DC Bias Simulation of 1000 kV UHV Transformer Based on MATLAB / Simulink

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Abstract: In order to study the effect of Direct Current bias on the excitation current of 1000kV UHV transformer caused by the parallel operation of DC transmission and AC transmission, this paper builds a simulation model of 1000kV three-winding autotransformer based on MATLAB/Simulink. This paper introduces the simulation model of simulation model parameters, and builds a simulation model of 1000kV UHV AC transmission system. Based on the analysis of the change trend of excitation current when the DC voltage source is applied at the neutral point of the transformer, 1000kV transformer, the conclusion is that the DC bias suppression measures and the transmission line design work to provide a theoretical reference.

1. Introduction

China's major load centers and energy centers of the geographical characteristics of the distribution of energy-intensive areas led to energy over, while the central and eastern regions in short supply, so large-scale, long-distance, low loss of Ultra High Voltage (UHV) Direct Current (DC) transmission technology increasingly important [1], China's first ± 1100kV UHV DC project Zhundong - Wannan line will be completed and put into operation in 2018, when the line can be through the Wannan converter station 1000kV UHV transformer group and Huainan - Wannan - Shanghai 1000kV UHV Alternating Current (AC) transmission Network connection to further improve China's UHV transmission network structure, improve the overall economic efficiency of the power grid [2]. UHVDC transmission system into the earth's DC current is relatively large, when the DC current through the 1000kV transformer neutral point into the transformer winding, seriously affect the transformer performance, so the impact of the ground current on the 1000kV transformer is very Necessary [3-4].

According to the J-A hysteresis theory [5], the influence of CGI on the excitation current of 750 kV single-phase autotransformer is studied in this paper. In [6], the influence of DC bias on the excitation current of 750kV transformer is studied based on the finite element method. In [7], a 500 kV autotransformer model was established based on J-A theory, and the DC bias resistance of the transformer was simulated. Because of the large difference in the structure of the transformer, the results of the literature [5-7] can not correctly describe the mechanism of 1000kV UHV transformer affected by DC bias. Because the structure of 1000kV transformer is complex, this paper is based on Matlab / Simulink simulation. The change of 1000 kV autotransformer main transformer and the variable voltage excitation current under the action of DC bias, and provide the theoretical support for the optimization design and protection work of 1000kV transformer.
2. Modeling of 1 1000kV UHV Transformer

2.1 1000kV UHV transformer structure

1000kV UHV transmission line transmission capacity is very large, calculated by the transformer single-phase design capacity to reach 1000MVA, if the use of ordinary transformer to achieve such a large capacity, then had to design a large volume of the transformer, which will bring the transformer loss increases, the operating efficiency is reduced, the system economy is bad and so on many problems. In order to reduce the cost of the transformer to choose a relatively low insulation requirements of the neutral point without excitation voltage regulator, but the voltage regulator will change and result in over-excitation and low-voltage winding voltage offset phenomenon, in order to eliminate these problems 1000kV transformer selection of the regulator transformer and autotransformer split operation design principles [8]. Voltage regulator by the regulator compensation transformer and low-voltage compensation transformer, high, medium and low voltage side windings were used Yn, Yn, dll connection, as shown in Figure 1. In order to minimize the fluctuation of the low-side winding voltage of the main transformer, it is necessary to adjust the core magnetic flux density by adjusting the voltage regulator coil in series with the medium-voltage side coil during the pressure regulation process. In order to further stabilize the level of the transformer core excitation, the low-voltage compensation winding is designed and its compensation winding is connected in series with the main transformer low-voltage side winding, and the excitation winding is connected in parallel with the voltage regulating coil.

![Figure 1. Structure diagram of 1000kV single phase Auto transformer](image)

2.2 UHV transformer modeling method

The simulation system is changed in general three-winding transformer actual wiring to replace the three-winding autotransformer, as shown in Figure 2, the ordinary three-winding transformer second winding connected to the first end of the first winding to form an autotransformer series winding and common winding. The third winding simulator autotransformer low-voltage winding, voltage regulation and compensation variable excitation coil and the main transformer low-voltage winding in parallel, voltage regulator coil and compensation variable compensation coil and the main transformer winding in series, the literature [9-10]. The feasibility of the above modeling method is verified.

![Figure 2. Equivalent simulation model of 1000kV single phase Auto transformer](image)

2.3 Model parameter correction calculation

The use of matlab / simulink to establish the transformer model need to enter the three winding rated
voltage effective value (V), resistance per unit value (p.u.) and reactance per unit value (p.u.). Transformer nameplate will provide the transformer rated voltage of the winding voltage (rated voltage), the three windings between the two winding short circuit test short circuit loss and short circuit voltage percentage (short circuit voltage), where the short circuit loss is used to calculate the winding resistance. The short-circuit voltage is used to calculate the reactance [11]. In view of the three-phase autotransformer and ordinary three-winding transformer electrical characteristics are different, the actual transformer winding parameters and simulation transformer input parameters are not equal, the need for auto-couple transformer winding relationship between the actual transformer parameters converted into analog transformer parameters [12].

2.3.1 Rated voltage conversion. Assuming that the rated voltage of the high, medium and low voltage windings on the transformer nameplate are UH, UM and UL respectively, the series winding voltage UC, the common winding voltage UV and the low voltage winding voltage UD obtained as

\[ U_C = U_H - U_L, U_G = U_M \text{ and } U_D = U_L. \]

2.3.2 Reactance per unit value conversion. Assuming that the percentage of the short-circuit voltage between the high-middle and medium-low, high-low voltage windings on the transformer nameplate is

\[ U_H^\prime - M\% \quad U_M^\prime - L\% \quad U_H^\prime - H\% \]

so

\[ U_{H-M}^\prime\% = U_{H-M}^\prime\% \quad U_{M-L}^\prime\% = U_{M-L}^\prime\% \]

\[ U_{H-L}^\prime\% = U_{H-L}^\prime\% \left( \frac{S_N}{S_{N3}} \right) \] and

\[ U_{H-L}^\prime\% = U_{H-L}^\prime\% \left( \frac{S_N}{S_{N3}} \right). \]

where, \( U_H^\prime \%), \( U_M^\prime \%), \( U_L^\prime \%)\) are the short-circuit voltage (\%) for groups, common windings and low-voltage windings, respectively. Then the corresponding kink per unit value of each winding is

\[ X_H = \frac{U_H^\prime \%}{100} \times \frac{S_L}{S_N}, \quad X_M = \frac{U_M^\prime \%}{100} \times \frac{S_M}{S_N} \text{ and } X_L = \frac{U_L^\prime \%}{100} \times \frac{S_L}{S_N}. \]

And

\[ \begin{align*}
U_H^\prime \% & = \frac{1}{2} \left[ U_{H-M}^\prime \% + U_{H-L}^\prime \% - U_{M-L}^\prime \% \right] \\
U_M^\prime \% & = \frac{1}{2} \left[ U_{H-M}^\prime \% + U_{M-L}^\prime \% - U_{H-L}^\prime \% \right] \\
U_L^\prime \% & = \frac{1}{2} \left[ U_{H-L}^\prime \% + U_{M-L}^\prime \% - U_{H-M}^\prime \% \right]
\end{align*} \]

where, \( S_N \) is the transformer capacity and \( S_j \) is the reference capacity. The above reactance is the autotransformer parameter, so it should be converted into the normal three-winding transformer winding reactance per unit value. Assuming the autotransformer high - medium, high - low, medium - low voltage winding reactance per unitary values are \( X_{H-M}^\prime = X_H + X_M \), \( X_{H-L}^\prime = X_H + X_L \) and \( X_{M-L}^\prime = X_M + X_L \), then the conversion formula is as follows:

\[ \begin{align*}
X_{H-M} = X_{H-M} & \left( \frac{U_M}{U_H - U_M} \right)^2 \\
X_{H-L} = X_{H-L} & \left( \frac{U_L}{U_H - U_L} \right)^2 \\
X_{M-L} = X_{M-L} & \left( \frac{U_M}{U_H - U_M} \right) \cdot \left( \frac{U_L}{U_H - U_L} \right) - X_{H-M} \cdot \frac{U_H}{U_H - U_M} - X_{H-L} \cdot \frac{U_H}{U_H - U_L}
\end{align*} \]

Then, the series winding, the common winding and the low voltage winding per unit value of the simulated autotransformer after calculation are calculated according to the relationship between the perimeter value of the winding and the per unit value of each winding.

2 Simulation of DC Bias Magnetic Field of 1000kV Self-coupling Transformer Transformer

After the operation of Zhundong-Wannan \( \pm 1100kV \) UHVDC transmission project, there will be \( \pm 1100kV, \pm 800kV, \pm 500kV \) UHVDC transmission lines and 1000kV, 750kV UHV AC transmission lines in the central region of China. The following will be based on China's independent research and development of ODFPS-1000MVA / 1000kV single-phase self-coupled UHV transformer parameters.
and a special high-voltage AC system line parameters in MATLAB / Simulink in the establishment of UHV AC system simulation model, AC transformer grounding point access DC voltage Source to simulate the distortion law and degree of excitation current of 1000 kV UHV transformer.

**Figure 3.** Simulation model of real AC system contained 1000kV tree phase Auto transformer

Ultra-high voltage AC system simulation model parameters are as follows, ODFPS-1000MVA / 1000kV transformer parameters: the main transformer high, medium and low three-rated capacity and rated voltage were 1000: 1000: 334MVA and 1050 /: 525 /: 110kV, The percentage of voltage is%,%,% is 18%, 62%, 40%, respectively, and the rated capacity is 59 / 18MV A, the rated voltage is 110: 5% 1050 / and 5% 1050 /: 5.4kV And the ratio is 3.63 and 5.16 respectively. The three single-phase autotransformers are integrated into a single three-phase autotransformer sub-system. The transmission line parameters are: 360km long, [0.263,0.8306] Ω / km, The resistance is [7.36e-5,2.5786e-3] Ω / km and the capacitance is [1.397e-2,0.3e-2] μF / km. The capacity of the starting side capacitive reactive power compensation reactor is 9600Mvar, the main reactance and grounding resistance are 1300Ω and 280Ω respectively. The capacity of the end capacitive reactive power compensation reactor, the main reactance and the ground reactance are 720Mvar, 1680Ω and 370Ω respectively. UHV transformer 110kV bus capacitance, reactance compensation capacity are 240Mvar, Figure 3 for the system matlab simulation diagram.

In the UHV transformer neutral point when the application of different DC voltage waveform distortion start time comparison chart and the main transformer excitation current waveform is as follows.

**Figure 4.** The start time contrast of waveform distortion

**Figure 5.** Waveform of excitation current of main transformer under different DC bias

It can be seen from Figure 4, with the increase in the voltage applied to the main excitation current began to appear more and more front-time harmonics, indicating the greater the neutral point DC current
magnetic flux saturation faster, when Udc <10v When the excitation current is almost no distortion, which shows that if the use of reasonable measures to reduce the center of the transformer electromotive force to a certain value can effectively avoid the impact of DC bias.

It can be seen from Fig. 5 that when the Udc = 50v, the positive half-wave of the main transformer excitation current has a severe spike and the negative half-axis waveform is not affected, Udc is 100v, 200v, the excitation current phase exhibits a nonlinear growth trend. Half-wave distortion is more serious, the amplitude of inrush even more than 10 times the rated excitation wave.

3. Conclusion
Firstly, the basic structure of 1000kV three-winding autotransformer is introduced, and a simulation model is put forward. Based on the reasonable calculation model of the transformer, the rated voltage and reactance per unit value of the autotransformer simulation model are established. The real-time UHV AC transmission system simulation model is used to analyze the excitation current waveform of the 1000kV autotransformer under different DCs. It is found that the negative half-wave of the excitation current is not affected by the DC bias. The positive half-wave appears in the spire, the greater the DC voltage, The greater the value, the more severe the excitation current waveform distortion.

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