general voltage regulation method is shown in Figure 1. The fault of the on-load tap changer occupies a large proportion in the transformer fault. The fault rate of the on-load tap changer is about 4 times that of the unloaded tap changer, and the fault of the on-load tap changer itself accounts for about 40% [1], so the former will increase the complexity of the transformer structure and cost, and reduce the operational reliability of the transformer. At present, ultra-high power grid transformers generally use no-load voltage regulation.

Most of the ultra-high voltage transformers use medium-voltage side line voltage regulation, according to the box, single-phase auto-coupling or three-phase auto-coupling, used to contact 500kV and 220kV power grids, and its line-side voltage regulation insulation level is 220kV. If the UHV transformer adopts 500kV line end voltage regulation, the insulation level is relatively high. When the line end enters the wave, the voltage regulating switch and the voltage regulating winding are subjected to a higher electric field. Not only the insulation structure is complicated, but there is no voltage regulating switch available at present. . Therefore, at this stage, the UHV transformer can only be used in the neutral point variable flux regulation mode to connect the 1000kV and 500kV power grids.

2. Analysis of line end voltage regulation principle

The ultra-high voltage power grid often adopts a medium voltage line end voltage regulation mode. Since the voltage of each winding of the winding does not change during the voltage regulation, the core flux is not changed, so the voltage regulation method is called constant flux voltage regulation. When the voltage on the medium voltage side is adjusted, the voltage on the low voltage side is not affected or less affected. Because the rated current of the transformer on the medium voltage side is large, the lead wire is thick, and when the line end voltage is used, the insulation treatment of a large number of leads is difficult, and the range of the high field strength region is large, so the medium voltage side line end often becomes a weak point of the transformer insulation. The UHV transformer adopts the neutral point voltage regulation method, which is mainly determined by the characteristics of the transformer itself. The 1000kV transformer should first consider the insulation problem. If the line end voltage regulation method is adopted, the insulation level of the voltage regulator is very high, and its reliability is difficult to guarantee.

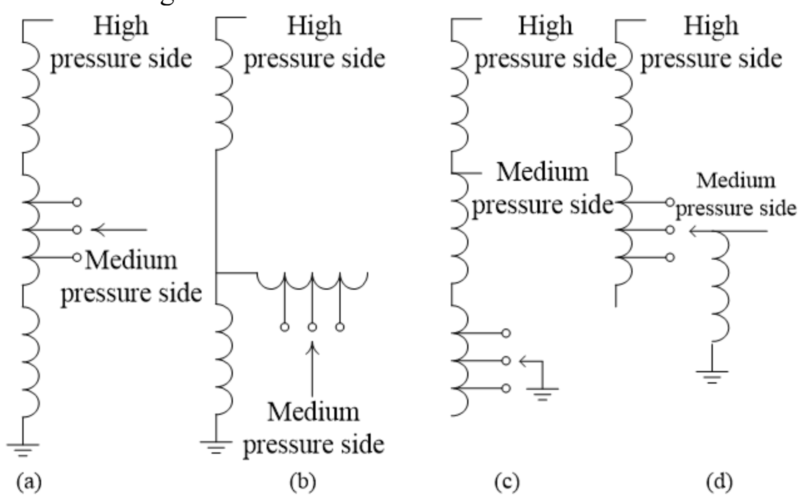

Figure 1. Transformer general voltage regulation method

The medium voltage side line end voltage regulation mode, the common wiring situation is shown in Figure 1 (a), (b). The voltage regulating mode directly connects the pressure regulating switch to the end of the medium voltage side outlet. When the voltage of the high voltage side remains unchanged and the voltage of the medium voltage side changes, the voltage is increased or decreased according to the voltage increase or decrease, and the number of turns is increased or decreased. The potential does not change, thereby ensuring that the magnetic flux density of the autotransformer core is a constant value, eliminating the overexcitation phenomenon, so that the voltage of the third winding does not fluctuate. If the voltage on the high voltage side changes, the excitation state of the transformer will change, affecting the voltage value on the low voltage side, but this change is much smaller than the neutral point voltage regulation method and will not be greater than the voltage fluctuation range.

The voltage regulation at the end of the series winding is shown in Figure 1(d). It directly regulates the voltage on the high-voltage side series winding. When the voltage on the high-voltage side increases, the number of turns of the coil is increased accordingly. When the voltage on the high-voltage side decreases, the number of turns of the coil is reduced accordingly, which is a kind of constant magnetic flux density of the core. Line end voltage regulation. This method can overcome the voltage fluctuation problem caused by the neutral point voltage regulation, so that the voltages on the medium voltage side and the low voltage side remain unchanged.

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Under normal circumstances, 1000kV transformers are often regulated by the voltage regulation method of Figure 1(c). The 500kV transformers are mostly regulated by the voltage regulation method of Figure 1 (a) and (b). The 330kV three-phase autotransformer is mostly used in Figure 1 (d) Pressure regulation method.

3. Analysis of the principle of neutral point voltage regulation

Neutral point pressure regulation method, as shown in Figure l(c), the biggest advantage of this voltage regulation method is that the voltage regulating winding and the voltage regulating device have low working voltage, low insulation level requirement; small working current, working current is The common winding current, that is, the difference between the medium voltage side current and the high voltage side current, is about 54% of the medium voltage side current. However, the problem of the neutral point voltage regulation method is that the voltage regulating coil is disposed on the common winding. When the tap position is adjusted, not only the voltage on the medium voltage side changes, but also the voltage on the high voltage side changes accordingly. At the same time, the voltage deviation phenomenon also occurs in the third winding. When the voltage on the medium voltage side is raised, the voltage on the low voltage side is lowered. If the voltage on the medium voltage side changes greatly, the low voltage side may be unusable. Moreover, the neutral point voltage regulation is also called the variable flux voltage regulation, and the induced potential of the main winding changes during the voltage regulation process, so that the overexcitation phenomenon may occur.

The biggest advantage of the neutral point voltage regulation method is that the voltage of the voltage regulating winding and the voltage regulating device is low, the insulation requirement is low, the manufacturing process is easy to implement, and the overall cost is low. In this paper, an ultra-high voltage transformer is taken as an example, the model is ODDPS-1000000/1000, 1050/√3 /525/√3 ±4×1.25% /110kV, and the overall external structure adopts independent external voltage regulation mode, namely transformer body and modulation. The pressure compensation transformer box is arranged, and the compensation winding limit is set to cause voltage fluctuation on the low voltage side due to the change of the tap position.

The main rated technical parameters of the ZF27-1100(L) type GIS breaker are: single pole parallel resistance value 600, the range is between -10% and 0, the shunt capacitance of each fracture is 1080±54pF, and the resistance fracture is closed in advance. The time is 8 to 11 ms. Under the rated oil pressure rated voltage, the opening time is 23.0±5, the closing time is 102±17ms, the opening speed is 8.0±1.0 m/s, and the closing speed is 3.0±1.0m/s [7].Formatting author names

The list of authors should be indented 25 mm to match the abstract. The style for the names is initials then surname, with a comma after all but the last two names, which are separated by ‘and’. Initials should not have full stops—for example A J Smith and *not* A. J. Smith. First names in full may be used if desired. If an author has additional information to appear as a footnote, such as a permanent address or to indicate that they are the corresponding author, the footnote should be entered after the surname.

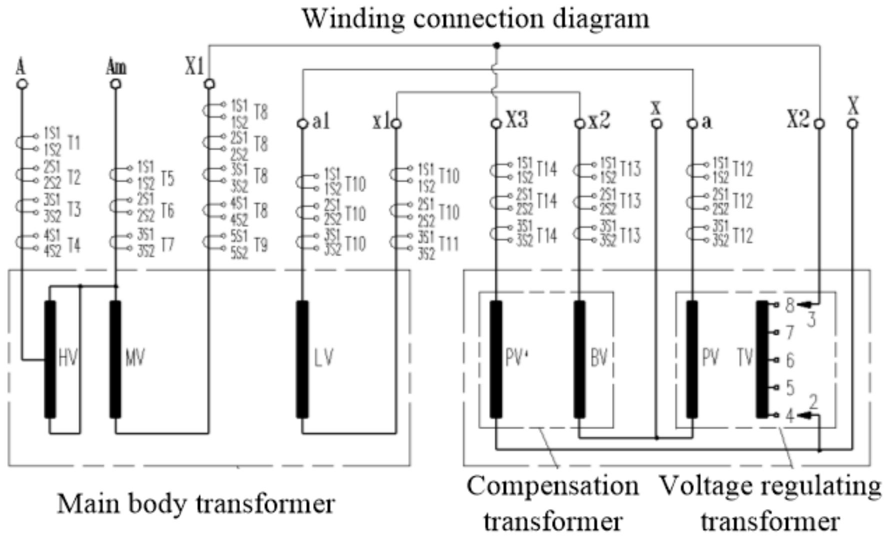

Figure 2. Winding connection diagram

Remarks (the same below): HV - high voltage winding, MV - medium voltage winding (common winding) , LV - low voltage winding, TV - voltage regulating winding, PV—Pressure excitation winding, BV—Low-voltage compensation winding, PV′—Compensated excitation winding

The core of a UHV main transformer adopts single-phase five-column type, and the high-voltage winding, medium-voltage winding and low-voltage winding of three columns are respectively taken out in parallel, and the order of windings on each column is: iron core column - low voltage winding = medium voltage (Common) winding - high voltage (series) winding. The number of turns of its 7 windings is as follows: $N_{HV} = N_{MV}$=854 , $N_{LV} = 310$, $N_{PV} = 649$, $N_{PV'} = 460$, $N_{BV} = 86$; $N_{TV} = \pm 45 \times 4$, 45*4 in 1st gear position, -45*4 in 9th gear position, and 1 to 9th gear tapping is decremented [5]. The first gear position X2 corresponds to the terminal of the tap changer being 8 [4].

Remarks: 2-1 tank, 2-2 conductor, 2-3 resistor unit, 2-4 main fracture, 2-5 resistance fracture, 2-6 resistor unit 2-8 conductor, 2-9 resistance measurement terminal 2 -10 pressure accumulator, 2-11 working cylinder, 2-12 adsorbent placement position, 2-13 support insulation cylinder, 2-14 hydraulic pump unit, 2-15 capacitor assembly.

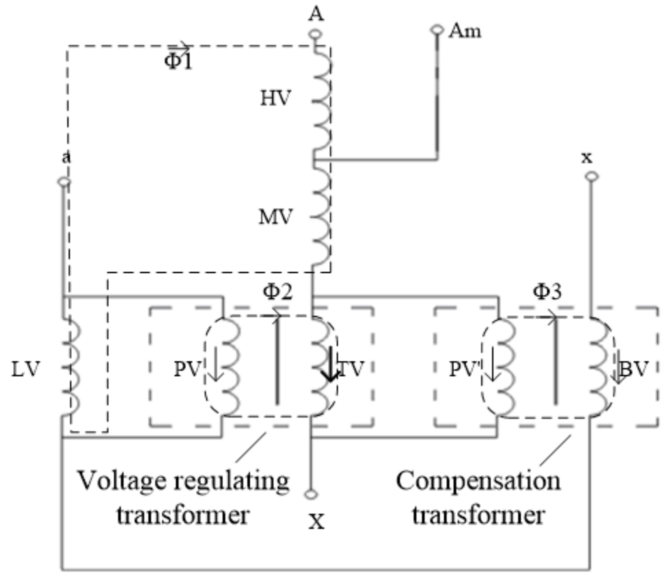

Figure 3. Neutral point pressure regulation schematic

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In order to ensure that the low voltage is constant, the compensation winding is connected to the low voltage winding, and PV' and BV are provided in the compensation transformer to compensate for the fluctuation of the low voltage. Since there are two iron cores in the pressure compensation compensation, there is one iron core in the main body change. The magnetic fluxes will be respectively Φ1, Φ2, Φ3, and the electromotive force induced by each flux causing the magnetic flux to flow through each winding of the winding is the same, which are e1, e2, and e3. The relationship between the magnetic flux $\Phi = e/4.44f$ and the induced electromotive force is the system frequency, and the dotted line in Fig. 3 indicates the schematic flow of the magnetic flux. Therefore, the electromagnetic coupling relationship of the seven windings is as follows: HV, MV, LV have electromagnetic coupling, PV, TV has electromagnetic coupling, PV', BV has electromagnetic coupling, according to the electromagnetic coupling relationship in Fig. 3, formula (1) ,(2).

$$\begin{bmatrix} N_{HV}+N_{MV} & N_{TV} & 0 \\ N_{LV} & -N_{PV} & 0 \\ 0 & N_{TV} & -N_{PV'} \end{bmatrix} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} 1.05\times 10^6 / \sqrt{3} \\ 0 \\ 0 \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} N_{HV}+N_{MV} & N_{TV} & 0 \\ N_{MV} & N_{TV} & 0 \\ N_{LV} & 0 & N_{BV} \end{bmatrix} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} U_{HP} \\ U_{MP} \\ U_{LP} \end{bmatrix} \quad (2)$$

U_{HP} ,U_{MP} ,U_{LP} are high voltage, medium voltage and low voltage phase voltages. The pressure regulation can be analyzed by the formulas (1) and (2). The rated gear position is the 5th gear position. At this time, the terminal of the tap changer of the voltage regulating winding TV is 4, and the number of turns of the voltage regulating winding is zero, which is equivalent to the short circuit of X and X3, X2 and X1, and the voltage regulation is changed. When the operation is exited, the compensation variable and the main body change operation, and e3 in the equation (1)(2) is 0.

4. Analysis of Neutral Point Pressure Compensation Principle

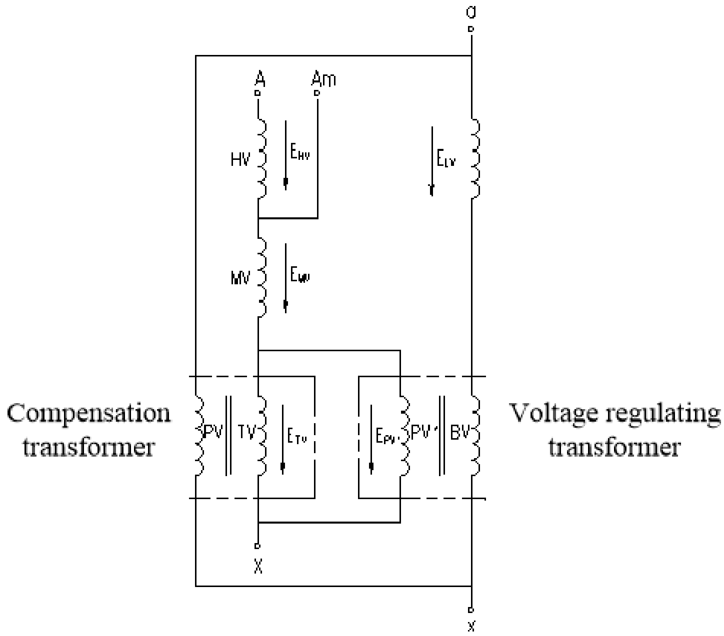

Figure 4. Winding potential diagram of tap changer taps for 1, 2, 3 and 4 gears

When the tap is 1, 2, 3, 4, the winding potential is shown in Figure 5. At this time, the main commutating common winding (MV) end is connected in series with the voltage regulating winding (TV), the main body transformation ratio and the potential direction are fixed, the voltage regulating variable voltage winding (TV) and the main body high voltage winding (HV) and the common The winding (MV) potential is the same, and the high-voltage side potential is $E_{AX} = E_{HV} + E_{MV} + E_{TV}$ .The medium voltage side potential is $E_{AmX} = E_{MV} + E_{TV}$ .The magnitude and direction of the compensated variable excitation winding (PV') are the same as those of the regulated voltage regulating winding (TV). The compensation winding (BV) is connected in series with the main transformer low voltage winding (LV) in the forward direction, the potential direction is the same, and the low voltage side potential is $E_{ax} = E_{LV} + E_{BV}$ .The voltage-variable field winding (PV) potential is the same in magnitude and direction as the low-voltage side($E_{PV} = E_{ax} = E_{LV} + E_{BV}$).Set the voltage of the high-voltage side to be the same, compared with the rated gear position, due to the forward series voltage-regulating winding (TV), the positive partial pressure causes E_{HV} , E_{MV} , E_{LV} is reduced,And E_{HV} reduction will make the medium pressure side E_{AmX} larger, to achieve the adjustment of the voltage on the medium voltage side($E_{AmX} = E_{MV} + E_{TV}$).At the same time, the E_{TV} forward partial pressure increases the $E_{PV'}$ size and increases accordingly, thereby compensating for the change of the low voltage side E_{LV} due to the decrease of E_{ax} , and realizing the low side compensation function($E_{ax} = E_{LV} + E_{BV}$).

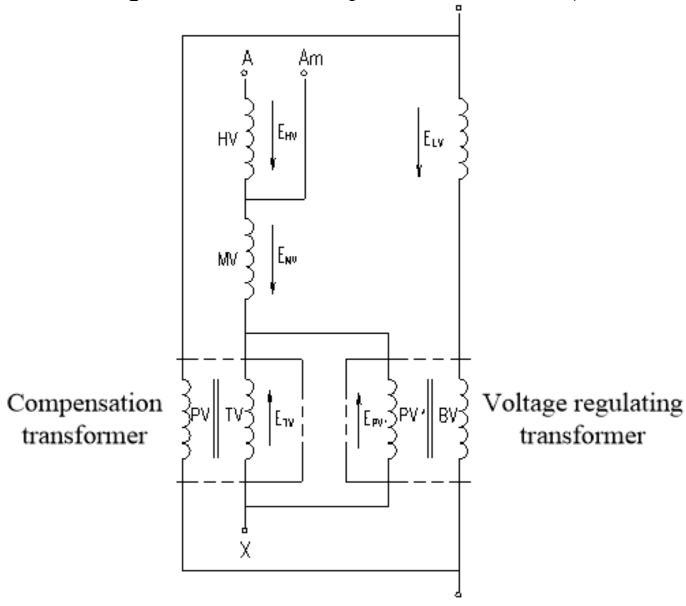

Figure 5. Winding potential diagram of tap changer taps for 6, 7, 8, and 9 stops

When the tap is 6, 7, 8, and 9, the winding potential is shown in Figure 6. At this time, the main commutating common winding (MV) end is reversely connected in series with the voltage regulating winding (TV), the main body variable ratio and the electric potential direction are fixed, the voltage regulating variable voltage winding (TV) and the main body high voltage winding (HV) and the common The winding (MV) potential is opposite in direction, and the high-voltage side potential is $E_{AX} = E_{HV} + E_{MV} - E_{TV}$, the medium voltage side potential is $E_{AmX} = E_{MV} - E_{TV}$ .The compensation variable-winding winding (PV') potential is the same in magnitude and direction as the voltage-regulating variable-voltage winding (TV) (in this case, the potential direction of the tap is opposite in the 1, 2, 3, and 4 steps), and the compensation winding (BV) is connected in series with the main transformer low-voltage winding (LV) in the forward direction, the potential is opposite, and the low-voltage side potential is $E_{ax} = E_{LV} - E_{BV}$ .The voltage magnitude and direction of the regulated variable field winding (PV) are the same as those of the main transformer low voltage winding (LV)($E_{PV} = E_{ax} = E_{LV} - E_{BV}$).Set the voltage of the high voltage side unchanged. Compared with the rated gear position, due to the reverse series voltage regulating winding (TV), the E_{TV} reverse voltage division causes the E_{HV} , E_{MV} , E_{LV} and the size to increase, and the E_{HV} increase will make the medium voltage side E_{AmX} Decrease ($E_{AmX} = E_{MV} - E_{TV}$) to realize the adjustment of the voltage on the medium voltage side; at the same time, the E_{TV} reverse partial pressure increases the $E_{PV'}$ reverse direction, and then E_{BV} increases in the reverse direction, thereby compensating for the change of the low voltage side E_{LV} due to the increase of E_{ax} , and realizing the low side compensation. Features($E_{ax} = E_{LV} - E_{BV}$).

5. Conclusion

The overall external structure of an ODFPS-1000000/1000 transformer adopts an independent external voltage regulation mode, that is, the transformer body and the voltage regulation compensation transformer box arrangement. The transformer body is connected with the voltage regulation compensation through external leads.

The 1000kV transformer adopts a neutral point variable flux voltage regulation method. If no measures are taken, its low voltage output voltage will change with the change of the tap position. Analysis of the rate of change will exceed ± 5%, which is not allowed by the operation of the system. By way of example, in order to control this change, the winding is compensated to compensate the low-voltage voltage, so that the low-voltage output voltage deviation is controlled within 1%. The voltage regulation changes are linear and meet the relevant technical requirements.

This paper starts with the analysis of line end voltage regulation, neutral point voltage regulation and compensation principle, and expounds the voltage regulation method and principle of UHV transformer, which has certain reference value for equipment production, operation and maintenance.

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