Analysis of Grading Ring Design Parameters and Heat Sink Numbers Effect on Voltage Distribution and Leakage Current in Metal Oxide Surge Arrester

M. Khodsuz* and M. Mirzaie*(C.A.)

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 230 kV surge arrester with and without grading ring. Then equivalent circuit of surge arrester has been achieved by applying Maxwell software for 230 kV 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.

1 Introduction

Metal oxide surge arresters are widely used as protective device for protection of electrical device against switching and lightning 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].

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In this paper through applying the Maxwell software, electric field distribution and potential distribution of 230 kV surge arrester (built in pars arrester Co.) with and without grading ring is studied. Such investigation has been done on insulators to study voltage and electrical field distribution [11-12]. In [13] several 230 kV insulator strings with different porcelain and glass units were simulated using 3-D FEM based software, and their electric fields and voltage distributions were calculated and compared together, to investigate the effect of insulator types on these quantities.

Also, in this paper 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 spacers numbers on leakage current variation is analyzed.

2 Technical Information of 230 kV 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. Fig. 1 shows the geometry model of 230 kV arrester simulated in Maxwell software for evaluation of voltage and field distribution.

3 Maxwell Voltage and Electric Field Simulation Results

Fig. 2 shows electric field along the surge arrester with and without grading ring respectively. Fig. 3 shows the electrical field along the line touching the shed edge of the 230 kV surge arrester. According to the figures grading ring creates a great improvement in the electric field distribution in surge arrester. In fact installation of grading ring on the upper flange can partially compensate the influence of stray capacitors and modify electric field distribution.

Table 1 Arrester technical information.

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

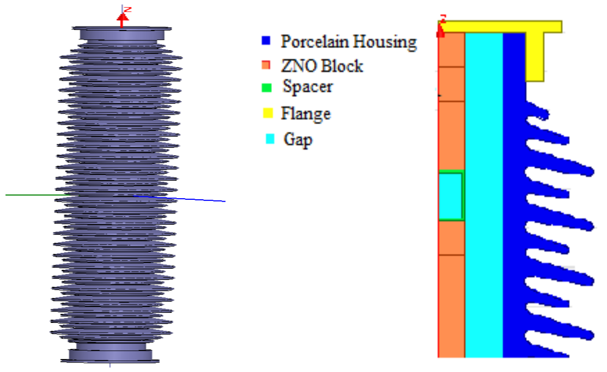


Fig. 1 Geometry model of 230 kV arrester in Maxwell software.

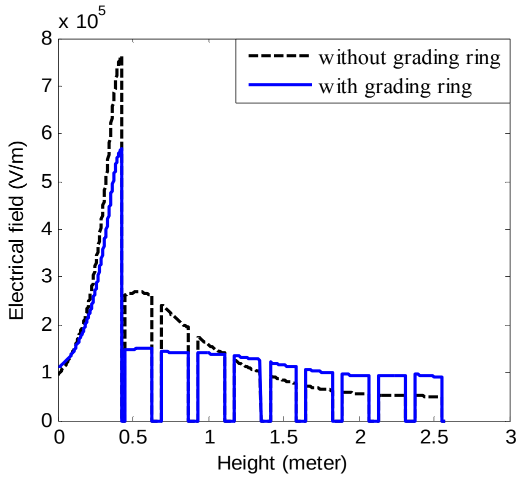


Fig. 2 Field distribution of 230 kV surge arrester with and without grading ring.

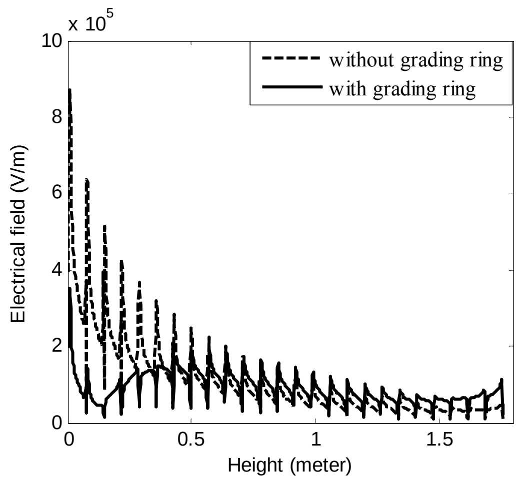


Fig. 3 Electrical field at the edge shed of the surge arrester.

Figs. 4 and 5 show voltage distribution, voltage drop between every two spacers. 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%.

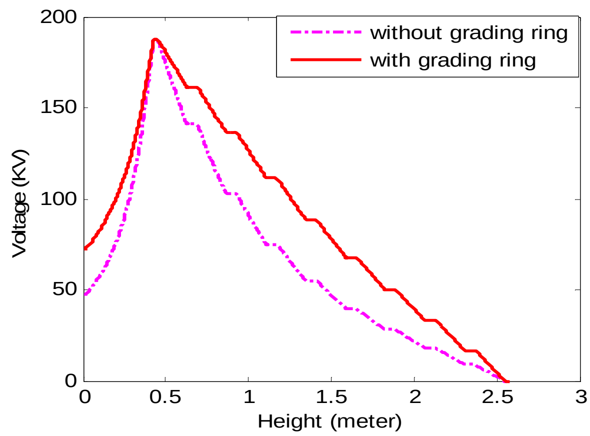


Fig. 4 axial Voltage distribution of 230 kV surge arrester with and without grading ring.

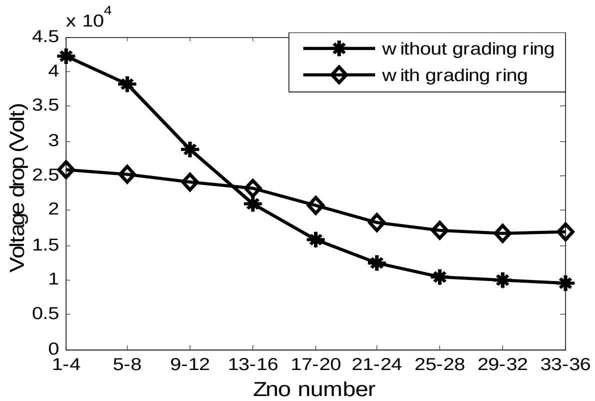


Fig. 5 Voltage difference of 230 kV surge arrester with and without grading ring.

It is also noticeable that the maximum voltage drop reduces to 3.46% when grading ring is used. So the existence 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. Therefore results show positive effect of grading ring on uniformity of voltage distribution.

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. 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. 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. 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 = 32.5 mm, D = 425 mm and h = 1724 mm, 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 it is known, the height of surge arrester housing depends to the rated voltage of surge arrester and the environmental pollution conditions. If total height of the discs will be less than the height of housing, 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.

Case 1. One spacer between every three ZNO blocks (totally 12 spacers) is considered.

Case 2. One spacer between every four ZNO blocks (totally 9 spacers) is considered.

Case 3. One spacer between every five ZNO blocks (totally 8 spacers) is considered.

Case 4. One spacer between every six ZNO blocks (totally 6 spacers) is considered.

Case 5. One spacer between every seven ZNO blocks (totally 6 spacers) is considered.

Table 2 shows spacer numbers affect on surge arrester maximum voltage difference. Because of the influence of Spacers location on stray capacitances, 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 [V]
Case 1	6565
Case 2	6492
Case 3	13060
Case 4	11400
Case 5	11100

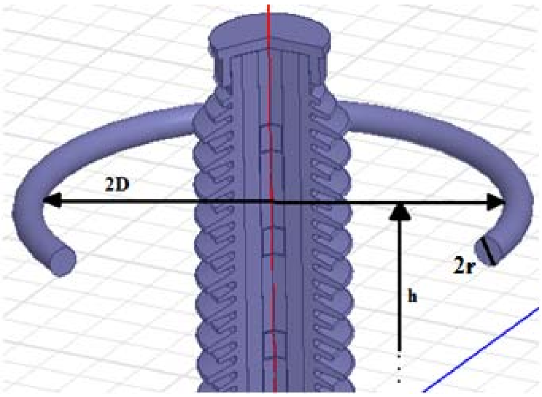


Fig. 6 the installation locations and structural size parameters of surge arrester.

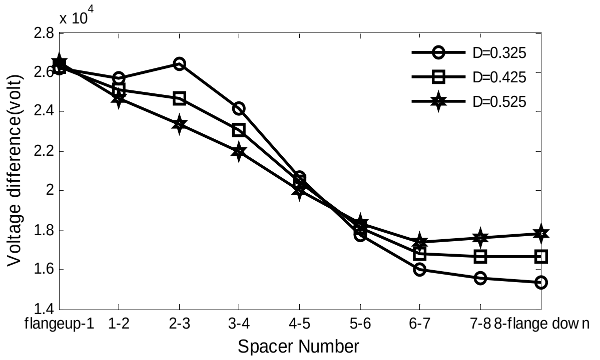


Fig. 7 Radius effect on voltage difference between any two adjacent spacers.

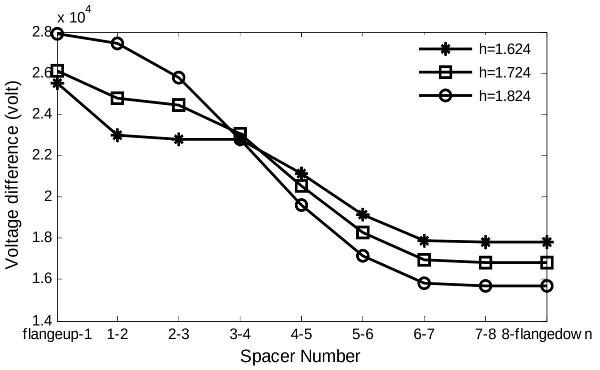


Fig. 8 Height effect on voltage difference between any two adjacent spacers.

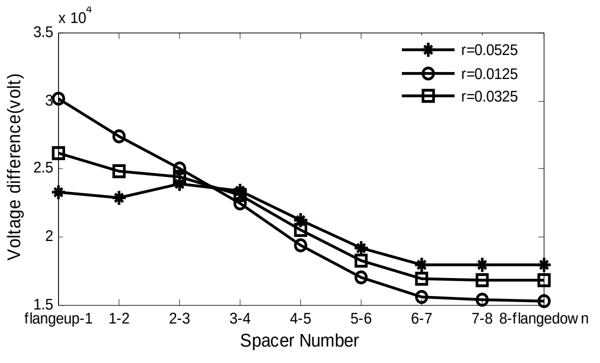


Fig. 9 Inner radius effect on voltage difference between any two adjacent spacers.

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. One of the capabilities of Maxwell software is to calculate stray capacitances. So the MOA's stray capacitances between spacers and flanges, upper flange and down flange, spacers and spacers , flanges and spacers and also ZNO blocks capacitances are extracted. 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 an extracted capacitance. Nonlinear resistive characteristic of ZNO block is adopted from IEC 60099 [14]. 36 ZNO discs were divided into 9 sections and between each section there is one spacer. In this software total leakage current, capacitive current and resistive current of the surge arrester with and without grading ring was simulated and studied.

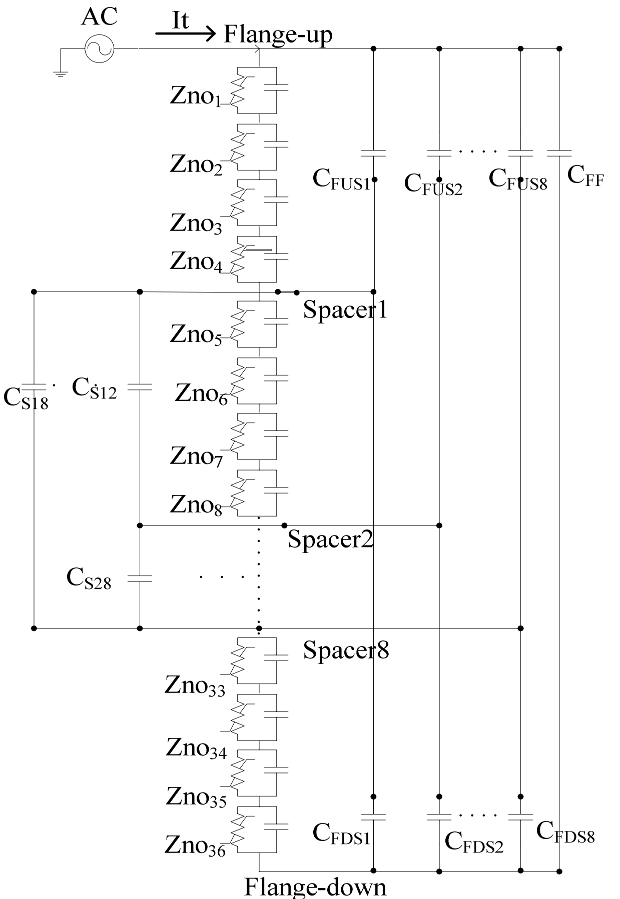
6.1 Studying Surge Arrester Leakage Current without Grading Ring

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 proposed circuit model is an accurate and suitable model for 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 Table 1).

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, capacitive and resistive components are 2.378, 2.376 and 0.04049 mill amperes respectively.



C_{Sij} (i=1,2,…,8 j=1,2,…,8 i≠j): capacitance between the two spacer	C_{FF}: Capacitance between upper and lower flange
C_{FUSi} (i=1, 2… 8): Capacitance between the upper flange and the spacers	C_{FDSi} (i=1, 2… 8): Capacitance between lower flange and the spacers

Fig. 10 Circuit model of surge arrester.

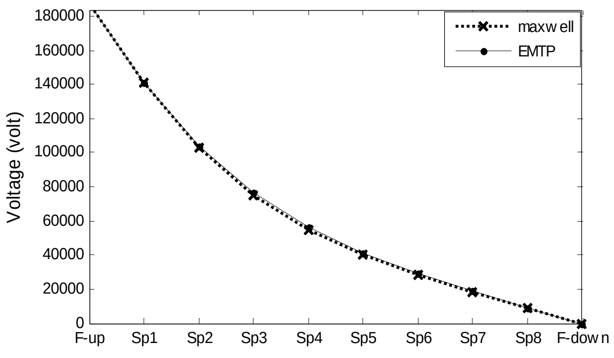


Fig. 11 Voltage distribution of circuit model and Maxwell software.

Results show that grading ring due to voltage regulation increases capacitive current. Since the majority of the total leakage current is capacitive current thus total leakage current increased. In presence of grading ring, voltage difference on above ZNO discs close to high voltage electrode is dropped when compared to its value without the existence of grading ring. It is clear from the results that resistive current has reduced. Grading ring causes voltage regulation and reduces voltage drop on ZNO disc (especially above ZNO block). Thereby, according to the nonlinear characteristic of ZNO block, resistive leakage current reduces.

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.

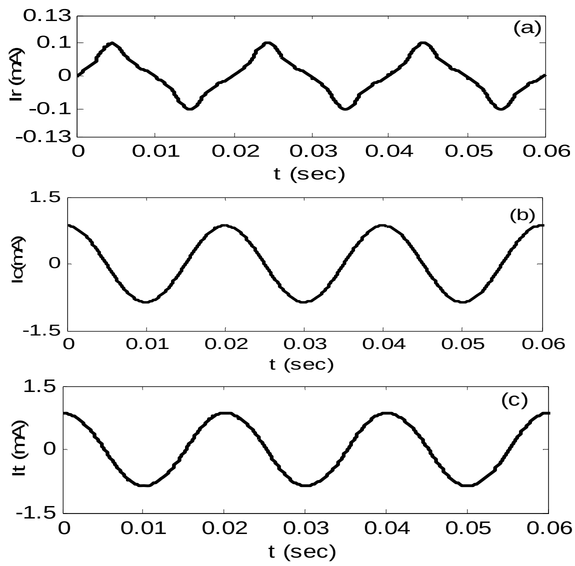


Fig. 12 Surge arrester leakage current without grading ring (a) Resistive current (b) Capacitive current (c) Total leakage current.

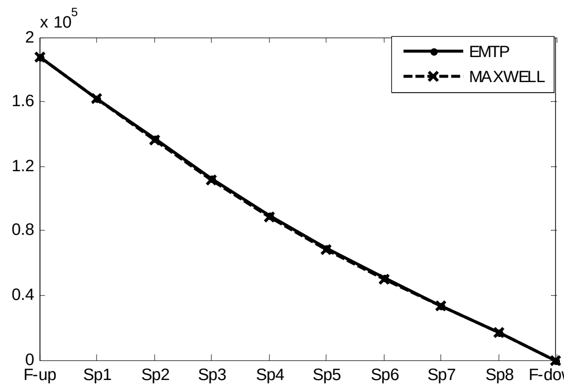


Fig. 13 Voltage distribution of circuit model and Maxwell software.

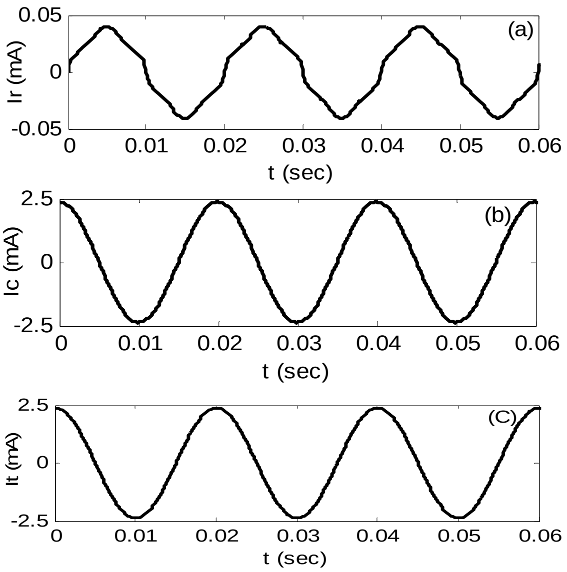


Fig. 14 Surge arrester leakage current with grading ring (a) Resistive current (b)Capacitive current (c) Total leakage current.

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 it can improve voltage distribution and decreases resistive leakage current. Lower leakage current is desirable and causes lower accession of surge arrester temperature.

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.

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:

Case 1. One spacer between every three ZNO blocks (totally 12 spacers) is considered.

Case 2. One spacer between every four ZNO blocks (totally 9 spacers) is considered.

Case 3. One spacer between every five ZNO blocks (totally 8 spacers) is considered.

Case 4. One spacer between every six ZNO blocks (totally 6 spacers) is considered.

Case 5. 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.

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 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 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

Table 6 Effect of spacer numbers on surge arrester leakage current.

Spacers Number	It (mA)	Ir (mA)
Case 1	2.4412	0.040611
Case 2	2.3752	0.04049
Case 3	2.4125	0.040937
Case 4	2.4185	0.0403
Case 5	2.4221	0.0521

7 Conclusion

In this paper the grading ring influence on voltage distribution and electric field in 230 kV 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%.

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 it is known, to cool and fill ZNO column space, some spacers 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 (case 1).

References

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

[2] C. A. Christodoulou, M. V. Avgerinos, L. Ekonomou, I. F. Gonos and I. A. Stathopulos, "Measurement of the resistive leakage current in surge arresters under artificial rain test and impulse voltage subjection", *IET Journals, Science, Measurement & Technology*, Vol. 3, No. 3, pp. 256-262, 2009.

[3] R. J. Hollman, D. V. Heirman and J. Gorman, "Overvoltage protection and insulation coordination in power systems", *IEEE standard 1313-1999, IEEE Guide for the Application of Insulation Coordination*.

[4] B. H. Lee and S. M. Kang, "A new on-line leakage current monitoring system of ZnO surge arresters Original Research", *Article Materials Science and Engineering.* Vol. 119, No. 1, pp. 13-18, May. 2005.

[5] K. Feser, W. Kohler, D. Qiu and K. Chrzan, "Behavior of zinc oxide surge arresters under pollution", *IEEE Transaction on Power Delivery*, Vol. 6, No. 2, pp. 688-695, April 1991.

[6] L. Xie, J. Zheng, Z. Li, W. Dong, K. P. Zha and G. Tang, "Optimization of grading ring design for a new UHV equipotential shielding capacitor voltage transformer", *IEEE Conf. Electrical Insulation and Dielectric Phenomena,* pp. 748-751, 2011.

[7] J. He, J. Hu, S. Gu, B. Zhang and R. Zeng, "Analysis and Improvement of Potential Distribution of 1000-kV Ultra-High-Voltage Metal–Oxide Arrester", *IEEE Trans. Power Delivery,* Vol. 24, No. 3, pp. 1225-1233, 2009.

[8] J. He, R. Zeng, Sh. Chen and Z. Guan, "Potential distribution analysis of suspended-type Metal-oxide surge arresters", *IEEE Trans. Power Delivery*, Vol. 18, No. 4, pp. 1214-1220, October 2003.

[9] U. Kumar and V. Mogaveera, "Voltage distribution studies on Zno arresters", *IEEE Proc.- Generation. Transmission. Distribution*, Vol. 149, No. 4, pp. 457-462, July. 2002.

[10] N. Alame and G. Melik, "Axial voltage and gradient distribution of metal oxide surge arresters", *Proceedings of the 3rd Int. Conf. on Properties and Applications of Dielectric Materials*, Tokyo, Japan, pp. 1149-1151, July. 1991.

[11] E. Akbari, M. Mirzaie, M. B. Asadpoor A. Rahimnejad, "Effects of Disc Insulator Type and Corona Ring on Electric Field and Voltage Distribution over 230-kV Insulator String by Numerical Method'', *Iranian Journal of Electrical and Electronic Engineering,* Vol. 9, No. 1, pp. 44-57, 2013.

[12] J. Du, Z. Peng, J. Li, S. Zhang, N. Li and Ch. Fan, "Electric field calculation and grading ring optimization for 1000 kV AC post porcelain insulator" *IEEE Int. Conf. on Solid Dielectrics (ICSD),* pp. 198-201, 2013.

[13] D. Huang, Zh. Zheng, Zh. Huang, W., J. Ruan and P. Li, "Calculation model simplification study for porcelain insulator string potential and grading ring surface electric field distribution of UHV AC transmission line" *IEEE Conf. on Electrical Insulation and Dielectric Phenomena (CEIDP)*, pp. 634-637, 2013.

[14] *IEC 60099 Standard*, second edition.

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