# PAPER • OPEN ACCESS

Calculation of electric field in wire penetration monitoring device on strong electromagnetic environment

To cite this article: Jianhong Hao et al 2020 IOP Conf. Ser.: Earth Environ. Sci. 617 012018

View the article online for updates and enhancements.

# You may also like

- <u>Calculation and Analysis of</u> <u>Electromagnetic Environment Indexes and</u> <u>Influence Factors of ±1100 kV UHVDC</u> <u>Transmission Lines</u> Huiqi Li, xin Guo, Bo Qu et al.
- An optimal adaptive S-transform timefrequency space model for electromagnetic interference complexity evaluation Baiqiang Yin, Fangwen Deng, Ruoyu Wang et al.
- Analysis of Electromagnetic Environment and Influencing Factors of Yihua DC Transmission Lines Yong Liu, Minggang Sun, Xin Guo et al.





DISCOVER how sustainability intersects with electrochemistry & solid state science research



This content was downloaded from IP address 3.144.25.74 on 06/05/2024 at 04:19

# Calculation of electric field in wire penetration monitoring device on strong electromagnetic environment

Jianhong Hao<sup>1,a</sup>, Yuguan Zhang<sup>1,b</sup>, Haipeng Shi<sup>1,2</sup>, Lianguang Liu<sup>1</sup>

<sup>1</sup> North China Electric Power University, School of Electrical and Electronic Engineering, Beijing, China

<sup>2</sup> Mengdong electric power company, Huhehot, Inner Mongolia, China

<sup>a</sup>jianhonghao@ncepu.edu.cn

<sup>b</sup>email: z18813041276 @163.com

Abstract. In a strong electromagnetic environment, there is a great demand for the parameters needed to monitor the operation of lines or substation equipment, and the reliability of the monitoring device is a problem that needs to be researched. According to the need for heat dissipation and assembly of the cavity of the wire penetration monitoring device, for the high-voltage and high-current wire access point and the hole structure inside the device, this paper establishes a cavity model with a ring-shaped gap through a wire and derives the analytical formula of the electromagnetic field in the cavity, then the influence of plane wave pitching angle, the structure parameters of the conductor and the position of the wire on the internal resonance characteristic transformation of the through wire cavity are analyzed. The simulation analysis results can be used for the structure and shielding design of the wire penetration.

## 1. Introduction

With the development and construction of smart grids, there is an increasing demand for monitoring the operation status of power transmission and trans-formation equipment. Among them, the use of wire penetration monitoring devices to detect the temperature of the wires of the transmission line, or the AC and DC current of the neutral point loop of the trans-former is a new demand. The wire penetration monitoring device used for transmission lines generally adopts the integrated design of information acquisition and inductance energy acquisition[1,2]; used for the detection of AC and DC current at the neutral point, generally temporary detection[3-6], because the low-voltage monitoring device is connected to the neutral point of the transformer for a long time, it does not meet the requirements of national standards such as the neutral point grounding method and insulation level requirements of the transformer. At present, the operating reliability of the wire penetration monitoring devices used in these occasions is not high, and further research is needed to improve the reliability of low-voltage devices in high-voltage environments.

The electrical environment of the monitoring device for the neutral point of the line or transformer is very harsh. In addition to being affected by wind, mechanical vibration, and outdoor temperature and humidity, the problem of strong electromagnetic interference caused by high current is also more serious. This kind of wire-through outdoor monitoring device is more susceptible to high-frequency electromagnet-ic interference such as corona discharge and electrostatic discharge. The study of resonance forms when there are holes is one of the hot spots of electromagnetic compatibility research

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd 1 [7-10], Li et al. [9] used the FDTD method to analyze the length and number of the holes on the hole resonance, cavity mode resonance and cavity-slot resonance Influence of form. Liu Enbo[10] used CST software simulation to study the influence of different positions and structural parameters on the form of electromagnetic resonance inside the cavity with the through-wall gap as the re-search object. Tkachenko[14] et al. studied the scattered electric field of thin wires in the cavity. Rambousky[15] et al. analyzed the influence of the antenna inside the cavity when the wire is in the cavity. These studies are of great significance to the design of the device, but the influence on the penetrating conductor and the sur-rounding apertures, and the electric field distribution on resonance are rarely seen in the literature.

This paper establishes a cavity model with a ring-shaped gap through the wire and uses the dyadic Green function of the cavity to derive the analytical formula of the electromagnetic field in the cavity, and then analyzes the wire structure parameters, the plane wave pitch angle, and the position of the wire and the gap around the device on the resonance characteristics of the penetrating conductor cavity, and finally the conversion characteristics of cavity resonance and slot-cavity coupling resonance with changing conditions are studied. Through the study of these issues, new reference data is provided for the structural design and shielding design of the wire penetration monitoring device and its auxiliary equipment.

# 2. Calculation model and algorithm

# 2.1. Calculation model



Fig.1 Structural model diagram of cavity

## 2.2. Calculation algorithm

Figure 1 is the equivalent calculation model of the wire penetration device, considering that the rectangular opening and the wire are on the same surface, and the plane electromagnetic wave propagation di-rection is perpendicular to the opening surface. The radius of the wire is ra, and the radius of the hole on the cavity surface is rb. Calculate the electric field transmitted by the plane wave through the annular gap in the cavity, set the vacuum in the metal cavity, the sagittal potential related to the magnetic field is Am, and the electric field generated by the magnetic current in the cavity

$$E = -\frac{1}{\varepsilon_0} \nabla \times A_m \tag{1}$$

Where  $\epsilon_0$  is the dielectric constant in vacuum, and  $A_m$  can be expressed as

$$A_m = \iint_{S'} \bar{\bar{G}}_m(r,r') \cdot M(r,r') dS'$$
<sup>(2)</sup>

In the formula, r is the field point coordinates, r = (x, y, z); S' is the area in the ring gap; r' is the source point on the ring gap area, r' = (x', y', z'); M is the equivalent surface magnetic current density

IOP Conf. Series: Earth and Environmental Science 617 (2020) 012018 doi:10.1088/1755-1315/617/1/012018

of the annular hole at the plane  $z = d_0$ ;  $\overline{G}_m(r, r')$  is the dyadic Green function of the cavity, which satisfies the Helmholtz equation

$$\nabla^2 \bar{G}_m(r,r') + k_0^2 \bar{\bar{G}}_m(r,r') = -\bar{\bar{I}}\delta(r,r')$$
(3)

In the formula,  $k_0$  is the wave number in vacuum,  $k_0 = \omega \sqrt{\epsilon_0 \mu_0}$ ;  $\omega$  is the angular frequency;  $\mu_0$  is the permeability in vacuum;  $\overline{I}$  is the unit dyadic function,  $\overline{I} = e_x e_x + e_y e_y$ ;  $\delta(r, r')$  is the unit impulse function.

Considering that the annular hole is on the xOy plane, that is, the equivalent surface magnetic current has only components in the x-axis and y-axis directions, so the dyadic Green function only considers  $G_{mxx}(r,r')e_xe_x$  and  $G_{myy}(r,r')e_ye_y$  component is sufficient. Reference [12] adds appropriate boundary conditions, the expressions of the problem are

$$G_{mxx}(r,r') = \sum_{m,n}^{\infty} \frac{\varepsilon_0 \varepsilon_{0m} \varepsilon_{0n}}{abk_z} \sin(k_{xm}x) \cos(k_{yn}y) \frac{\cos[k_z(z+d)]}{\sin[k_z(d-d_0)]} \times \sin(k_{xm}x') \cos(k_{yn}y') \delta(z'+d_0)$$

$$\tag{4}$$

$$G_{myy}(r,r') = \sum_{m,n}^{\infty} \frac{\varepsilon_0 \varepsilon_{0m} \varepsilon_{0n}}{abk_z} \cos(k_{xm}x) \sin(k_{yn}y) \frac{\cos[k_z(z+d)]}{\sin[k_z(d-d_0)]} \times \cos(k_{xm}x') \sin(k_{yn}y') \delta(z'+d_0)$$
(5)

Where  $k_{xm} = \frac{m\pi}{a}$ ;  $k_{yn} = \frac{n\pi}{b}$ ;  $k_z = \sqrt{k_0^2 - k_{xm}^2 - k_{yn}^2}$ , where (m, n) is the field distribution

pattern in the cavity, m, n = 0, 1, 2, 3, ...;  $\epsilon_{0m}$ ,  $\epsilon_{0n}$  are Neumann constants, when m(n) = 0,  $\epsilon_{0m(n)} = 1$ , when  $m(n) \neq 0$ ,  $\epsilon_{0m(n)} = 2$ . Substituting formula (4) and formula (5) into the expression of  $A_m$  can be obtained

$$A_{m} = \iint_{S'} G_{mxx}(r,r') M_{x}^{pw} dS' e_{x} + G_{myy}(r,r') M_{y}^{pw} dS' e_{y}$$
(6)

The plane wave is transmitted into the cavity through the annular gap. In order to obtain the coefficient of the equivalent surface magnetic current on the aperture, the expressions of the transmitted electric field in the x-axis and y-axis directions are calculated respectively

$$E_{ty} = \frac{(-2\eta_1)H_x^{pw}e_y}{(\eta_1)e^{jk_0d_0} - (\eta_1)e^{-jk_0d_0}} = \eta(d_0)H_x^{pw}e_y \tag{7}$$

$$E_{tx} = \frac{(-2\eta_1)H_y^{pw}e_x}{(\eta_1)e^{jk_0d_0} - (\eta_1)e^{-jk_0d_0}} = \eta(d_0)H_y^{pw}e_x$$
(8)

In the formula,  $\eta_1$  is the characteristic impedance of free space, and  $E_{ty}$  and  $E_{tx}$  are respectively the tangential vector electric field in the y-axis and x-axis directions in the ring-shaped gap region on the  $z = d_0$  plane. From the mirror image method, the equivalent surface magnetic current density is

$$M_{y}^{pw} = 2E_{tx} = 2H_{y}^{pw}\eta(d_{0})$$
(10)

In summary, the electromagnetic field component in the cavity can be obtained

N

$$E_{x} = 2H_{y}^{pw}\eta(d_{0})\sum_{m}\sum_{n}\frac{\varepsilon_{0m}\varepsilon_{0n}}{ab\sin[k_{z}(d-d_{0})]}\sin[k_{z}(z+d)]$$

$$\times \iint_{S'}\cos(k_{xm}x')\sin(k_{yn}y')\,dS'\cos(k_{xm}x)\sin(k_{yn}y) \qquad (11)$$

$$E_{y} = 2H_{x}^{pw}\eta(d_{0})\sum_{m}\sum_{n}\frac{\varepsilon_{0m}\varepsilon_{0n}}{ab\sin[k_{z}(d-d_{0})]}\sin[k_{z}(z+d)]$$

$$\times \iint_{S'}\sin(k_{xm}x')\cos(k_{yn}y')\,dS'\cdot\sin(k_{xm}x)\cos(k_{yn}y) \qquad (12)$$

$$E_{z} = 2\eta(d_{0}) \sum_{m}^{\infty} \sum_{n}^{\infty} \frac{\varepsilon_{0m} \varepsilon_{0n} \sin(k_{yn}y)}{abk_{z} \sin[k_{z}(d-d_{0})]} \cos[k_{z}(z+d)] \times$$

 $\sin(k_{xm}x)\left[k_{yn}H_x^{pw}\iint_{S'}\sin(k_{xm}x')\cos(k_{yn}y')\,dS'-k_{xm}H_y^{pw}\iint_{S'}\cos(k_{xm}x')\sin(k_{yn}y')\,dS'\right]$ (13)

IOP Conf. Series: Earth and Environmental Science 617 (2020) 012018 doi:10.1088/1755-1315/617/1/012018

Next, calculate the electric field scattered by the transmission wire in the cavity. Since the wire is located at a symmetrical position in the cavity, the electric field here is only related to the z-axis component of the dyadic Green's function. Then the dyadic Green's function  $G_{zz}^{E}$  can be Derive [15]as

$$G_{ZZ}^{E}(\vec{r},\vec{r}) = \frac{\eta_0 c}{jk} \left( k^2 + \frac{\partial^2}{\partial z^2} \right) G_{ZZ}^{A}(\vec{r},\vec{r})$$
(14)

In the formula,  $G_{zz}^A$  is the zz component of the Green's function of the vector potential in the cavity, and c is the speed of light.

$$G_{ZZ}^{E}(\vec{r},\vec{r_{1}}) = \frac{4\eta_{0}}{jkV} \sum_{\substack{n_{1},n_{2}=1\\n_{3}=0}}^{\infty} \varepsilon_{n3,0}(k^{2}-k_{\nu z}^{2}) \cdot \frac{\sin(k_{\nu x}x)\sin(k_{\nu x}x_{1})\sin(k_{\nu y}y)\sin(k_{\nu y}y_{1})\cos(k_{\nu z}z)\cos(k_{\nu z}z_{1})}{k_{\nu}^{2}-k^{2}+j\delta}$$
(15)

Among them,  $\overrightarrow{k_v} = (k_{vx}, k_{vv}, k_{vz})$ ,  $v \coloneqq |n_1, n_2, n_3 \rangle$ ,  $k_{vx} = n_1 \pi/a$ ,  $k_{vy} = n_2 \pi/b$ ,  $k_{vz} = n_1 \pi/a$  $n_3\pi/h$ ,  $\delta \to +0$ , and  $\varepsilon_{n, m} = \begin{cases} 1, m = n \\ 2, m \neq n \end{cases}$ . Thus the relationship between the scattered electric field and the wire current can be obtained

$$E_z^{SC}(\vec{r}) = \int_0^n G_{zz}^E(\vec{r}, \vec{r}) I(z) \, dz \tag{16}$$

)

The decomposition of the electric field relative to its coordinates is as follows

$$E_z^{SC}(x_0, y_0 + r_0, z) = \int_0^h G_{zz}^E(x_0, y_0 + r_0, z, x_0, y_0, z)I(z) dz$$
(17)

In addition to the external electric field, the excitation effect of the lumped power supply (at one or both ends of the wire) on the wire must also be considered. So the total wire current can be expressed as

$$I(z) = I_l(z) + I_r(z) + I_f(z)$$
(18)

The lumped source current on the left side of this wire is

$$I_l(z) = \frac{jkU_l}{\eta_0 h} \sum_{m_3=0}^{\infty} \frac{\varepsilon_{m_3,0} \cos(\pi m_3 z/h)}{((k_z^{\nu})^2 - k^2)S(x_0, y_0)}$$
(19)

Similarly, the current generated by the lumped source on the right side of the wire can be obtained

$$I_r(z) = \frac{j_k v_r}{\eta_0 h} \sum_{m_3=0}^{\infty} \frac{(-1)^{-2} e_{m_3,0} \cos(\pi m_3 2/n)}{((k_z^p)^2 - k^2) S(x_0, y_0)}$$
(20)

The wire excitation current generated by the external electric field can be equivalent to

$$I_f(z) = \frac{jk}{\eta_0} \sum_{m_3=0}^{\infty} \frac{E_{z,m_3}^0(x_0,y_0) \cos(\pi m_3 z/h)}{((k_z^\nu)^2 - k^2) S(x_0,y_0)}$$
(21)

The two-dimensional Green's function S(x, y) perpendicular to the plane of the transmission line can be based on the literature [13][14], which shows the different representations of the function, of which the most suitable for numerical calculation is

$$S(x_0, y_0) = \frac{1}{b} \sum_{m_2=1}^{\infty} \sin^2(k_x^{\nu} x_0) \cdot \left[ \frac{2\sinh(\tilde{\gamma}_{\nu}(a-y_0))\sinh(\tilde{\gamma}_{\nu} y_0)}{\tilde{\gamma}_{\nu}\sinh(\tilde{\gamma}_{\nu} b)} - \frac{1}{k_x^{\nu}} \right] + \frac{1}{2\pi} \ln\left[ \frac{a|\sin(\pi x_0)|}{\pi r_0} \right]$$
(22)

 $\tilde{\gamma}_v^2 \coloneqq (k_v^v)^2 + (k_x^v)^2 - k^2 + j\delta, \ \delta \to +0$ , this is the representation of the one-dimensional sum of the S function, which can clearly show the singularity in the space coordinates. The Fourier component of the external electric field can be expressed as

$$E_{z,m_{3}}^{0}(x_{0},y_{0},\omega) = -\frac{2}{3}\frac{d^{3}}{bh}jkE_{0}(\omega)\cdot\sum_{m_{2}=1}^{\infty}\varepsilon_{m_{2},m_{3}}\sin(k_{x}^{v}x_{0})\sin(k_{x}^{v}x_{1})\cos(k_{z}^{v}z_{1})\frac{\sin h(\gamma_{v}y_{0})}{\sin h(\gamma_{v}b)} \quad (23)$$

In the formula,  $\gamma_v = \sqrt{(k_x^v)^2 + (k_z^v)^2 - k^2}$ ,  $E_0(\omega)$  is the plane wave Fourier transform formula, in summary the transmission electric field of the wire can be passed through the formula (23) Substituting equations (21) and (16) to obtain, the total z-axis electric field component in the cavity can be obtained by superimposing equation (16) and equation (13)

#### 3. Calculation results

According to the actual situation, the dimensions of the cavity in Figure 1 are as follows, a=400mm, b=150mm, d=200mm, thickness t=1mm, radius ra=20mm, and radius rb=25mm.

Using the model algorithm in this paper and CST software to simulate the shielding effectiveness in the cavity, as shown in Figure 2, the comparison shows that the simulation results of the model algorithm in this paper and the CST time domain method are in good agreement. In Figure 2, the frequency point corresponding to the extreme point of the shielding curve is the cavity resonance frequency. At these frequencies, the field strength inside the cavity is greater due to resonance.



Fig.2 Calculation model and CST calculation simulation results

## 4. Results analysis

According to the above algorithm, the influence of many factors in the cavity needs to be considered in the actual situation, including changes in the structure parameters of the wire, the pitch angle and the position of the wire.

# 4.1. Influence of conductor radius

When the wire radius is 20mm, 30mm, 40mm, the corresponding E-f curve is shown in Figure 3. Under different radius conditions, the radius of the circular gap of the cavity at the joint is 2mm larger than the radius of the wire. In combination with Figure 3, it can be seen that as the radius of the wire decreases, the intensity of the electric field coupled into the cavity gradually decreases, and the SCR coupling resonance and cavity resonance frequency remain unchanged.



Fig.3 E-f curve diagram corresponding to different conductor radius

#### 4.2. Influence of the number of wires

The double wire is set on the other side of the original wire to the observation point A, and the observation point B is set at the center of the X=200mm plane. The comparison of E-f between a single wire and a double wire is shown in Figure 4.



Fig.4 E-f curve diagram corresponding to different number of conductors

As shown in Figure 4, at the observation point, the electric field strength of the double wire is higher than that of the single wire, that is, the double wire couples from the external electric field into the cavity more paths than the single wire. Since the standing wave of the area where the wire passes is easily affected by the electric field strength and shape, the area where the double wire passes through the cavity just covers the area where the two standing waves of TE201 resonance occur, and the electric field component of the standing wave is dispersed to the slot interface and the surrounding area of the wire near the interface, so that the large-area cavity area between the two wires has almost no electric field component, and other resonance frequencies in the cavity remain basically unchanged.

#### 4.3. Influence of different positions at the end

Shielded cases often have wires that only pass through the wall of one side of the box. At this time, the other end of the wire is inside the cavity, so take the end of the wire at the Z=-100mm plane position inside the cavity and compare it with the end outside the cavity. The E-f diagram is shown in Figure 5.



Fig.5 E-f curve diagram corresponding to the end of conductor inside and outside the cavity

As shown in Figure 5, in the low-frequency range below 400MHz, the electric field value inside the single-sided penetration wire cavity is lower than that of the double-sided penetration, while in the mid-to-high frequency range above 400MHz, multiple SCR resonances and resonances are excited. The cavity is resonant, so the electric field value is higher than the end of the cavity outside the cavity. Two new SCR resonances appeared inside the cavity, with frequencies of 898.7MHz and 1100.7MHz, which were formed by the coupling of TE201 and TE301 with the gap. An intracavity resonance is added inside the cavity, namely TE022, with a frequency of 1610MHz.

## 4.4. Influence of different pitch angles

When the actual shielded chassis equipment is subjected to electromagnetic interference, the incident direction of the interference source is not only the forward direction, but the disturbance source may exist in any position. The angle between the electric field direction of the plane wave and the Y-axis is called the pitch angle Theta. The electric field at the observation point at the pitch angles of  $0^{\circ}$ ,  $30^{\circ}$ , and  $45^{\circ}$  through the wire cavity is calculated as a graph of the electric field changes with frequency, as shown in Figure 6.



Fig.6 E-f curve diagram of through conductor at 3 Theta angles

As shown in Fig. 6, when the pitch angle Theta=0°, the electric field value in the cavity is small. This is because the incident angle enters the cavity surface in the forward direction, and the electric field component is small; when the pitch angle Theta=30° and Theta=45° When the two E-f curves are roughly similar, the E-f curve at Theta=45° is slightly higher than the E-f curve at Theta=30° because the direction of the electric field intensity is gradually approaching to the surface of the cavity. this is. However, as the pitch angle increases, the incident direction deviates from the forward direction of the cavity surface, resulting in more cavity resonance and coupling resonance. When Theta=30°, two cavity resonance points TM110 and TM210 are excited inside the cavity, and an SCR coupling resonance point is added; when The-ta=45°, an additional one is added on the basis of Theta=30° The new SCR resonance, the SCR resonance with a frequency of 1700.3MHz is formed by the coupling of TE302 and the slot.

## 4.5. Influence of different cavity positions

When the penetrating wire is in a single-sided position, the observation point B is set at the center of the x=200mm plane. The comparison diagram of E-f between the unilateral position and the center position of the penetrating wire is shown in Figure 7.

IOP Conf. Series: Earth and Environmental Science 617 (2020) 012018 doi:10.1088/1755-1315/617/1/012018



Fig.7 E-f curve diagram corresponding to the different cavity positions

In Figure 7, since the distance between the wire and point A when the wire is in the center position is equal to the distance between the wire and the point B when the wire is on one side, the electric field values of the two E-f curves at the resonance frequency are basically the same.

When the wire is in the unilateral position, the cavity resonance point TE021 in the cavity disappears, and a new cavity resonance point TE501 is added. TE021 has 1 standing wave on the X-axis, TE301 and TE302 has 3 standing waves, TE501 has 5 standing waves, that is, the cavity resonance when the wire is in the center position is a single standing wave on the X-axis.

# 4.6. Influence of different gap positions

Considering that in the process of metal material processing and splicing, the interface between the penetrating wire and the gap cannot be completely closed, and a small amount of gaps will appear. A common measure is to fix the wire through the internal structure so that the wire is at the center of the gap of the circular interface. Since the position of the penetrating wire generally does not change, but with time, the fixing device of the device interface position may cause the wire to be on the upper side of the interface gap due to the gravity of the device itself. Calculate when the wire is in the center of the gap and the position on the upper side of the gap, the electric field at the observation point varies with frequency, as shown in Figure 8.



Fig.8 E-f curve diagram corresponding to the different slot positions

It can be seen from Figure 8 that when the wire is on the upper side of the interface gap, the electric field value at the observation point is much higher than the electric field value of the wire at the center of the gap. The analysis shows that when the wire is on the upper side of the gap, the exposed gap on the lower side of the gap can be roughly equivalent to a size of  $40 \text{mm} \times 5 \text{mm}$  (length  $\times$  width) and a thickness of 1mm. Therefore, there are not only electromagnetic waves coupled by the external electric field through the wire in the electric field. There is also the electric field component directly incident through the lower slit. The resonance when the wire is at the upper side of the slot, except for TM210, other resonances are SCR coupling resonance points. The original cavity resonance is basically converted to SCR coupling resonance.

# 5. Conclusion

Compared with the chassis cavity with only slots, the resonance characteristics in the cavity through which the high-current wire penetrates are different:

(1) In the penetrating wire cavity, the aperture is not the main way for electromagnetic waves to be coupled into the cavity. Because the wire more affects the coupling environment of electromagnetic waves, SCR resonance becomes the earliest cavity resonance, so that the disturbance sources in the middle and low frequency bands, such as corona discharge, will not cause too much influence on the internal electronic equipment of the monitoring device.

(2) The change of the wire radius has little effect on the resonance of the cavity. If the detection equipment is within the required range, the location of the transmission line with a small radius can be selected for installation.

(3) When the wire is in a single-sided position and the two wires are symmetrical at the center point, it will cause a certain change in the resonance frequency in the cavity. Electronic equipment should be installed in the central area of the space without wires to reduce the influence of the resonant electric field component.

(4) When the end is inside the cavity, it will affect a large area around it. At this time, the electronic equipment should be kept as far away as possible from the wire in the cavity.

(5) The change of the pitch angle will produce more cavity resonance and SCR coupling resonance, which will have a greater impact on the cavity at medium and high frequencies.

(6) When the wire is on one side of the interface gap, the shielding of the chassis will be greatly reduced and multiple SCR coupling resonances will be increased. Therefore, when installing a shielded case, try to ensure that the wire is fixed in the center of the interface gap to reduce the path of the hole coupling into the cavity.

## Acknowledgments

This work was financially Supported by the Project Natural Science Foundation of China (51577060).

# References

- [1] Li Xiangkun,Gao Ning, Wu Weimin, A modified self-powered wireless temperature measurement system for high voltage switchgear[C], 2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA), 1425–1430, Jun. 2018
- [2] Liu Shulin, Xu Dandan, Research on self-powered short-circuit fault alarming system in power grid[C], 2017 IEEE Electrical Design of Advanced Packaging and Systems Symposium (EDAPS), 1–4, Dec. 2017
- [3] Hao Jianhong, Teng Wanyi, et al. Research on Distribution Characteristics of DC Potential Near the UHVDC Grounding Electrode[J], IEEE Access, vol. 8, pp. 122360–122365, 2020.
- [4] Hao Jianhong, Yu Zebang, et al. Vibration and audible noise characteristics of AC transformer caused by HVDC system under monopole operation[J], IEEE Trans. Power Del., vol. 27, no. 4, pp. 1835–1842, Oct. 2012.
- [5] Yu Zebang, Hao Jianhong, Liu Lianguang, and Wang Zezhong, Monitoring experiment of electromagnetic interference effects caused by geomagnetic storms on buried pipelines in

IOP Conf. Series: Earth and Environmental Science 617 (2020) 012018 doi:10.1088/1755-1315/617/1/012018

China[J], IEEE Access, vol. 7, pp. 14603–14610, 2019.

- [6] Liu Lianguang, Yu Zebang, Liu Wenlin, The effect of tidal geoelectric fields on GIC and PSP in buried pipelines[J], IEEE Access, vol. 7, pp. 87469–87478, 2019.
- [7] LI M, et al. An EMI estimate for shielding-enclosure evaluation[J]. IEEE Transactions on Electromagnetic Compatibility, 2001,43(3):295-304
- [8] WU Xian, DU Ping-an, NIE Baolin, et al. Research on the electromagnetic shielding performance of enclosure with slots by numerical simulation[J]. China Journal of Engineering Design, 2011,18 (3): 197-203 (in Chinese).
- [9] LI M, NUEBEL J, DREWNIAK J L, et al. EMI from cavity modes of shielding enclosures—FDTD modeling and measurements [J]. IEEE Transaction on Electromagnetic Compatibility,2000,42(1):29-38.
- [10] Liu Enbo, Wang Dandan, CHEN K, et al. Simulation analysis on electromagnetic resonance characteristics of cavity with slots[J]. China Scinece paper ,2016,11(16):1808-1812(in Chinese).
- [11] Deshpande M D. Electromagnetic field penetration studies[R]. NASA Technical Paper, National Aeronautics and Space Administration, Jun, 2000.
- [12] Hao Jianhong, Gong Yanfei, et al. Analytical Formulation for the Shielding Effectiveness of a Cascaded Double Metallic Enclosures with an Annular Aperture Sealed by Conductive Material[J]. Transactions of China Electrotechnical Society, 2018, 33(01): 131-139. (in Chinese).
- [13] S. Tkachenko, J. Nitsch, and R. Rambousky, Electromagnetic field coupling to transmission lines inside rectangular resonators[J], Interaction Notes, no. 623, Jun. 2011.
- [14] S. Tkachenko, R. Rambousky, and J. B. Nitsch. Electromagnetic field coupling to a thin wire located symmetrically inside a rectangular enclosure[J], IEEE Trans. Electromagn. Compat., 2012.
- [15] R. Rambousky, S. Tkachenko and J. Nitsch. Calculation of currents induced in a long transmission line placed symmetrically inside a rectangular cavity[C], 2013 IEEE International Symposium on Electromagnetic Compatibility, 2013, pp. 796-801,