X-Ray Radiation of a 126 kV Vacuum Interrupter

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***Abstract*- X - ray emission occurs between a pair of opened contacts in vacuum interrupters (VIs) while a rated voltage or a power frequency test voltage is applied. Therefore, VIs are considered as sources of stray radiation, which should be controlled by laws and standards. The objective of this paper is to understand what is the X-ray radiation level of a 126 kV vacuum interrupter and an influence of the radiation level by applied power frequency voltage. The X–ray radiation emitted by the 126 kV vacuum interrupter was measured by a FJ347 radiometer with a power frequency voltage applied on the 126 kV vacuum interrupter. The experimental results showed that the dose of X – ray radiation emitted by the 126 kV vacuum interrupter did not exceed the IEC 62271-1 standard requirements 5 μSv in case of a rated voltage at 126 kV and that of 150 μSv in case of a rated power frequency withstand voltage at 230 kV. The mean value of X – ray radiation dose increased from 2.9 μSv to 14.4 μSv and then 29 μSv with the applied power frequency voltage increasing from 126 kV to 150 kV and then 170 kV, respectively when contact gap was 20 mm. The mean value of X – ray radiation dose increased from 0.75 μSv to 3.3 μSv and then 11.5 μSv with the applied power frequency voltage increasing from 126 kV to 150 kV and then 170 kV, respectively when contact gap was 30 mm. During a conditioning course, the X – ray dose reached an average value of 4.49 mSv, which means if a worker conditioned 180 126 kV vacuum interrupters or less in a year, he or she is safe in case of a distance of 6.4 meters away from the conditioned 126 kV vacuum interrupters.**

I. INTRODUCTION

Vacuum circuit breakers are approaching to transmission voltage from their dominant medium voltage level. However, vacuum circuit breakers emit X-ray when a rate voltage or a test power frequency voltage is applied. To prevent X-ray emitted by a vacuum circuit breaker from hurting people while a rated voltage and a corresponding power frequency withstand voltages are applied, an IEC standard [1] gives definitions and limits to an experimental condition and a X-ray emission dose. For example, the limited values required by the IEC standard for 126 kV VIs are: a) 5 μSv/h at 1 m distance at the maximum operating voltage 126 kV. b) 150 μSv/h at 1 m distance at the rated power-frequency withstands test voltage 230 kV. Renz and Gentsch [2] show that the X-ray dose emitted by 7.2~36 kV vacuum circuit breakers are not higher than 1 μSv/h regulated by the COUNCIL DIRECTIVE 96/29/EURATOM [3] in case of applying a rated power frequency withstand voltage from 36 kV to 70 kV at a distance of 0.1 m from a touchable surface. Li et al. [4] show that at a 50% contact gap, a X-ray dose emitted by 12~40.5 kV vacuum circuit breakers are higher than 1 mSv/a regulated by a Chinese national standard [5] for the public in case of applying a rated power frequency withstand voltage from 60 kV to 75 kV in a power frequency voltage conditioning process. It is well known that the higher voltage applied to a VCB, the more X-ray dose is emitted. The objective of this paper is to understand what are the radiation level of a 126 kV vacuum interrupter and the influence of the X-ray radiation level by applied power frequency voltage.

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II. EXPERIMENTAL SETUP

Measuring a X-ray emission dose is a type test for VCBs that is required by the IEC standard [1]. The X-ray dose is also limited by the Chinese national standard [5]. In the Chinese standard an acceptable and effective electromagnetic radiation to a professional is less than 20 mSv/year. Tests on the X-radiation emission levels of 126 kV vacuum interrupters shall be performed on new vacuum interrupters. The purpose of this type test is to verify that whether or not the X-radiation emitted from 126 kV vacuum interrupters exceeds the limited values.

The X-ray radiation dose was measured by using a FJ347 radiometer. The FJ347 radiometer meets the following requirements: energy response from 10 keV to 10 MeV, maximum dose 1000 μSv/h and an accuracy of 10% with a response time less than 8 s, therefore it follows the specifications that required by the IEC standards [1]. The sensing element of the radiation measuring instrument shall be positioned in the intermediate plane of the separated contacts of the tested 126 kV vacuum interrupter. According to the measurement method shown in the IEC standards [1], we measured five 126 kV VIs at an applied power frequency voltage 126 kV and 230 kV, respectively at a contact gap 60 mm. Then, the X – ray radiation of six 126 kV VIs was measured at an applied power frequency voltage of 126 kV, 150 kV and 170 kV, respectively with a contact gap 20 mm and 30 mm, respectively. The 126 kV vacuum interrupters were tested in air with an applied power frequency voltage of 126 kV, 150 kV and 170 kV, respectively. When the

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test voltage was raised to 230 kV, the 126 kV vacuum interrupters were put in an insulator with SF_6 inside to guarantee the external insulation of the vacuum interrupters.

Fig. 1 shows an arrangement of the X-ray radiation measurement of the 126 kV VIs with a X-ray instrument FJ347. Fig. 1 (a) shows a case that the 126 kV VI is put in air to withstand the applied power frequency voltage. Fig. 1 (b) shows the 126 kV VIs are put in a porcelain envelope with SF_6 gas inside as an external insulation of the VIs. According to the IEC standard[1], the radiation measurement instrument is placed on the intermediate plane of contact gap at a distance of 1 meter from the nearest external surface of the 126 kV vacuum interrupter. Fig. 2 shows a photo of the X-ray radiation measurement arrangement.

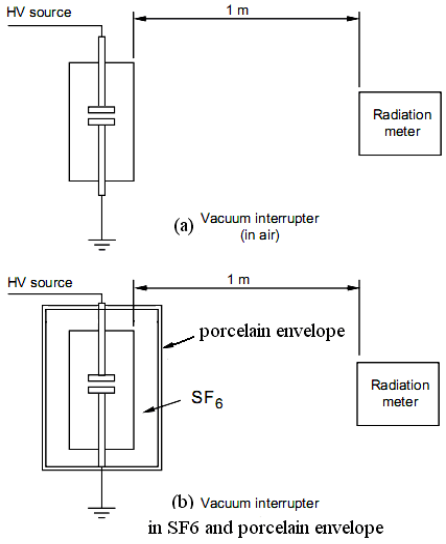


Fig. 1. Arrangement of radiation meter

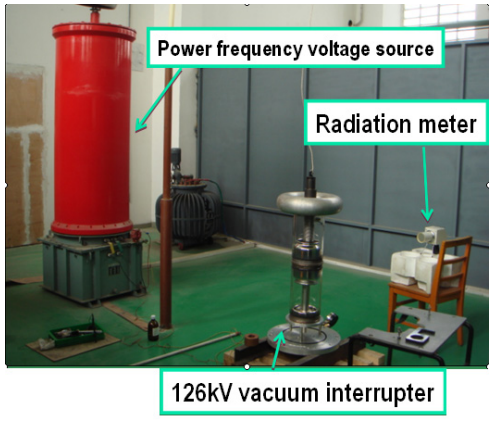


Fig. 2. Picture of measuring X-ray

III. EXPERIMENTAL REESULTS

A. X-ray Radiation Level of 126 kV VIs

The X-ray emission dose of five conditioned 126 kV vacuum interrupters was measured. The results of the tests are shown in Table 1 and Table 2. Table 1 shows that the X-ray dose emitted by five 126 kV vacuum interrupters, which was measured at 1m distance at a power frequency voltage 126 kV in the case of contact gap 60 mm. The dose rate is 3 μSv/h that is less than the threshold value 5 μSv/h regulated by IEC 62271-1[1]. Table 2 shows the X-ray dose emitted by the five 126 kV vacuum interrupters measured at 1 m distance at 230 kV voltage in the case of contact gap 60 mm. The measured dose rate is between 41.4 μSv/h and 148 μSv/h that is less than the threshold value 150 μSv/h regulated by IEC 62271-1 [1].

TABLE 1. THE X-RAY RADIATION DOSE OF 126 kV VACUUM INTERRUPTERS AT AN APPLIED VOLTAGE OF 126 kV

Number	Dose in 3min (μSv)	Dose rate (μSv/h)	threshold value[1] (μSv/h)
1	0.15	3	5
2	0.15	3	5
3	0.15	3	5
4	0.15	3	5
5	0.15	3	5

TABLE2. THE X-RAY RADIATION DOSE OF 126 KV VACUUM INTERRUPTERS AT AN APPLIED VOLTAGE OF 230 KV

Number	Dose in 3min (μSv)	Dose rate (μSv/h)	threshold value[1] (μSv/h)
1	6.27	125.6	150
2	7.40	148.0	150
3	3.70	74.0	150
4	2.07	41.4	150
5	2.35	47.0	150

The X-ray dose emitted by three 126 kV vacuum interrupters during a power frequency voltage conditioning courses was measured. The X-ray dose in six steps during the conditioning courses was shown in Table 3 and Table 4. It is found that the average dose of X-ray radiation emitted by the 126 kV vacuum interrupters during the conditioning courses reached an average value of 4.49 mSv. According to the following calculation

$$d = \sqrt{\frac{4.49mSv \times 180}{20mSv}} = 6.4m \qquad (1)$$

It means if a worker has a distance of 6.4 meters away from the 126 kV vacuum interrupters under conditioning, he or she will be safe (less than 20 mSv/year as regulated by the Chinese standard [5]) if he conditioned 180 or less 126 kV vacuum interrupters in a year.

TABLE3. THE X-RAY DOSE OF SIX STEPS DURING A CONDITIONING COURSE

number	step1(μSv)	step2(μSv)	step3(μSv)
1	3642	2080	59.2
2	667.6	3070.6	224.2
3	2189.4	405.8	192.2

number	step4(μSv)	step5(μSv)	step6(μSv)
1	11.2	100	100
2	48.2	15	22.4
3	512.6	37.4	92

B. Effect of an Applied Voltage

The X-ray dose emitted by six 126 kV vacuum interrupters was measured by the radiation instrument FJ347 at 1 m distance from the surface of the vacuum interrupters at a power frequency withstand test voltage 126 kV, 150 kV and 170 kV, respectively. The contact gap was 20 mm and 30 mm, respectively. The duration of X-ray dose measuring lasts 3 minutes. The results of the tests are shown in Fig. 3. Fig. 3 (a) shows the case of contact gap 30 mm and Fig. 3 (b) shows the case of contact gap 20 mm. It can be found that the variation of X-ray dose increases with an increase of power frequency voltage from 126 kV to 150 kV and 170 kV.

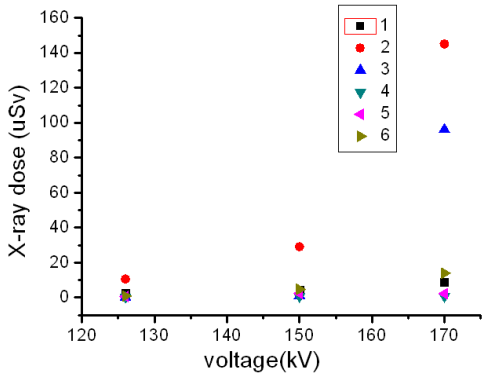
Fig. 4 shows the mean value of the X-ray dose emitted at the contact gap 30 mm and 20 mm, respectively. It shows that the mean value of X – ray radiation dose increased from 0.75 μSv to 3.3 μSv and then 11.5 μSv with the applied power frequency voltage increasing from 126 kV to 150 kV and then 170 kV, respectively when contact gap was 30 mm. The mean value data follows the equation

$$H = 3.0\times10^{-6}\cdot U^{4}\cdot e^{-916.9/U} \qquad (2)$$

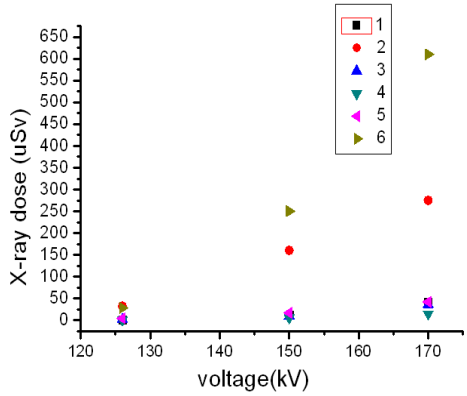
Where H (μSv) is the X-ray dose data emitted and U (kV) is the power frequency voltage applied. Fig4 also shows that the mean value of X – ray radiation dose increased from 2.9 μSv to 14.4 μSv and then 29 μSv with the applied power frequency voltage increasing from 126 kV to 150 kV and then 170 kV, respectively when contact gap was 20 mm. The mean value data follows the equation

$$H = 3.6\times10^{-6}\cdot U^{4}\cdot e^{-724.6/U} \qquad (3)$$

Therefore, the X-ray dose emitted at the contact gap 20 mm is significantly higher than that of contact gap 30 mm.



(a) Contact gap 30 mm



(b) Contact gap 20 mm

Fig. 3. The X-ray dose at power- frequency voltage 126 kV, 150 kV and 170 kV

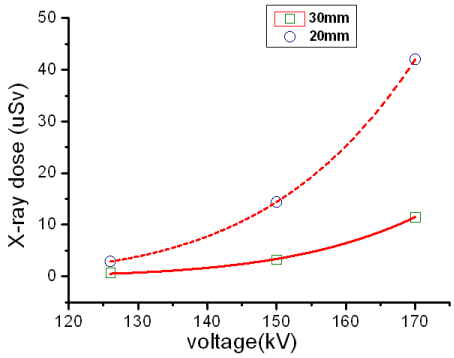


Fig. 4. Fitting curves of mean values of X-ray dose emitted at power frequency voltage from 126 kV to 150 kV and 170 kV at contact gap 20 mm and 30 mm

IV. CONCLUSION

The X-ray dose emitted by 126 kV vacuum interrupters measured at 1 meter distance at a rated voltage 126 kV in case of rated contact gap 60 mm is 3 μSv/h that is less than 5 μSv/h regulated by IEC 62271-1. The X-ray dose emitted by 126 kV vacuum interrupters measured at 1 meter distance at power frequency withstanding voltage 230 kV in case of rated contact gap 60 mm is between 41.4 μSv/h and 148 μSv/h that is less than 150 μSv/h (IEC 62271-1). During a normal conditioning course (see Table 3) for the 126 kV VI, the X–ray dose reached an average value of 4.49 mSv, which means if a worker conditioned 180 126 kV vacuum interrupters or less in a year, he or she is safe in case of a distance of 6.4 meters away from the conditioned 126 kV vacuum interrupters. The relationship between the X-ray dose H emitted by the 126 kV VIs and the applied voltage U was approximated by $H = \mathrm{a}\cdot U^{4}\cdot e^{\mathrm{b}/U}$.

ACKNOLEDGMENT

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