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Research on the UHF Microstrip Antenna for Partial Discharge Detection in High Voltage Switchgear

***Abstract**. In order to detect the ultra-high-frequency (UHF) signals generated from partial discharges (PDs) in high voltage switchgear, a microstrip antenna sensor is designed. Influences of geometric parameters on the capability of the proposed antenna sensor are researched by numerical simulation. Measured characteristic results show that this antenna sensor is very suitable for partial discharge detection.*

Streszczenie**. W celu wykrycia sygnałów w zakresie ultra wysokich częstotliwości (UHF) generowanych przez wyładowania niezupełne (PD) w rozdzielnicy wysokonapięciowej zaprojektowano czujnik w postaci anteny. Wpływ parametrów geometrycznych przetwornika na jego własności został zbadany za pomocą symulacji numerycznych. Wyniki pomiarów pozwalają stwierdzić, że powyższy czujnik umożliwia skuteczne wykrycie wyładowań niezupełnych.**(Wykorzystanie mikropaskowej anteny UHF do wykrywania wyładowań niezupełnych w rozdzielnicy wysokonapięciowej).

Keywords: Ultra-high-frequency (UHF), Partial discharge, Microstrip antenna sensor.
Słowa kluczowe: Ultra wysokie częstotliwości (UHF), Wyładowania niezupełne, Czujnik antenowy w technice mikropaskowej.

Introduction

High voltage switchgear are widely used as important fundamental equipment in electric power system, which are directly relative to the power supply reliability and quality. Partial discharge (PD) as a potential threat directly affects the insulation safety in high voltage switchgears and power system [1]. The PD signal contains abundant information of insulation states and the ultra-high frequency (UHF) method, as one of the most important detection methods, is widely used in inspecting insulation defects and fault diagnosis in electric equipments [2].

In previous studies, many scholars focus on the application of UHF sensors for PD detection in transformers [3-4] and gas-insulation switches [5-8], but the study on the application of an ultra-wideband (UWB) antenna is not enough.

In this paper, an UWB planar monopole microstrip antenna is proposed and it is developed based on the optimal design procedure. The voltage standing wave ratio (VSWR) of the antenna are obtained through simulation and measurement.

Design Criteria of the Antenna Sensor

The design of UHF antenna plays a crucial role to the accuracy and sensitivity of the PD online detection system. According to the structure and PD characteristics of the high voltage switchgears, the design criteria of an UHF antenna sensor for PD detection are:

a) Considering the major concentrated frequency band of the PD energy, the lowest and highest resonant frequencies of an UHF antenna can approach 500 MHz and 1500 MHz, respectively;

b) The built-in UHF antenna should be chosen for PD detection in high voltage switchgears;

c) The UHF antenna should have a higher gain;

d) The designed UHF antenna should achieve omnidirectional radiation patterns in H plane;

e) For the built-in UHF antenna, it should have a reasonable size and shape so that it has no influence to insulation safety of the high voltage switchgears in operation.

Optimization of the Antenna Sensor

Initially, the rectangular microstrip antenna is designed with the use of commercial software Ansoft HFSS. The dimension parameters and schematic configuration of this antenna are shown in Table 1 and Fig.1, respectively.

Table 1. Dimension parameters of rectangular microstrip antenna.

Parameter	W_0	L_0	H	W_f	L_f	W_p	L_p	L_g
Unit (mm)	208	247	2	3	143	149.5	88	105.3

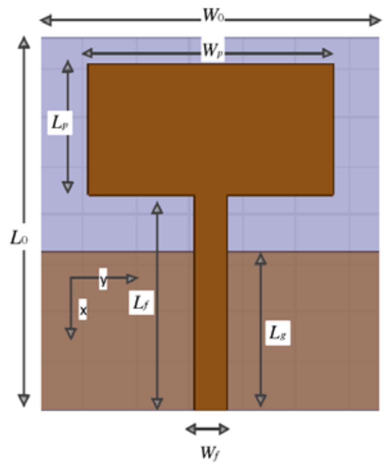


Fig.1. Schematic configuration of rectangular microstrip antenna.

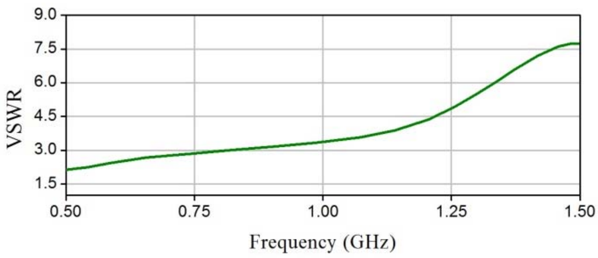
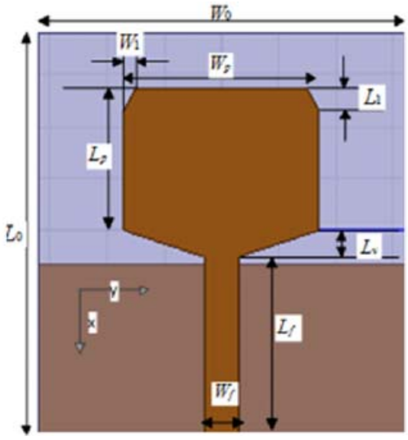


Fig. 2. VSWR curve of rectangular microstrip antenna.

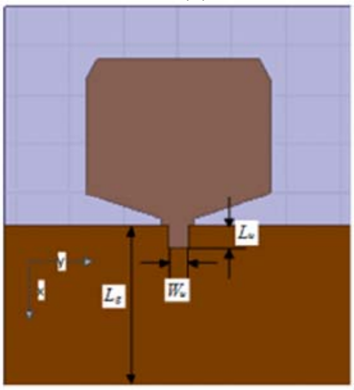
Due to the bandwidth performance of the rectangular microstrip antenna is far from enough to meet the design requirement of an UWB microstrip antenna, as shown in Fig.2, the structure optimization of the rectangular microstrip antenna is needed to be studied.

Table 2. Dimension parameters of antenna after the 1st optimization.

Parameter	W_0	L_0	H	W_f	L_f	W_p	L_p
Unit (mm)	208	247	2	3	109.2	110.5	88
Parameter	L_g	W_u	L_u	W_1	L_1	L_v	
Unit (mm)	105.3	1.9	2.5	6.5	13	16.25	



(a)



(b)

Fig.3. Schematic configuration of antenna after the 1st optimization. (a) Top view; (b) Back view.

According to the theory of antenna, it can be known that the change of radiation patch and ground plate can have great influence on the parameter indexes of the microstrip antenna and the structure optimization of radiation patch and ground plate is an effective way to improve the bandwidth performance. After the 1st optimization, the dimension parameters and schematic configuration of this antenna are shown in Fig.3 and Table 2, respectively.

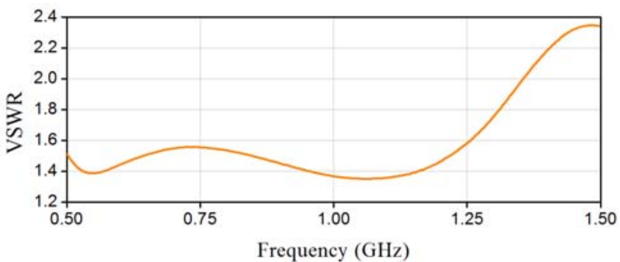


Fig. 4. VSWR curve of antenna after the 1st optimization.

Fig.4 shows that the VSWR characteristics of antenna after the 1st optimization is better than that in Fig.2, because the structure changes can lead to the changes of the impedance matching or surface current distribution on the patch of microstrip antenna.

In order to realize miniaturization of the radiation patch, cutting an inverted T-shaped slot on the radiation patch is applied, as shown in Fig.5. After the simulation optimization of HFSS software, the dimensions of the antenna are summarized in Table 3.

Table 3. Dimension parameters after the final optimization.

Parameter	W_2	L_2	W_3	L_3
Unit (mm)	16	19.5	52	52

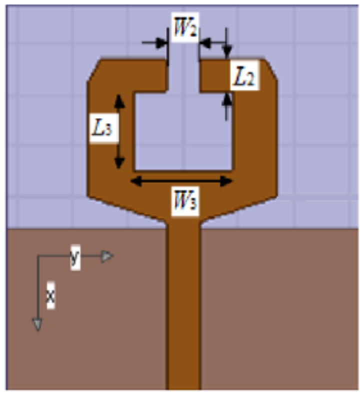


Fig.5. Schematic configuration after the final optimization.

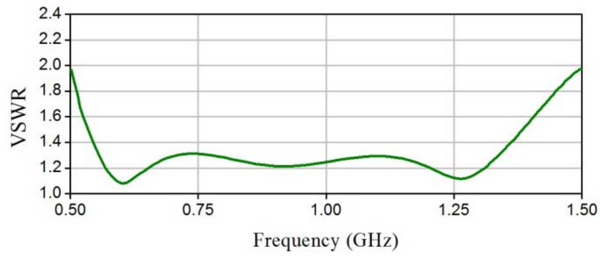
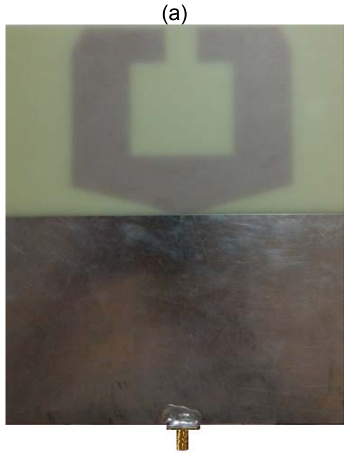


Fig.6. Simulated VSWR of the proposed UWB antenna after the final optimization.

The voltage standing wave ratio (VSWR) of the proposed antenna is shown in Fig.6. Compared with that in Fig.2, it can be indicated that the bandwidth performance of the antenna sensor increased obviously after the structure optimization of radiation patch and ground plate. It is also observed that the VSWR of the proposed antenna is less than 2 between 0.5GHz and 1.5GHz.

(a)



(b)

Fig.7. Photographs of the fabricated UWB planar monopole microstrip antenna. (a) Top view; (b) Back view.

Fabrication and Measurement Results

In order to verify the validity of the simulated results, the actual physical model of the proposed antenna is fabricated. Fig.7 shows the photographs of the fabricated UWB planar monopole microstrip antenna. The feed port of the antenna is connected to the coaxial line of characteristic resistance 50 Ω through a coaxial Sub-Miniature Version A (SMA) connector.

The VSWR parameter of the fabricated antenna has been measured with an Agilent Technologies E5071B programmable network analyzer and the result curve is shown in Fig.8. It can be found that close agreement between the measured and simulated results of VSWR is observed in the targeted frequency range and the measured result shows that the work frequency (VSWR < 2) of the fabricated UWB planar monopole microstrip antenna is from 565 MHz to 1500 MHz, which can satisfy the bandwidth requirements for PD UHF detection in high voltage switchgear.

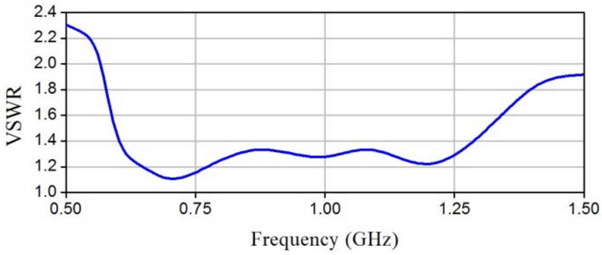
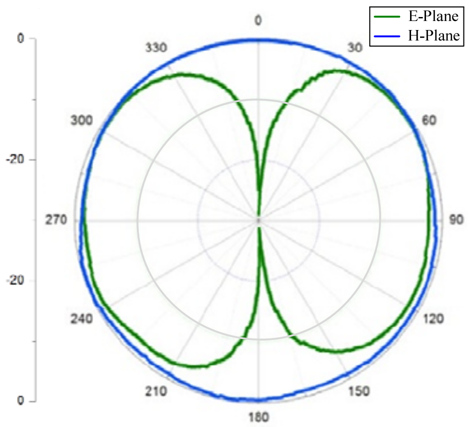
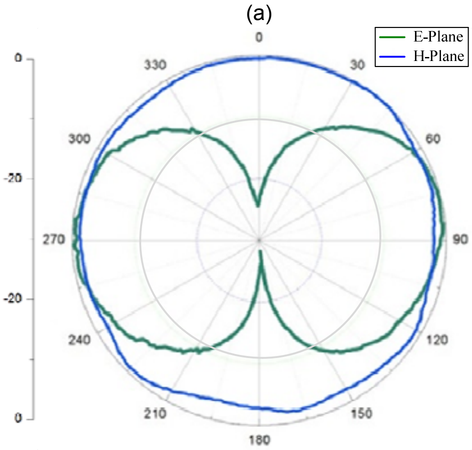


Fig.8. Measured VSWR of the fabricated UWB antenna sensor.

Fig.9 presents the measured 2D normalized radiation patterns of the fabricated antenna at 500, 1000 and 1500 MHz. It can be seen that the fabricated antenna has a good omnidirectional radiation pattern in the H-plane, and a dipole-like radiation pattern in the E-plane.



(a)



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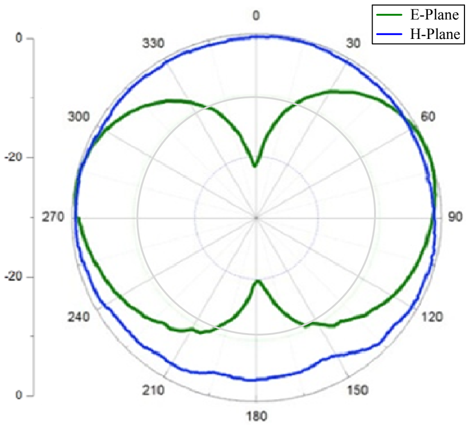

(c)

Fig.9. Measured 2D normalized radiation patterns of the fabricated UWB antenna sensor. (a) 500MHz, (b) 1000MHz, (c) 1500MHz.

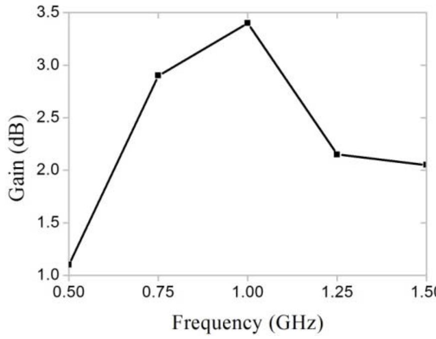

Fig.10. Measured peak gain of the fabricated UWB antenna sensor.

The measured peak gain of the fabricated UWB planar monopole microstrip antenna for operating frequency within the 0.5-1.5 GHz band is shown in Fig.10. It is observed that the measured antenna peak gain are about 1.1–3.5 dB with an average value of 2.32 dB. From the measured results of the radiation patterns and peak gain, it can be concluded that the performance of the fabricated antenna meets the design criteria of an UHF antenna for PD detection in high voltage switchgear perfectly.

Conclusion

An UWB planar monopole microstrip antenna sensor for PD UHF detection in high voltage switchgears was presented. The design of the antenna is optimized through simulation studies. The results of the work can be summarized as follows:

a) Measurement results show that the work frequency (VSWR < 2) of the UWB planar monopole microstrip antenna sensor is from 565 MHz to 1500 MHz.

b) The UWB planar monopole microstrip antenna sensor has a good omnidirectional radiation pattern in the H-plane and the peak gain variation are about 1.1–3.5 dB with an average value of 2.32 dB.

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REFERENCES

[1] Iliana E Protugues, et al, RF-based partial discharge early warning system for air-insulated substations, IEEE Trans. Power Del., vol. 24, no. 1, pp. 20-29, 2009.
[2] Shak A M, et al, A study of UHF partial discharge signal propagation in power transformers using FDTD modeling, Universities Power Engineerin Conference, 2010: 1-5.
[3] G. Robles, et al, Shielding effect of power transformers tanks in the ultra-high-frequency detection of partial discharges, IEEE Trans. Dielectr. Electr. Insul., vol. 20, no. 2, pp. 678-684, 2013.
[4] J. Li, et al, Optimization of UHF Hilbert antenna for partial discharge detection of transformers, IEEE Trans. Antennas Propagat., vol. 60, no. 5, pp. 2536-2540, 2012.
[5] T. Li, et al, Development simulation and experiment study on UHF partial discharge sensor in GIS, IEEE Trans. Dielectr. Electr. Insul., vol. 19, no. 4, pp. 1421-1430, 2012.
[6] M. Hikita, et al, Influence of insulating spacer type on propagation properties of PD-induced electromagnetic wave in GIS, IEEE Trans. Dielectr. Electr. Insul., vol. 17, no. 5, pp. 1642-1648, 2010.
[7] S. Kaneko, et al, Detecting characteristics of various type antennas on partial discharge electromagnetic wave radiating through insulating spacer in gas insulated switchgears, IEEE Trans. Dielectr. Electr. Insul., vol. 16, no. 5, pp. 1462-1472, 2009.
[8] M. Hikita, et al, Electromagnetic (EM) wave characteristics in GIS and measuring the EM wave leakage at the spacer aperture for partial discharge diagnosis, IEEE Trans. Dielectr. Electr. Insul., vol. 14, no. 2, pp. 453-460, 2007.