Effects of Grading Ring Design Parameters and Heat Sink Numbers on voltage Distribution and Leakage Current in Metal Oxide Surge Arrester

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Abstract: Metal oxide surge arresters (ZNO) are used widely in power system to protect equipments from over voltages. Non uniform potential distribution leads to the depressed service life and low safe reliability, so grading ring is applied on HV surge arrester order to uniform the electric field distribution. One of the problems of arresters is leakage current in power frequency that different parameters such as internal structure of varistors, heat sinks, grading ring can be influence on leakage current.

In this paper Maxwell and EMTP/ATP software has been applied to calculate the electric field, voltage distribution and leakage current in a high voltage surge arrester. First Maxwell is used to calculate the electric field and voltage distribution of a 230kV surge arrester with and without grading ring. Then equivalent circuit of surge arrester has been achieved by applying Maxwell software for 230kV surge arrester and extracting stray capacitances. The derived equivalent circuit has been simulated in EMTP/ATP software for evaluation of leakage current. Also in this work, the effect of grading ring dimensions and number of heat sinks on leakage current variation has been investigated. Results show grading ring dimension and heat sinks number impact on arrester leakage current.

Keywords: grading ring, surge arrester, total leakage current, resistive leakage current, voltage distribution

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1 Introduction

Metal oxide surge arresters are widely used as protective device for protection of electrical device against switching and lightening overvoltage. The physical construction of modern light surge arrester consists of metal oxide discs stacked up inside a porcelain or polymer insulator. The function as high impedances at normal operating voltage and becomes low impedances during surge condition. The electrical characteristics are determined by the properties of the metal oxide discs, which would degrade due to the power frequency operating voltage applied continuously. The degradation of the arrester is determined by the potential distribution of arrester [1-3].

Several different types of arresters are available [e.g. gapped silicon carbide (sic), non-gapped metal oxide (MO)]. The arresters installed today are almost MO arrester without gaps. This kind of arrester has been used more and more, due to high energy absorption capability and highly nonlinear V-I characteristic of ZNO discs that allow the arresters project without gaps [1].

Metal oxide surge arresters are continuously stressed at the system voltage, this leads to small leakage current flowing through the arrester elements. This current is the range several microampere to several tens of microamperes. Under steady state conditions the total leakage current is composed of a large capacitive component and a small resistive component, which lead to consider that the voltage distribution is mainly determined by the arrester capacitances [4].

In MOA, the ZNO discs placed near HV electrode, are highly stressed by excessive electric fields existed in vicinity the HV electrode. In the other words, the electric field distribution is non-uniform along the axis of MOVs that causes to a faster aging of the varistors placed near the HV electrode. The grading ring is a well known means to uniform the voltage distribution along the arresters, so in high voltage surge arresters installed these rings near the HV electrodes for improving voltage distribution but this ring may influence of total leakage current through surge arrester [5-10].

In this paper through applying the Maxwell software, electric field distribution and potential distribution of 230KV surge arrester (built in pars arrester Co.) with and without grading ring is studied. In addition, the influence of spacer numbers and grading ring design parameters on voltage distribution are also discussed. The 3-D Maxwell is used to obtain the MOA's stray capacitances to utilize in the equivalent circuit of the MOA. With the equivalent circuit, the influence of grading ring parameters and spacer numbers on leakage current variation is analyzed.

2 Technical information of 230kv ZNO surge arrester

Table 1 represents the surge arrester technical information consisting of 36 ZNO discs being divided to 9 equal sections so that one alumina spacer (heat sink) between every part is contrived. Figure1 shows the geometry model of 230KV arrester simulated in Maxwell software for evaluation of voltage and field distribution.

Table 1 Arrester technical information

rated voltage	198KV
Continuous operating voltage	158KV
ZNO height	44mm
ZNO diameter	58mm
Total width of arrester	2205mm
Internal diameter of insulator	140mm
Max. diameter of insulator	343mm
Capacitive current	1.1mA
Resistive current	0.1mA

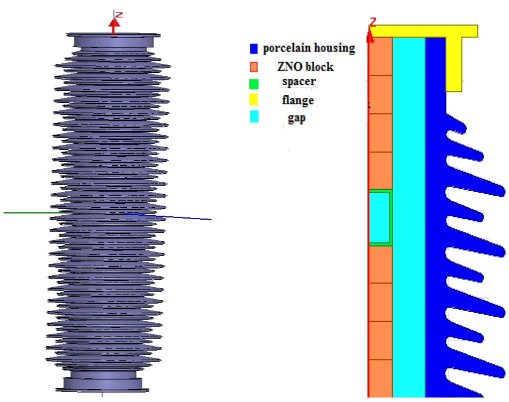


Fig. 1 Geometry model of 230KV arrester in Maxwell software

3 Maxwell voltage and electric field simulation results

Figs. 2-4 show voltage distribution, voltage drop between every two spacers, and electric field along the surge arrester with and without grading ring respectively. It can be observed that potential distribution without grading ring is too non-uniform and maximum voltage drop in ZNO disc near upper flange is 7.05%. It is also noticeable that the maximum voltage drop reduces using grading ring to 3.46%. Therefore installation of grading rings on the top flange can partially compensate the influence of stray capacitors, improving the voltage distribution and thus reducing the voltage difference. So results show clearly positive effect of grading ring on uniformity of voltage and field distributions on arrester.

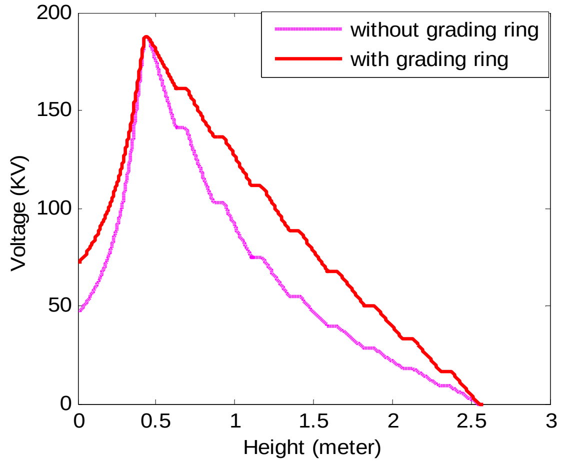


Fig. 2 axial Voltage distribution of 230KV surge arrester with and without grading ring

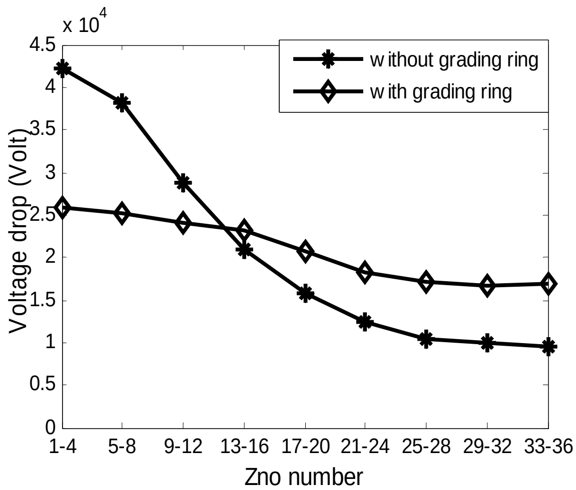


Fig. 3 Voltage difference of 230KV surge arrester with and without grading ring

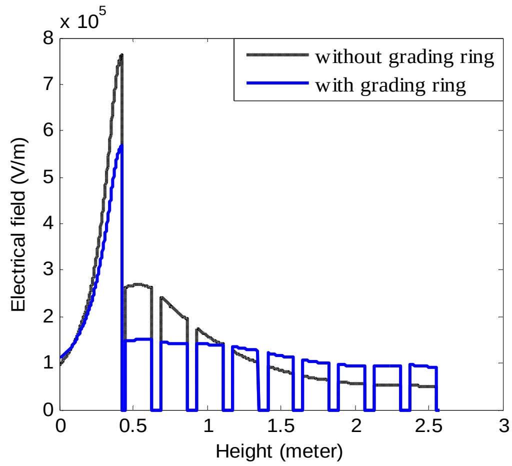


Fig. 4 Field distribution of 230KV surge arrester with and without grading ring

Fig. 5 shows the electrical field along the line touching the shed edge of the 230KV surge arrester. It is clear that grading ring creates a great improvement in the electric field distribution of sheds edge.

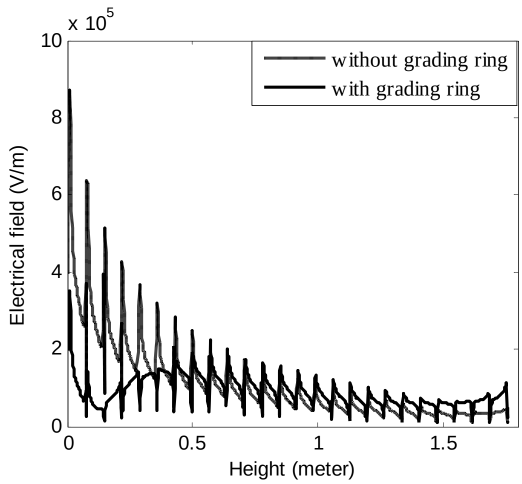


Fig. 5 Electrical field at the edge shed of the surge arrester

4 Effect of grading ring design parameters on voltage distribution

The installation height and structural size parameters are shown in Fig. 6 in which r and D are inner and outer radius of grading ring respectively and h is its relevant height than to the down flange. According to the Pars Switch Co. information for this kind of arrester r, D and h are 32.5, 425 and 1724 mm, respectively. In this section the effect of these parameters on surge arrester voltage distribution is investigated.

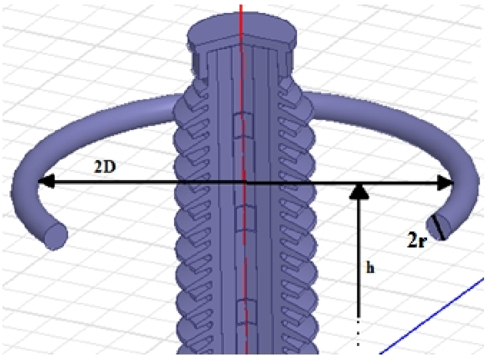


Fig. 6 The installation locations and structural size parameters of surge arrester

Fig.7 represents outer radius (D) effect on voltage difference between any two adjacent spacers. It is clear that increasing outer radius causes voltage distribution to improve. It should be noted that excessive increasing of outer radius is not economical and it must be chosen within the acceptable range considering construction constraints.

Fig. 8 Shows grading ring height (h) effect on voltage distribution between any two spacers. Changing ring installation height will affect voltage distribution and the lower installation height (down to about 1724 mm) causes more voltage distribution improvement.

Fig. 9 represents inner radius (r) effect on voltage difference between any two adjacent spacers. It is clear that increasing inner radius causes voltage distribution to improve.

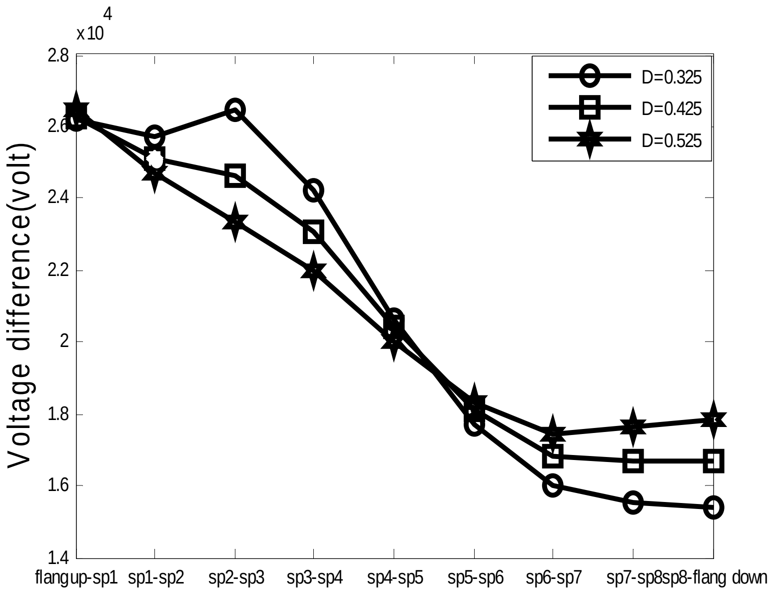


Fig.7 Radius effect on voltage difference between any two adjacent spacers

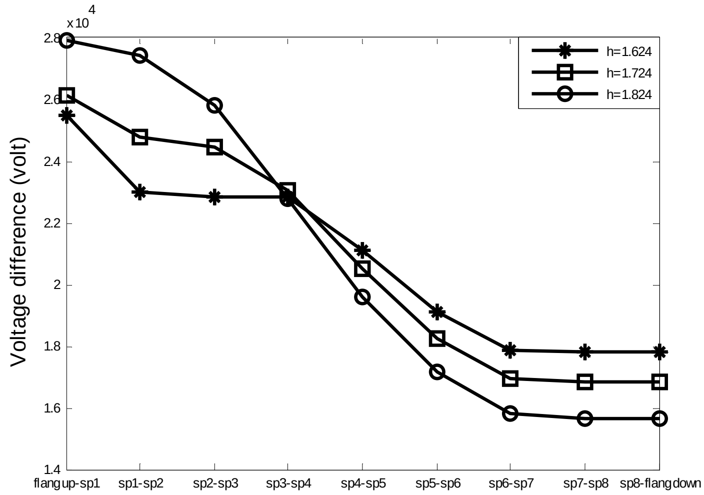


Fig. 8 Height effect on voltage difference between any two adjacent spacers

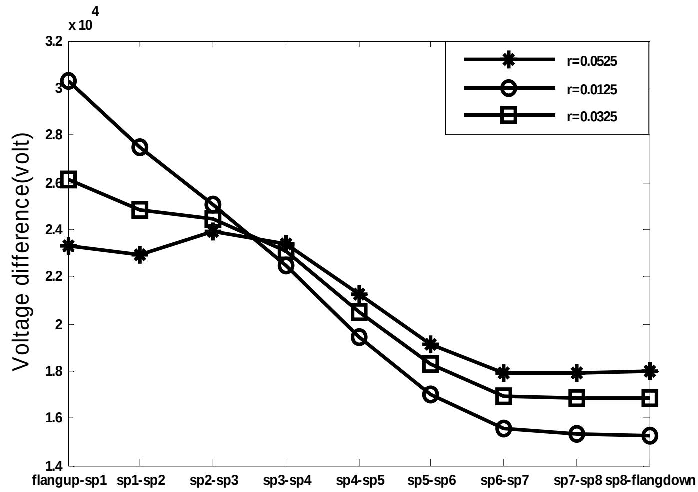


Fig. 9 Inner radius effect on voltage difference between any two adjacent spacers

So given the above results, the effects of grading ring parameters on voltage distribution are evident. Therefore in Surge arrester design, the impact of these parameters must be considered. Pars arrester co for this kind of arrester chooses r=32.5mm, D=425mm and h=1724mm, which seems to be a good choice according to the represented results and manufacturing constraints.

5 The effect of Spacers location on voltage difference

As we know the height of the porcelain housing is dependent on the voltage rating of the arrester and the environmental pollution conditions. Thus for given voltage rating, the total height of the discs will be less than the height of housing and hence metal spacers are employed to constitute the extra height. The number and location of spacers on voltage distribution may be effective, so the influence of these factors on voltage difference would be investigated. Five different locations for spacers are considered.

Case1. One spacer between every three ZNO blocks (totally 12 spacers) is considered.

Case2. One spacer between every four ZNO blocks (totally 9 spacers) is considered.

Case3. One spacer between every five ZNO blocks (totally 8 spacers) is considered.

Case4. One spacer between every six ZNO blocks (totally 6 spacers) is considered.

Case5. One spacer between every seven ZNO blocks (totally 6 spacers) is considered.

Table (2) shows spacer numbers affect on surge arrester maximum voltage difference. Results show that maximum voltage distribution is changed by changing the number of spacers. In comparison with other cases, when one spacer between every four ZNO blocks exists, voltage difference is low.

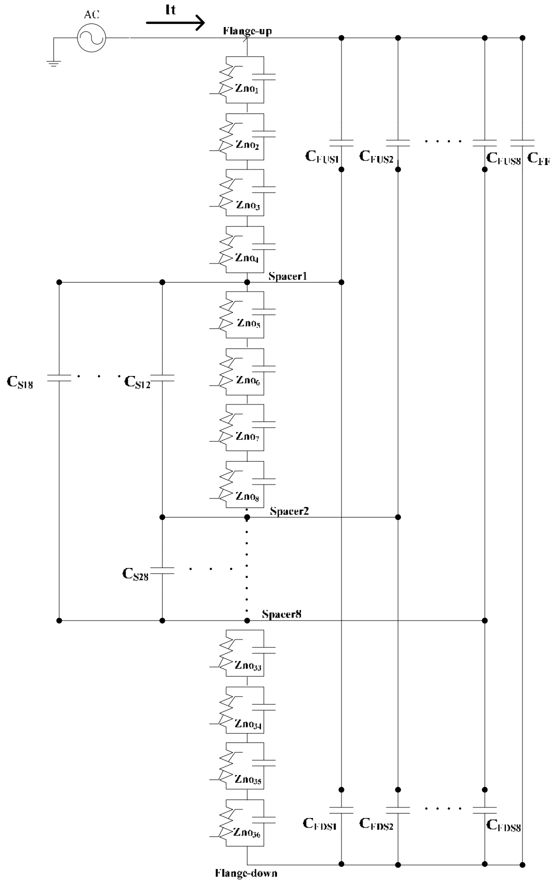
Table 2 Effect of the number of spacers on surge arrester leakage current

Spacers number	Maximum voltage difference (volt)
Case1	6565
Case2	6492
Case3	13060
Case4	11400
Case5	11100

6 Studying surge arrester leakage current

As previously mentioned one of the problems of ZNO surge arresters is leakage current under continuously operating voltage. By considering of V-I characteristic of ZNO block, this current consists of a large capacitive component and a small resistive component. The capacitance of each element can be determined approximately in proportion with the geometry and permittivity of each element. In order to calculate the leakage current the 3-D Maxwell is used to obtain the MOA’s stray capacitances to utilize in the equivalent circuit of the MOA simulated in EMTP-ATP software. In this software total leakage current, capacitive current and resistive current of the surge arrester with and without grading ring was simulated and studied.

Fig. 10 represents circuit model of surge arrester depicted in EMTP-ATP software. Each ZNO block is modeled with a nonlinear resistance in parallel with a capacitance. 36 ZNO discs were divided into 9 sections and between each section there is one spacer.



C_{Sij} (i=1,2,…,8 j=1,2,…,8 i≠j): capacitance between the two spacer

C_{FUSi} (i=1, 2… 8): Capacitance between the upper flange and the spacers

C_{FF}: Capacitance between upper and lower flange

C_{FDSi} (i=1, 2… 8): Capacitance between lower flange and the spacers

Fig. 10 Circuit model of surge arrester

6.1 Studying surge arrester leakage current without grading ring

The purpose of this section is surge arrester leakage current studying via EMTP-ATP circuit model. To validate the accuracy of the circuit model, Fig. 11 shows voltage distribution of circuit model in EMTP-ATP and Maxwell software. It is obvious that voltage distribution of the circuit model (derived via EMTP-ATP software) is the same as voltage distribution in Maxwell software, indicating that applied circuit model is an accurate model of studied surge arrester.

Fig. 12 represents total leakage current, capacitive and resistive components of surge arrester leakage current without grading ring. According to this figure maximum amplitudes of total leakage current capacitive and resistive components are 1.152, 1.14 and 0.109 mill amperes respectively. This result is similar to pars arrester co information (see table1).

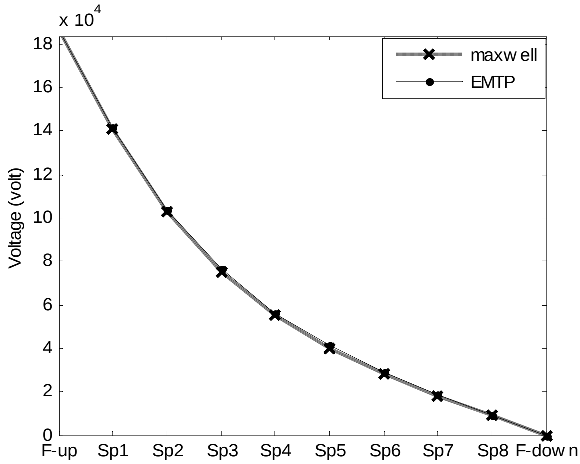


Fig. 11 Voltage distribution of circuit model and Maxwell software

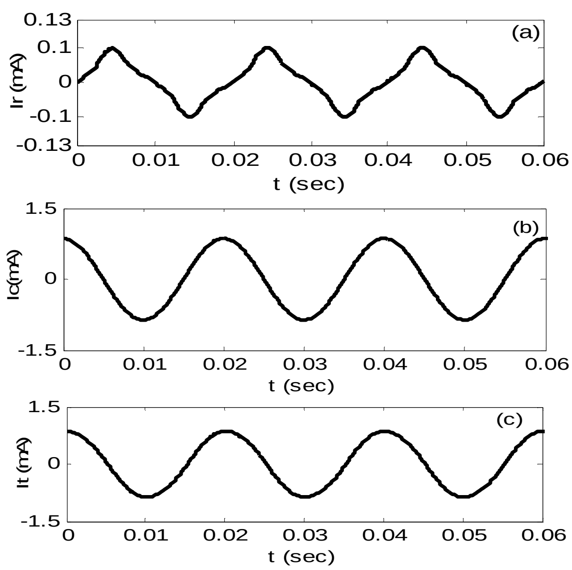


Fig. 12 Surge arrester leakage current without grading ring
(a). Resistive current (b). Capacitive current (c). Total leakage current

6.2 Effect of grading ring on leakage current of surge arrester

The effect of grading ring on leakage current changes in circuit model is investigated. For the sake of investigation of the circuit model accuracy, voltage distribution obtained from EMTP-ATP and Maxwell software is compared in fig. 13. It is obvious that voltage distribution of the circuit model

(EMTP-ATP software) is the same as Maxwell voltage distribution. Fig. 14 represents total leakage current, capacitive and resistive components of surge arrester with grading ring. According to figure maximum amplitudes of total leakage current and capacitive and resistive components are 2.378, 2.376 and 0.04049 mill amperes respectively.

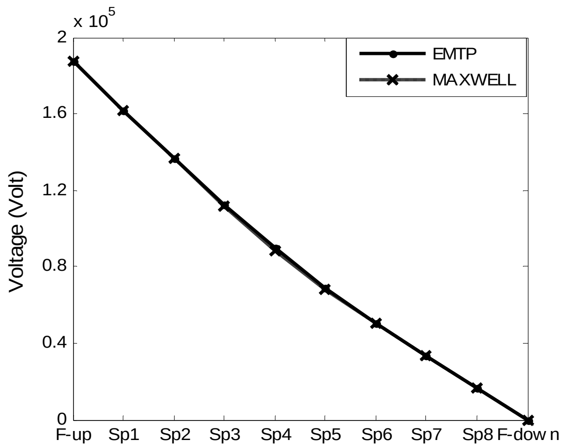


Fig. 13 Voltage distribution of circuit model and Maxwell software

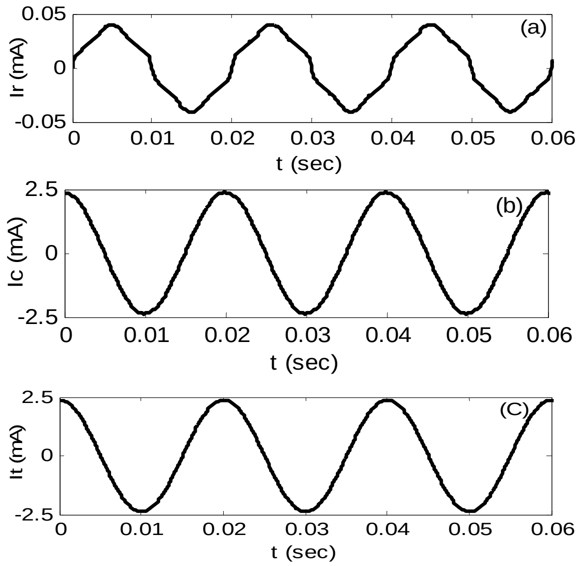


Fig. 14 Surge arrester leakage current with grading ring
(a). Resistive current (b).Capacitive current (c). Total leakage current

6.3 Effect of grading ring position on leakage current

Table (3) shows the influence of outer radius on surge arrester leakage current variation. Results show increasing outer radius not only improves potential distribution but also decreases resistive leakage current and increases total leakage current. The resistive current increase causes varistor temperature to boast and thus leads to degradation or damage of the arrester.

Table 3 Radius effect on surge arrester leakage current

Outer radius (m)	It (mA)	Ir(mA)
0.525	2.7425	0.038856
0.425	2.3752	0.04049
0.325	2.0691	0.042612

Table 4 represents mounting height affect on surge arrester leakage current. It is obvious that high installation height increases resistive leakage current and decreases total leakage current. So the low installation height is effective, because improves voltage distribution and decreases resistive leakage current.

Table 4 Installation height effect on surge arrester leakage current

Installation height (m)	It (mA)	Ir (mA)
0.774	2.3633	0.042612
0.674	2.3752	0.04049
0.574	2.4544	0.03739

Table 5 shows the influence of inner radius on surge arrester leakage current variation. Results show that increasing inner radius not only improves potential distribution but also decreases resistive leakage current and also increases total leakage current. High resistive current increases power losses and varistors temperature so it leads to degradation or damage of the arrester. So larger radius is better, Note that increasing radius must be within the acceptable range of engineering.

Table 5 Installation height effect on surge arrester leakage current

Inner radius (m)	It (mA)	Ir (mA)
0.0525	2.604	0.037627
0.0325	2.3752	0.04049
0.0125	2.1484	0.04462

6.4 The effect of Spacers number on surge arrester leakage current variation

For investigating spacers influence on surge arrester leakage current five different locations are considered:

Case1. One spacer between every three ZNO blocks (totally 12 spacers) is considered.
Case2. One spacer between every four ZNO blocks (totally 9 spacers) is considered.
Case3. One spacer between every five ZNO blocks (totally 8 spacers) is considered.
Case4. One spacer between every six ZNO blocks (totally 6 spacers) is considered.
Case5. One spacer between every seven ZNO blocks (totally 6 spacers) is considered.

Table 6 shows spacer numbers affect on surge arrester leakage current. Results show that the leakage current changes as the numbers of spacer vary. In comparison with other cases, when one spacer exists between four ZNO blocks, total and resistive leakage currents are low.

7 Conclusion

In this paper the grading ring influence on voltage distribution and electric field in 230KV surge arrester was studied. Results show significant effect of this ring on potential and field regulation so that grading ring maximum voltage drop changes from 22.4% to 13.7%.

Table 6 Effect of spacer numbers on surge arrester leakage current

Spacers number	It (mA)	Ir (mA)
Case1.	2.4412	0.040611
Case2.	2.3752	0.04049
Case3.	2.4125	0.040937
Case4.	2.4185	0.0403
Case5.	2.4221	0.0521

In order to study grading ring effect on leakage current, stray capacitances of the metal oxide arrester applying Maxwell software, which would be used to simulate the equivalent circuit of the metal oxide arrester in EMTP-ATP software, were extracted.

Results show that variation of grading ring design parameters changes total leakage current and its components. The presence of ring increases total leakage current and capacitive component but decreases resistive current. This reduction in resistive amplitude is due to decreases in voltage drop in ZNO disc near the upper flange. Because lower voltage at ZNO disc causes that this nonlinear disc works in the region with low resistive current.

As we know, to cool and fill ZNO column space, spacer between ZNO blocks are used. The numbers of spacers can be effective on the leakage current, so the influence of number and location of spacers on leakage current was investigated. Furthermore, five different locations for spacers were considered. Results are reasonable and good, applying one spacer between every four ZNO block (case1.).

References

[1] Carlos. A. D. & Rafael A. R., "Surge arresters" *IEEE, Potentials*. 1996.

[2] Christodoulou, C.A.; Avgerinos, M.V.; Ekonomou, L.; Gonos, I.F.; Stathopulos, I.A, "Measurement of the resistive leakage current in surge arresters under artificial rain test and impulse voltage subjection", *IET journals, Science, Measurement & Technology*, Volume. 3, Issue. 3, Page(s). 256 – 262, 2009.

[3] Richard J.Hollman and Donald V.Heirman and Judith Gorman, "Overvoltage protection and insulation coordination in power systems" *IEEE std 1313-1999, IEEE Guide for the Application of Insulation coordination*.

[4] Bok-Hee Lee, Sung-Man Kang, "A new on-line leakage current monitoring system of ZnO surge arresters Original Research", *Article Materials Science and Engineering.* B, Volume 119, Issue 1, Pages 13-18, May. 2005.

[5] K.feser et at, “Behavior of zinc oxide surge arresters under pollution”, *IEEE Trans. on power Delivery*, Vol.6, No.4,pp 688-695, April 1991.

[6] Xie, Lingdong; Zheng, Jianchao; Li, Zhiqi; Dong, Wei; Zha, Kun Peng; Tang, Guangfu, “Optimization of grading ring design for a new UHV equipotential shielding capacitor voltage transformer”, *IEEE Conference on* Electrical Insulation and Dielectric Phenomena pp 748 – 751, 2011.

[7] He, J.; Hu, J.; Gu, S.; Zhang, B.; Zeng, R, “Analysis and Improvement of Potential Distribution of 1000-kV Ultra-High-Voltage Metal–Oxide Arrester”, *IEEE Transactions on Power Delivery*, Volume. 24, Issue. 3, pp 1225-1233, 2009.

[8] Jinliang He, Rong Zeng, Shuiming and Zhicheng Guan, “Potential distribution analysis of suspended-type Metal-oxide surge arresters”, *IEEE Transactions on Power Delivery*, Vol.18, No.4, pp 1214-1220, October 2003.

[9] Kumar U. and Mogaveera V, “Voltage distribution studies on Zno arresters”, *IEE Proc.-Gener. Transm. Distrib*., Vol.149, No.4, pp 457-462, July. 2002.

[10] Alame N. and Melik G., “Axial voltage and gradient distribution of metal oxide surge arresters”, *Proceedings of the 3rd International conference on properties and applications of dielectric materials*, Tokyo, Japan, pp.1149-1151, July. 1991.