Analysis of Coupling Mechanism of VFTO in 1000kV GIS Substation on the Secondary Cables

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Abstract — Switching operations in GIS substation may generate very fast transient overvoltage (VFTO), and it's characterized by short rise time, high frequency and high peak value [1]. For those factors, switchgear produces transient EMI fields that would emission to other apparatuses in substation and secondary cables either. This paper analyzed main coupling approaches on cables from this emission, and then used Agrawal method to model field-to-line coupling on the secondary cables. Transmission line theory and finite difference time domain (FDTD) method are used in analyzing and calculating the induced voltages and currents in the model. At the end of the paper, a practical measurement is carried out in 1000kV GIS substation, common mode voltages and differential mode voltages on the secondary cables are measured under four different types of grounding.

I. Introduction

A GIS substation contains a large number of primary equipments and secondary equipments. This makes the electromagnetic environment very complex especially while disconnect switch is operating. It may generate VFTO in the switchgear, and then form a travelling wave on the enclosure of the switch. In 1000kV GIS substation, VFTO can be nanoseconds level, up to 100MHz frequencies and thousands volts of voltages. However, the impedances at the two ends of the switchgear are not match with each other, this result in transient EMI field emission at the mismatch point. The emission fields will couple on the long secondary cables directly, and disturb the core wire via transfer impedance between core wire and shielding layer. The interference voltage will affect secondary system that connects with the cable. If shielding layer is both grounding at the two ends, it may produce great current on the shield. This may cause switch malfunctions, secondary equipment damages or the burning of the cable.

II. Coupling Approaches

There are many EMI sources in a GIS substation. They come from those aspects: (1) routine connect or disconnect switch and breaker operations, (2) lightning and short circuiting in power system, (3) partial discharge, (4) electric field or magnetic field created by high voltage busbar, (5) radiation created by automatic devices and radio devices[2].

While disconnect switch is operating, there are two ways to coupling EMI on the secondary cables. One is field-to-line coupling; the other is ground potential difference coupling.

A. Field-to-line coupling

As mentioned above, when secondary is close to the switchgear, the emission field will first couple on the shielding layer of the cable through electric field or capacitors between busbar and cables, then transform in the induced voltage on shield. The voltages will couple on the core wire via transfer impedance.

B. Ground potential difference coupling

Switching operations may generate great current which will flow into the whole ground grid. However, there is ground impedance between the two ends of the cable. Therefore, ground potential is not equivalent with each other at these two ends.

III. Modeling and Simulation

At present, three different transmission line models are widely used in cable modeling. (1) Taylor model [3]: this model contain distributed voltage source and distributed current source; (2) Agrawal model [4]: this model only contain distributed voltage source; (3) Rachidi model: this model only contain distributed current source. All these models are equivalent in the final results. Therefore, Agrawal model is applied in calculating terminal response voltage in the paper..

A. Agrawal transmission line model

According to Agrawal model [4], two multiconductor transmission-line equations in the time domain are given as following:

$$\frac{\partial [V_i^s(z)]}{\partial z}+[R_{ij}][I(z)]+[L_{ij}]\frac{\partial [I_i(z)]}{\partial t}=[E_{zi}^i(z,h_i)-E_{z0}^i(z,0)] \quad (1)$$

$$\frac{\partial [I_i(z)]}{\partial z}+[G_{ij}][V_i^s(z)]+[C_{ij}]\frac{\partial [V_i^s(z)]}{\partial t}=0. \quad (2)$$

Here, $[R_{ij}]$, $[L_{ij}]$, $[G_{ij}]$ and $[C_{ij}]$ denote the per-unit-length parameter matrixes of the cable, respectively. $V_i^s(z)$ and $I_i(z)$ are the scattered voltage and current on the *i*th conductor. The right-hand side of (1) is the induced source term along the conductors and the reference conductor.

The total voltage $V_i^T(z)$ on the *i*th conductor is given by

$$[V_i^T]=V_i^S(z)-\int_0^{h_i} E_x^i(x,z)dx. \quad (3)$$

E_x^i is the transverse (x-direction) component of the incident electric field and h_i is the height between reference conductor and *i*th conductor along the x-axis. Equations (1) and (2) could be solved by using FDTD technique, see Fig.1.

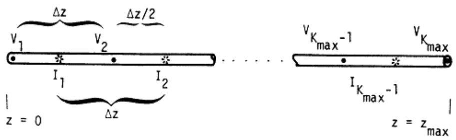


Fig.1. The finite-difference gridding imposed on each wire with $Z_{max}=(K_{max}-1)\Delta z$.

And the scattered voltage matrix

$$[V_{i,k}^{n+1}] = [\frac{G_{ij}}{2}+\frac{C_{ij}}{\Delta t}]^{-1}\{[\frac{I_{i,k}^{n} - I_{i,k+1}^{n}}{\Delta z}]+[\frac{C_{ij}}{\Delta t}-\frac{G_{ij}}{2}][V_{i,k}^{n}]\} \quad (4)$$

where k denotes the incremental position and n denotes the incremental time, and $k=1,2,\ldots,k_{max-1}$ and $n=0,1,\ldots,N_{max-1}$.

Therefore, the total voltage E_x^i could be determined in the time domain.

B. *Modeling of field-to-line coupling*

In [5], shielded cables which placed on the ground in the high frequency area could be divided into two transmission systems, see Fig.2.

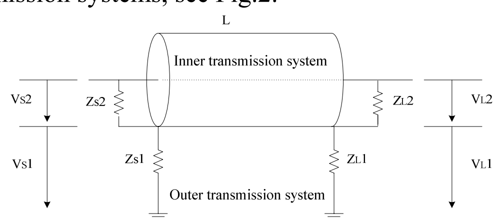


Fig.2. Equivalent circuit of transmission line system

Where Z_{S1}, Z_{L1} denote impedance between shielding layer and ground. Z_{S2}, Z_{L2} denote transfer impedance between core wire and shielding layer. V_{S1}, V_{L1} denote shield to ground voltage at the two ends. V_{S2}, V_{L2} denote core wire to shield voltage at the two ends.

Excitation (VFTO) which is generated by switching operations in 1000kV substation will first induced on cable shielding layer of outer transmission system. The induced voltage and current will then couple on inner transmission line system (Agrawal model) via transfer impedance. Thus, the terminal response voltage V_{L1} and V_{L2} could be calculated.

One calculated results is plotted in Fig.3 under the condition of grounding at the both ends of the cable.

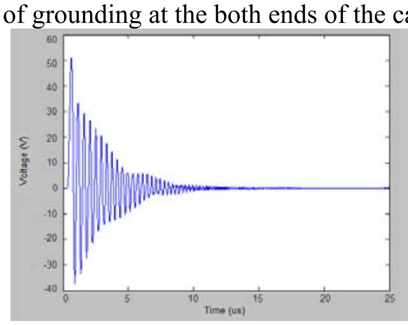


Fig.3. Plot of response voltage

IV. PRACTICAL MEASUREMENT

In the practical measurement, common mode voltages (CMV) and differential mode voltages (DMV) on the four shielded cables had been measured while switch operations. Those tested cables were placed on the ground. The length of parallel section between switchgear enclosure and cables is 6m, and the height of the switchgear is 0.7m. The DS connects only single phase AC source and no load is attached on it. Grounding conditions of above cables are can be:

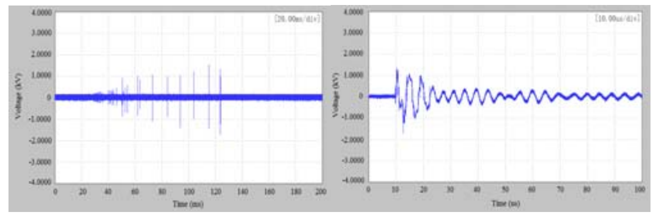
(I) Both grounding at the two ends of the shielding;

(II) Grounding at the far end (control room);

(III) Grounding at the near end (switch yard);

(IV) None of the end is grounded.

Under those conditions, 50 times of switching operations are carried out, and the measurement results are shown below:



(a) Plot of group pulse (b) Plot of single pulse

Fig.4. One plot of the measurement results

Fig.4 is the result of DMV under the grounding condition of III while switching off.

V. CONCLUSION

From above analysis, VFTO which is generated by DS switching operations can pass through space and ground impedance, and then couple on the secondary cables. Calculation results which applied in Agrawal method can well simulate the induced voltages on cables. Practical measurement shows that: (1) common mode voltage is greater than differential mode voltage; (2) voltages under condition of III and IV is much greater than that of I and II; (3) duration under different grounding condition is also different from each other; (4) domain frequency varies with each other at different conditions.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

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