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# UHF Sensor를 이용한 SF6 절연 MV 개폐기의 부분방전 검출 시스템

이도훈[1], 강원종[1], 신양섭[1], 김영근[1], 오일성[1], 김동명[2], 권태호[2]
[1]LS산전(주) [2]전력연구원

# Partial Discharge Monitoring for $SF_6$ Insulated MV Switchgear using UHF sensors

Do-Hoon LEE[1], Won-Jong KANG[1], Yang-Sop SHIN[1], Young-Geun KIM[1], Il-Sung OH[1], Dong-Myung KIM[2] and Tae-Ho Kwon[2]
[1]LS Industrial Systems. Co. Ltd. [2] Korea Electric Power Research Institute

**Abstract** - In this paper, the UHF PD(Partial Discharge) sensors for $SF_6$ insulated MV $SF_6$ switchgear have been proposed and related investigations have been performed in order to detect the PD which were produced inside the MV $SF_6$ switchgear. Firstly, the internal type UHF PD sensor based on spiral antenna theory has been developed. This type sensor is highly sensitive and has lowly effect on by on-site noise. Secondly, the external type UHF PD sensor was developed based on log periodic antenna concept. This type sensor is removable and detectable for operating switchgear. These sensors were designed and simulated using RF simulation tool.

In order to verify the sensitivity of these sensors, we performed the on-site test using the mock-up switchgears including the artificial defects which were the protrusion on high voltage conductor, free moving metal particle and surface defect on insulator. These mock-up switchgear were installed on the test distribution line.

## 1. 서 론

Determining whether $SF_6$ MV switchgears are suffering from dangerous levels of PD is important because failure without warning can result in damage to neighboring equipment, customer dissatisfaction and disruption to economic activity. Detection of PD in MV switchgear can be seen as a means of anticipating imminent MV switchgear failure, thus saving the cost and time[1].

To detect the UHF PD signal in MV switchgear, we designed and developed internal type UHF PD sensor which was designed based on the spiral antenna theory[2]. The sensor was mounted on the 24kV MV switchgear tank through sensor installation hole, which maintain the gas seal. UHF PD signals from the sensor were amplified using a 20dB gain, 100~2000MHz amplifier and recorded using a commercial spectrum analyzer (Anritsu MS2721A). After a PD data measurement completes, analysis based on the phase resolved PD pattern was processed to distinguish the PD sources (protrusion, free moving particle, floating electrode, insulator defect and noise).

## 2. UHF PD monitoring System

To detect the electromagnetic waves excited somewhere inside the MV switchgear, the internal and the external type UHF PD sensor were used. And using handheld spectrum analyzer, the detected PD signals were analyzed in frequency domain.

Finally, the analysis software which was installed on the notebook computer has been used for spectrum analyzer control, data acquisition, storage and analysis of the measuring data. The basic structure of the UHF PD detection system is shown in Fig. 1. It contains:

1) An internal and an external type UHF PD sensor
2) A spectrum analyzer
3) A notebook computer with the analysis software

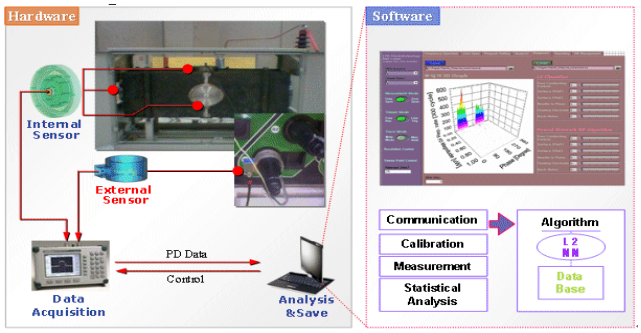
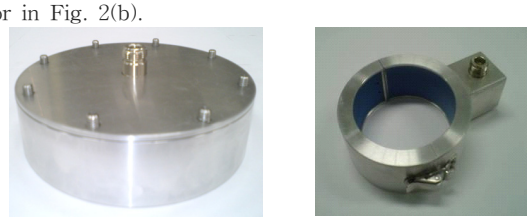



**Fig. 1: Structure of the UHF PD detection system for MV switchgear**

### 2.1 UHF PD sensors for MV Switchgear

In this work, we developed two type UHF sensors. One is the internal type UHF sensor mounted on the MV switchgear enclosure as manufacturing process. This type is highly sensitive and accurate but can't apply to the operating switchgear in Fig. 2(a). The other is able to mount and remove for the operating switchgear as the external type UHF sensor in Fig. 2(b).



(a) Internal type UHF sensor (b) External type UHF sensor

**Fig. 2: The UHF PD sensors for MV switchgear**

### 2.2 Incoming external noise into the switchgear

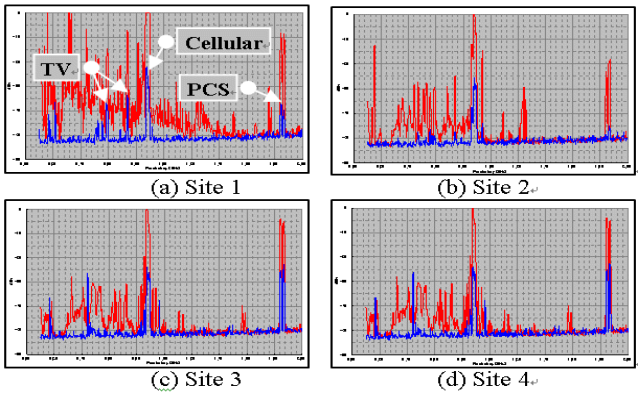



**Fig. 3: The comparison between external noise spectra and incoming noise spectra (Red line: external noise, blue line: incoming noise)**

The measured spectrum at each site is shown in Fig. 3. The detection frequency of this test is in range of 100~2,000MHz and measurement was made in "max-hold"mode over period of about fifteen minutes

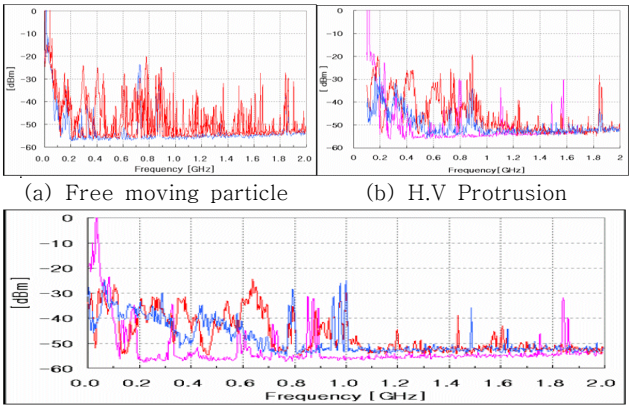
The following frequencies are the major commercial bands: The UHF television transmission (470~750MHz), the mobile phone services Cellular (820~880MHz) and PCS (1.8~1.9GHz), HAM (1.22~1.26GHz), wireless microphone (740MHz). Besides, such frequency bands have strong signal strength. Therefore some frequencies (noise) are able to propagate into the switchgear through bushings and connectors. We have leaved aside such noise band from PD signal analysis.

### 2.3 PD measurement using artificial defects

The main defects in MV switchgear that cause PD signal have been selected a free moving particle, a protrusion and an insulator defect.

In order to verify the reliability of the internal type UHF PD sensor and the risk as a result of PD's incidence, we have installed the internal UHF sensor and the artificial defects in MV switchgears on the test distribution network in July 2006.

Fig. 4 shows examples of frequency spectra detected for each defect.




(a) Free moving particle (b) H.V Protrusion

(c) Insulator defect

**Fig. 4: PD spectra of each artificial defect**

Fig. 4(a) shows a spectrum pattern (Red line) of the free moving particle and the incoming background noise (Blue line) in MV switchgear. Failure pattern by free moving particle has a contingency failure mode without aging process. Fig. 4(b) shows a spectrum of protrusion by using an internal and an external sensor. The pink line was detected using the internal sensor on July 7th 2006 and the red line was measured on the January 17th 2007 after six months. As shown in this result, PD is increased signal of magnitude and occurrence frequency as aging has made steady progress. Blue line is detected signal using external sensor on the January 17th 2007. Like the preceding, insulator defect as shown in Fig. 4(c) is increased signal of magnitude and frequency as aging has made steady progress. The goal of PD monitoring is to predict failures before they occur.

To perform a risk assessment, it is essential to research about relation between PD trend and aging process.

### 2.4 Risk assessment by UHF PD method

If we execute PD measurement in MV switchgear with UHF PD monitoring system, the measurements need to convert this value by apparent discharge pC for correct assessment because dBm is measurement unit of the electromagnetic waves. For this, after insert artificial defect into the mock-up switchgear, generate PD pulse of 10pC, 20pC and 50pC as test voltage is adjusted. And UHF PD signal was detected at frequency bands of 610~630, 1150~1170 and 1300~1320 MHz.

The apparent PD magnitude has been measured with the commercial PD detector (Robinson) and UHF PD spectrum has been simultaneously measured using the spectrum analyzer. First of all, we selected the free moving particle among various defects because more likely to cause accidents and more fatal.

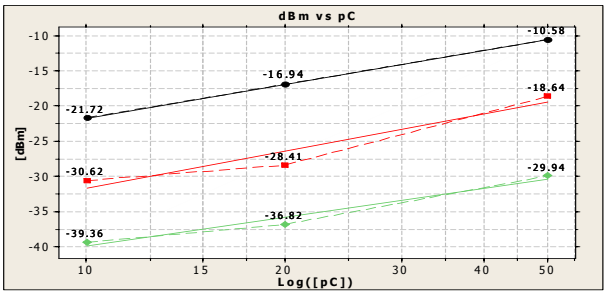



**Fig. 5: Converting graph by regression analysis**

Using test results, we were able to get Fig. 5 and (1). And Tab. 1 is conversion and risk assessment standard table by (1).

$$\begin{aligned} Y\,[\mathrm{dBm}] &= -37.67 + (15.94 \times \log[\mathrm{pC}]) \quad \text{at} \quad 620\,\mathrm{MHz} \\ Y\,[\mathrm{dBm}] &= -49.26 + (17.53 \times \log[\mathrm{pC}]) \quad \text{at} \quad 1170\,\mathrm{MHz} \\ Y\,[\mathrm{dBm}] &= -53.61 + (13.68 \times \log[\mathrm{pC}]) \quad \text{at} \quad 1310\,\mathrm{MHz} \end{aligned} \tag{1}$$

We proposed the risk assessment standard that red zone (more than 100pC) is fault state, orange zone (from 3pC to 90pC) is fault initiation state and yellow zone (less than 2pC) is normal state form Tab. 1.

**Tab. 1: Conversion and risk assessment standard table**

| 620MHz | | 1170MHz | | 1310MHz | |
|---|---|---|---|---|---|
| dBm | pC | dBm | pC | dBm | pC |
| 0 | 231 | | | | |
| -5 | 112 | -5 | 335 | -20 | 286 |
| -6 | 97 | -10 | 174 | -25 | 123 |
| -10 | 54 | -14 | 102 | -26 | 104 |
| -15 | 26 | -15 | 90 | -30 | 53 |
| -20 | 13 | -20 | 47 | -35 | 23 |
| -25 | 6 | -30 | 13 | -40 | 10 |
| -30 | 3 | -40 | 3 | -45 | 4 |
| -35 | 1 | -45 | 2 | -50 | 2 |
| | | | | -55 | 1 |

Here, 2pC which is based on standard of the normal state and fault initiation state is the smallest level that can separate PD signal from noise. And 100pC which is based on standard of fault initiation state and fault state is breakdown level by defects.

## 3. Conclusion

In this study the development of UHF PD detection system and its application are described. The following conclusions can be made on the base of this study.

- ▷ The portable PD detection system for $SF_6$ MV switchgear using UHF method was developed.
- ▷ The external noise spectrum (100~2,000MHz) and incoming noise to MV switchgear were measured.
- ▷ Using this system, the PD detection of the MV switchgear defects is possible. In accordance with the defect type PD spectrum shows the different pattern.
- ▷ The optimal frequency band is selected to detect PD when electromagnetic environment was considered
- ▷ The risk assessment standard is proposed by PD monitoring for MV switchgear.

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