Electromagnetic Interference Prediction of ±800 kV UHVDC Converter Station

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Electromagnetic interference (EMI) is mainly caused by the periodic valve switching in HVdc converter stations. This EMI can result in high-frequency conducted and radiative interference toward the adjacent communication, computer equipment, carrier system, and radio stations. Therefore, a wideband model of a converter system is necessary to predict the characteristics of the EMI source. Methods of modeling are proposed, and the equivalent circuits of the main equipment in ultra-HVdc (UHVDC), including valve section, converter transformer, smoothing reactor, filters, and so on, are developed in this paper. The whole wideband model is simulated by PSCAD/EMTDC. Based on this model, the characteristics of the conducted EMI under normal operation conditions are calculated. Ground-level electric field strength and magnetic field strength in and around a UHVDC converter station are calculated. For validity, a comparison between the simulated and the measured data is conducted.

Index Terms—Converter station, electromagnetic interference (EMI), HVdc, thyristor valves, wideband modeling.

I. INTRODUCTION

Conducted electromagnetic interference (EMI) in HVdc converter stations is generated during the processes of firing and turning off of the thyristors in the converter valves. This interference is produced and conducted through bushing, along the buses connected with the valve hall, and hence to the ac and dc switchyards. Radio interference is radiated from the valves to the switchyards and transmission lines. The EMI caused by the UHVDC converter station may pose direct and indirect threats to the electromagnetically sensitive devices and facilities, such as computers, control systems, and communication systems.

From 1970 to 1990, many methods and techniques were developed to calculate and predict the EMI in HVdc converter stations. In [1] and [2], the equivalent circuits were too simple and some parasitic parameters were not considered. In [4]–[6], a method based on impedance measurements was developed to model the main equipment in HVdc converter stations, where all the impedances were connected in order to analyze the node voltages and branch current. This method was more accurate than the methods mentioned above, yet the large-scale measurement for different converter stations with different equipment became the drawback of the method and made it unpractical. Method of moment in [7] was used to calculate the electromagnetic field in HVdc converter stations, but the radiated source was difficult to determine. Only an accurate equivalent circuit model can fulfill such expectation with success.

In this paper, a wideband model of the converter system is presented, including thyristor valve towers, converter transformer, smoothing reactor, filters, and so on. Based on the whole wideband model, conducted EMI is simulated by PSCAD/EMTDC. The radiated EMI calculation of a converter station is also proposed in this paper. The method of simulation is verified by comparing calculated results with the measurements in a ±800 kV UHVDC converter station.
As for the saturable reactor, the parameter $L$ is the main inductance, $R_{Cu}$ is the ohmic losses of primary winding, $R_{Eddy}$ is the eddy current loss, $R_D$ is the damping resistance, including secondary resistance, $L_{Leak}$ is the leakage inductance, including inductance of parallel resistance related to primary, and $C_{SR}$ is the equivalent capacitance between the two ports of the saturable reactor.

### B. Stray Parameters Extraction

The stray capacitances of the heat sinks can be represented by the capacitances between the heat sinks and the ground, as shown in Fig. 3. The finite-element method is used to calculate these parameters.

The distribution of the capacitances of one phase of the valve used in HVdc converter station is shown in Fig. 4. At high frequency, the capacitive coupling between the valve modules and modules to the ground should be considered. The capacitance between the valve modules of the same layer is represented by $C_{MM}$ and the capacitance between the valve modules of the adjacent layer is represented by $C_{LL}$. $C_{LG}$ is the valve module stray capacitance to the ground, $C_{LP}$ is the stray capacitance to the shielding plates, and $C_{PG}$ is the shielding plate’s stray capacitance to the ground.

The structure of the valves can be regarded as a solenoid-type inductor when the valves are conducting. Therefore, the stray inductance can be evaluated by

$$L = \frac{N^2 \mu ab}{h}$$

where $N$ is the layer number of the valve tower, $ab$ is the cross-sectional area of the current loop, $h$ is the total length of the valve layers, and $\mu$ is the permeability of the air core. This inductance can be divided into different valve components.

### C. Wideband Model of Valve Tower

The equivalent circuit of the valve components mentioned above is established according to the electrical connections with a certain sequence. Considering of the parasitic parameters of valve layers, a wideband model of the valve tower is constructed, as shown in Fig. 5.

III. WIDEBAND MODELS OF THE KEY EQUIPMENT

#### A. Converter Transformer

The parameters of the wideband model are defined as follows [8]. $L_{k1}$ and $L_{k2}$ are the leakage inductances, $R_{k1}$ and $R_{k2}$ are the resistances related to winding losses, $C_{11}$ and $C_{22}$ are the capacitances of the windings, $C_{12}$ is the capacitance between primary and secondary windings, $L_m$ is the magnetizing inductance, $R_m$ is the resistance due to core losses, and $C_{k1}$ and $C_{k2}$ are the leakage capacitances, as shown in Fig. 6.

#### B. Smoothing Reactor

The dc smoothing reactor is represented by inductance $L_m$, ohmic losses resistance $R_m$, and stray capacitances $C_{12}$ and $C_g$, as shown in Fig. 7. The stray capacitance between windings is represented by $C_{12}$, and the stray capacitances between coils and the ground are represented by $C_g$. In this paper, all the parameters of the smoothing reactor are obtained from the specifications provided by the manufacturer.

#### C. Filters

To absorb harmonics, dc filters are put to use in the converter station for HVdc transmission, which consists of parallel $RLC$ elements and series $LC$ elements, as shown in Fig. 8.

The ac filters installed in converter stations are used to limit the voltage distortion on the converter station ac buses and
the harmonic currents flowing into the connected ac systems. The group of ac filters is composed of double-tuned filter, triple-tuned filter, and shunt capacitor, as shown in Fig. 9. $L_1$ and $C_1$ are the high-voltage (HV) reactor and capacitor, respectively. $L_2$, $C_2$, and $C_2$ are the low-voltage (LV) reactor, capacitor, and resistor, respectively.

The equivalent circuit of dc power line carrier (PLC) noise filter is shown in Fig. 10. In this circuit, the equivalent circuits of the tuning devices and the coupled capacitance are included. So are the ac PLC noise filter and dc PLC filter. In these circuits, the equivalent circuits of the tuning devices and the coupled capacitance are also included. All the parameters mentioned above can be obtained from the specifications provided by manufactures.

The other equipment in the HVdc converter stations are similar to the ones in the HVAC power stations, such as tubular bus, surge arrester, current and voltage transformer, capacitive voltage transformer (CVT), circuit breakers, and so on.

IV. Conducted EMI of the Converter System

One 12-pulse ±800 kV 5000 MVA UHVDC converter station of China is simulated by PSCAD/EMTDC with the wideband equivalent circuits mentioned above. The topology of this converter system is shown in Fig. 11. By this simulation analysis method, the characteristics of the conducted EMI emitted from the converter system can be obtained. The calculation of currents flowing in RC snubber circuit and bus bar connecting the HV and the LV valve hall is shown in Figs. 12 and 13. It can be seen that these conducted EMIs are distributed in a wide frequency range.

The wideband model is also used to simulate the transient process of the disconnector closing of ac filters. The contrast between the measured and calculated waveforms of the three-phase transient current is shown in Fig. 14. There is good agreement between the calculated and the measured data.

V. Radiated EMI of the Converter System

Electric field of the UHVDC converter station is analyzed according to the element currents and the physical geometry of the source element related to, where the electromagnetic field quantities are to be determined. Phase retardation is considered due to the propagation from the source to the observation point. Therefore, the physical geometry of the contributing elements cannot be ignored. Calculation principle of electromagnetic field is shown in Fig. 15. The electric field strength can be evaluated as [9]

$$E_x = \frac{I_0 Z_0}{4\pi} (x - x') \times \begin{cases} e^{-j k (r_2 + z_2')} & \text{if } r_2 > r_1 \text{ and } z_2 > z_1 \text{ and } x > x' \\ e^{-j k (r_1 + z_1')} & \text{if } r_1 > r_2 \text{ and } z_1 > z_2 \text{ and } x < x' \\ \frac{1}{r_2^2} + \frac{1}{jkr_2^2} - \frac{1}{r_1^2} - \frac{1}{jkr_1^2} - \frac{1}{r_1(r_1 + z_1' - z)} & \text{otherwise} \end{cases}$$

(2)
EMI level at the same point is also measured. The comparison between measured and calculated results is shown in Fig. 16. Considering of the complexity of the circumstances, the calculation results are acceptable.

The electric field and the magnetic field at the typical location P1~P4, as shown in Fig. 17, are calculated, and the results are shown in Table I. The radiated EMI level in this UHVDC converter station is all below the limitations.

VI. CONCLUSION

In order to predict the EMI in UHVDC converter stations, a wideband model of the converter systems is established in this paper. The main apparatus in the UHVDC converter stations, such as converter transformer, smoothing reactor, and filters, is represented by wideband equivalent circuits. Based on this wideband model, the conducted EMI is simulated. The radiated EMI in the UHVDC converter station is also calculated. The proposed method is verified by the comparison between the calculated and the measured data.

The wideband model built in this paper and the EMI prediction methods could be used to guide the shielding design of HVdc and UHVDC converter stations.

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