Simulation of Radiated EMI in Valve Hall of ±800-kV HVDC Converter Stations

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***Abstract*— The wide-band frequency EM noise is generated during the processes of firing and turn-off of thyristor valves in converter stations. Due to antenna effects of converters, which consist of valves and accessory equipments, the radiated EM noise is generated. The noise may interfere with the systems in valve halls or in adjacent rooms by the way of radiated coupling. The radiated EMI level in valve halls are highest in converter stations. A method of simulation analysis based on the Method of Moments is proposed. The EMI level of the ±800-kV converter stations of the Yun-Guang ±800-kV HVDC transmission project in China, are analysed in the paper.**

Key words: Ultra HVDC, Radiated EMI, Thyristor valve, MOM.

I. Introduction

The voltage across valves and the current through them collapse or rise rapidly during the periodic processes of firing and turn-off. The wide-band electromagnetic noise is generated by the operation of valves in high voltage DC converter stations during the steady state [1].

The noise is conducted along the HVDC circuitry which consists of the converter, converter transformers, smooth reactor, buses, overhead lines, etc. The RF radiation takes place from the primary devices during the propagation of the noise because of the antenna effect. It may influence on adjacent systems such as the communication system, control and protection systems. The electromagnetic noise resulted from the switching of converter valve will be attenuated when propagating along the converter circuit. Thus, EMI in valve hall is most serious. Therefore, radiated EMI in valve halls is one of most important EMC issues of the converter stations.

A DC transmission project named the Yun-Guang project has been under construction since December 19th, 2006, and will operate in the mono-polar mode in 2009, and the bipolar mode in 2010. It will be the first practical ±800-kV UHVDC transmission project in the world. The voltage and power is much higher than current operating HVDC projects. Therefore, the electromagnetic interference (EMI) of its converter stations will be a new problem, and requires carefully study.

There are many other reasons causing the radio frequency interference, such as the corona phenomenon of conductor, spark discharge due to poor contact and casing radiation of equipment, etc. The corona phenomenon is suppressed by several efficient measures such as using grading rings and tube buses with large diameters. The RF noise caused by the equipment corona is relatively low. The radio interference generated due to the switching of converter valve is one of the main sources of converter station radio interference.

The RF radiation of converters depends on the current, material characteristics and the structure. The radiated EMI calculation of converters based on the method of moments (MOM) is proposed in the paper. The characteristics of the accessory equipment connected to valves are considered. The radiated EMI levels from converters of ±800-kV converter stations are calculated.

II. Basic structure of converter station

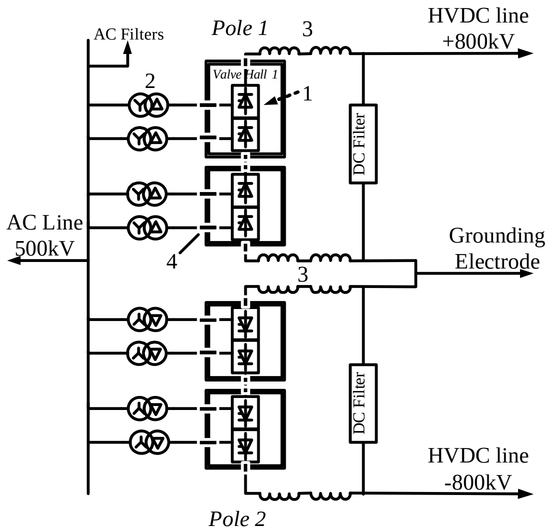


Fig. 1 Sketch of the primary circuitry of the converter station (1- 6-pulse converters, 2- single-phase two-winding converter transformers, 3-dry-type smoothing reactors, 4-wall bushings)

The Yun-Guang project under development in southern China is a bipolar two-terminal ±800-kV UHVDC transmission project. The two converter stations are located in Yunnan province and Guangdong province. A sketch of the primary circuitry of the converter station is shown in Fig. 1. The basic layout of these two stations is almost the same. The length of the DC transmission line is about 1438 km. Each pole consists of two 12-pulse converter units in series. The rated power capacity is 5000 MVA and the rated DC current is 3.125 kA. Single-phase two-winding converter transformers are used in the station. The symbol "2" represents three separate converter transformers.

III. Method of simulation Analysis

MOM is a frequency-domain method based on the Electromagnetic field integral equation. Because the integral equation automatically meets the radiation boundary condition, MOM is especially applicable to the solving of open-domain questions with relatively thin wires. The excitation source is a sine wave of certain frequency, and the electromagnetic field distribution is obtained from calculation under certain frequency.

A. The principle of the Method of Moments

In the MOM calculation program, EFIE and Magnetic Field Integral Equation (MFIE) are applied in the modelling of the electromagnetic response of certain structures. The EFIE is shown in formula (1), where the electric field (EF) is expressed in integral form of a surface current distribution $\vec{J}_s$ [2][3]:

$$\vec{E}(\vec{r}) = -j\omega\left[1+\frac{1}{k_0^2}\nabla\nabla\cdot\right]\int_S g(\vec{r},\vec{r}\,')\vec{J}_S(\vec{r}\,')ds' \tag{1}$$

Where

$\nabla\nabla\cdot A = \nabla(\nabla\cdot A)$, $k=\omega\sqrt{\mu_0\varepsilon_0}$,

$$g(\vec{r},\vec{r}\,') = \frac{e^{(-jk|\vec{r}-\vec{r}\,'|)}}{4\pi|\vec{r}-\vec{r}\,'|}$$

, is the Green's function.

The MFIE is shown in formula (2), where the magnetic field is expressed in integral form of a surface current distribution:

$$\vec{H}(\vec{r}) = \nabla\times\int_S g(\vec{r},\vec{r}\,')\vec{J}_S(\vec{r}\,')ds' \tag{2}$$

In this paper, the electric field integral equation is applied to the EM field calculation of converters.

B. The modelling of metal wires or bars

The metal wires or metal bars are represented by a serial of small wire elements, and the conductive surfaces are represented by wire grid. The material and geometric characteristics are both considered. It is assumed that the current is a filament of current on the segment axis.

The thin-long metal conductors are considered as a wire with its own physical parameters in MOM. The skin effect is taken into account in the calculation of the impedance of this conductor. The impedance of unit length wire is calculated with formula (3):

$$Z = \frac{j}{a}\sqrt{\frac{\omega\mu}{2\pi\sigma}}\frac{Ber(q)+jBei(q)}{Ber'(q)+jBei'(q)} \tag{3}$$

Where, $q=(\omega\mu\sigma)^{1/2}a$, a is the radius of the wire, σ is the conductivity of the wire, μ is the magnetic permeability of the wire (for non-ferrous metal, $\mu_0 = 4\pi\times10^{-7}\,H/m$), Ber, Bei are the Kelvin functions.

C. The modelling of converters

The sketch of a 12-pulse converter unit is shown in Fig. 2. Radiated EMD of valves is generated during the commutation processes between valve arms. For each commutation, one valve is turned-on, one is turned-off, and other three keep on-state.

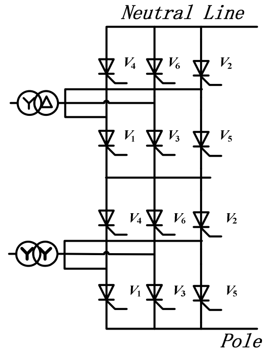


Fig. 2 Sketch of a 12-pulse converter

Since high frequency EMD is generated by turn-on and turn-off processes, to analyse electromagnetic fields, valves which are turning-on and turning-off can be considered as exciting sources. During every commutation, currents through two valves are both considered as sources. Considered the system as linear one, turn-on and turn-off can be treated separately according to the superposition principle. Thus, one work frequency period can be divided into 12 sections. After obtaining results in every section separately, frequency domain results corresponding to the whole time domain can be obtained considering the phase difference by method of vector superposition.

Metal conductors and rods are represented by thin wire segments, and thin metal faces are represented by grids made up of wire segments. Models of converters are established according to the geometric structure. Lumped parameter components are applied directly onto corresponding branches.

According to the arrangement of valve towers and valve halls (shown in Fig. 3), the equivalent MOM model of converters are obtain, shown in Fig. 4. The actual geometric and circuit parameters are considered in this model, both valve circuits and shielding covers are considered. The ground in valve halls are assumed to be ideal.

One valve module consists of two same valve sections, valve sections are represented by simplified equivalent circuits. Smoothing reactors and transformers connecting to converters are represented by transmission line model. In these model, windings are represented by coupled transmission lines. Filters are represented by lumped circuit components.

Other devices such as smoothing reactors, LFL coupling capacitors, are represented by equivalent lumped parameter circuit components. This model is excited by a current source.

The value of the current source is equal to the current injected into the buses, and the inner impendence is equal to the equivalent impendence of the HVDC converter.

Fig. 3 Converter arrange in valve hall

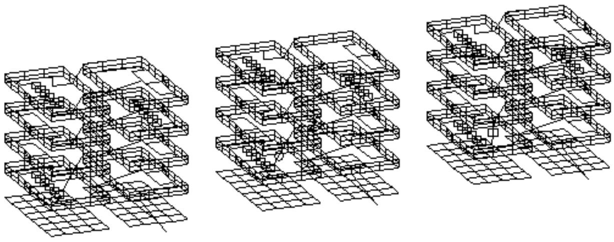


Fig. 4 MOM model of a converter

The simulation analysis method described above is validated in a ±500kV HVDC converter station located in Zhaoqing, Guangdong province. The comparison between measured and calculated results is shown in Fig. 8. The difference in most frequency range is less than 3.5 dB. The method is suitable for the EMI simulation.

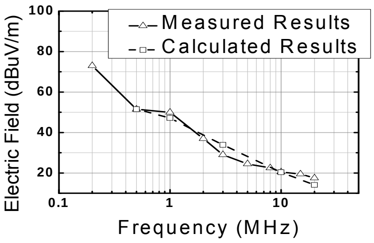


Fig. 5 Calculated and measured results of the radiated EMI

IV. CALCULATION RESULTS

A. The results with the unit current source

Using the MOM simulation method, we can obtain the maximum field strength point within the plane 1m away from and parallel to the wall of the valve hall when the converter valve is operating under different frequency. The distance of 1m is concerned because electrical equipments may not located in areas farther than 1m to walls typically. This data represent the maximum interference levels at locations 1m away from wall when switching the valve and the maximum field strength under different frequencies. Select unit current sources for all frequency point exciting sources, and then the impulse response is as shown in Fig. 6. Valleys and peaks on the spectrum is generated by resonance effect of converters.

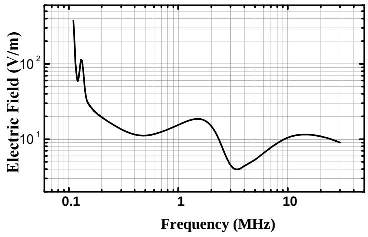


Fig. 6 Impulse response of the converter valve for the maximum field strength at a distance 1m from the wall of the valve hall

It can be known through calculation that the electromagnetic interference level becomes lower in the area farther away from the wall in the control building. Therefore, as long as the most serious area within 1m is taken into consideration, the safety of equipments in other areas can be guaranteed. Assuming that no shield is applied, the impulse response of the converter valve for the maximum field strength at locations within the control building and 1m from the wall can be obtained by using the same method, as shown in Fig. 7.

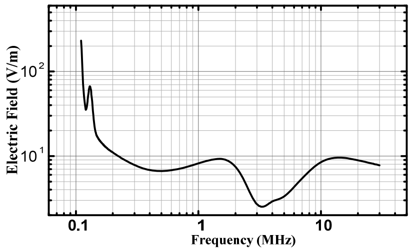
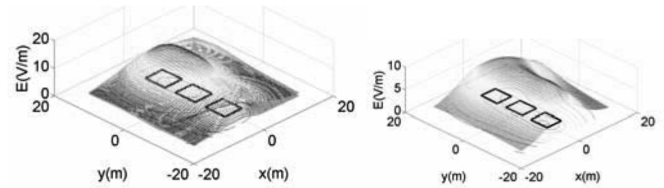
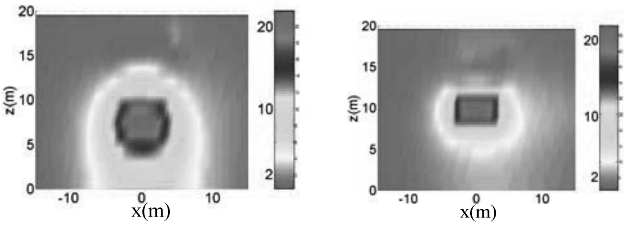


Fig. 7 Transfer function of the converter valve for the maximum field intensity at a distance 1m from the wall of the control building



(a) No.1 valve (b) No.2 valve

Fig. 8 Electric field pattern during turn-on of different valves near ground



(a) No.1 valve (b) No.2 valve

Fig. 9 Electric field pattern during turn-on of different valves near wall of valve hall

The distributions of ground electric fields and fields near wall of valve hall, are shown in Fig.8 and Fig.9 when a unit current at 500kHz flows through a valve. From the electric field pattern shown in the figures, it can be seen that the position of maximum field strength point are different when locations of operation valves are different.

The current waveforms flowing through valves can be derived from conducted EMI simulations (shown in Fig. 10)[4], the spectrum (shown in Fig.11) is obtained by FFT. The simulation method in [4] has been verified by measurements. Based on the unit impact response obtained through calculation in the above, the maximum field strength at a distance 1m from the wall of the control building in the valve hall with the converter valve in operation can be obtained using the above current waveform as the excitation source, as shown in Fig. 12.

The radiated interference level in the area near the wall of the valve hall generally refers to that in the area 1m or less away from the wall in the valve hall. To calculate the field strength in the area near the valve has no significance, for no equipments (except the equipments directly related to the operation of the valve) are not intended to be installed in this area. The equipments to be installed in this area are all designed with sufficient immunity to interference.

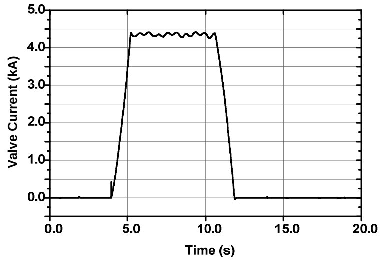


Fig. 10 Current waveform of the converter valve

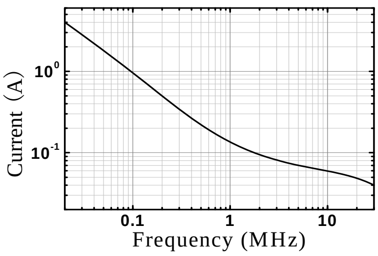


Fig. 11 Current frequency spectrum of the converter valve

It can be seen from Fig. 12, the field strength will decrease as frequency increases in general, however, there is a peak value at about 130 kHz. At about 110 kHz, the field strength reaches 373V/m which may influence the operation of some vulnerable equipment. For this reason, particular attention shall be given to this when selecting components. The electromagnetic interference level is approximately 20.9V/m at about 0.15MHz and that at 30MHz is approximately 0.60 V/m. Because of the rapid attenuation of the converter valve current within high frequency domain and the fact there is no obvious peak value, the average electromagnetic interference level is lower than 0.60V/m in frequency domain above 30MHz. The source of closer relation and greater importance in this frequency band is the electronic parts and assemblies of the control equipments, because these equipments contain high frequency emission sources, such as microprocessors etc. However, as these equipments are all designed as per international radiation standards, the emission source may be neglected.

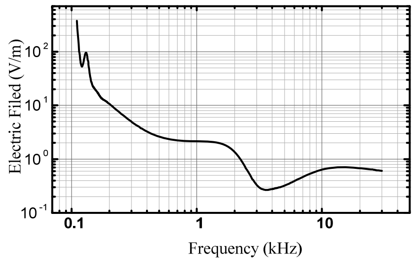


Fig. 12 the radiated interference level of the valve hall

Neglecting the shield effect of the wall of the valve hall, it is necessary to calculate the EMI level in the area near the wall of the valve hall, i.e. in the range 1m away from the wall, because in these areas equipments or cables between equipments may be arranged. Since these areas are near to the emission sources, the case is worst. The EMI levels in other areas are lower. Fig. 13 shows that at about 110 kHz, the electric field strength is up to 231V/m. Similarly, in the frequency domain above 30 kHz, the maximum strength value is lower than that at 30MHz (0.47V/m).

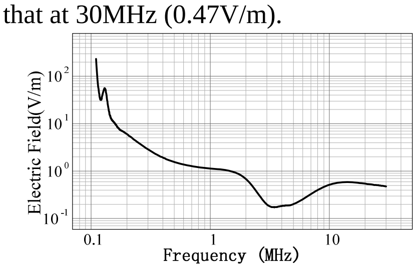


Fig. 13 Radiated interference level of the control building

V. CONCLUSIONS

(1) The radiated EMI calculation of converters based on the method of moments (MOM) is proposed.

(2) Electric field patterns around converters are analysed.

(3) According to simulation results, the field strength reaches 373V/m at 1m away from valve hall walls in a valve hall, while this value can reach 231V/m in the control building.

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