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Development of High Gradient ZnO Arrester Material for High Voltage Applications

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ABSTRACT The presence of stray capacitance in ZnO (Zinc Oxide) surge arresters causes hurdles in arrester operation and non-uniform voltage distribution along the arrester column, especially for High Voltage (HV) and Extra high voltage (EHV) applications. Since the magnitude of stray capacitance is directly proportional to the arrester height; the shortening of surge arresters is a preeminent method to enhance the arrester performance and voltage distribution. Particularly, this stray capacitive effect delays the arrester operation from in-action to action mode, especially against very fast surges. Moreover, the shortening of the arrester column improves the voltage distribution and hence the electric field varies between the stacks. Therefore, this research work focuses on the preparation of two new high gradient arrester materials doping with rare earth oxides. The microstructures of the newly developed materials are analyzed. It is found that there is a reduction of grain sizes and an increase of voltage gradients in the newly developed arrester materials. From this, the height requirement per unit is estimated and compared with the conventional ZnO arrester. Using these high gradient materials, the reduction of height and compactness of the arrester assembly may be achieved greatly. Thus, the developed ZnO surge arrester with high gradient materials enhances the arrester behavior with the attendant improvement of voltage distribution due to its reduced height and stray effect.

INDEX TERMS EMTP-RV, high voltage gradient, height of arrester, nanosecond surges, rare earth element, stray capacitance, ZnO arrester.

I. INTRODUCTION

In contemporary years, the evolution of EHV (Extra high voltage) and UHV (Ultra-high voltage) transmission technology has been promptly augmented across the world [1]. On account of this, the magnitude of Overvoltage's vastly increases in UHV systems, and it upsets the insulation of connected equipment, such as bushings, circuit breakers, transformers, Rely circuits, and secondary equipment because of the high degree of the upsurge in voltage (dU/dt) [2]. It is a well-known fact that the ZnO arresters have superior protection capability in the power system network against surges, especially for switching and lightning. It encompasses of series-connected Zinc oxide (ZnO) blocks concerning voltage rating, offers admirable V-I characteristics which warrant the protection of connected equipment. Therefore, for a higher voltage rating, the height of the arrester is more.

ZnO arresters in high voltage applications have a high stray capacitive effect because of its increased height. So it is very much essential to decrease its height and hence arrester operation and voltage distribution alongside the may be enriched. Moreover, voltage grading ring structure may also be simplified, especially for high voltage arresters [3]–[6]. The presence of higher stray capacitance affects the arrester operation specifically during the invading of nanosecond surges. Additionally, Valsalal *et al.* [7] reported that the arrester fails to turn on because arrester stray capacitance plays an important role against very fast surges and it causes higher residual voltages compared with Lightning impulse particularly in EHV network [8]. Additionally, Tavakoli *et al.* stated that the nanosecond transients are generated owing to

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the Switching of Circuit breakers and disconnectors in Gas Insulated Substation (GIS). It has a very short front-time of 4-100ns with a frequency range of 100 kHz to 50 MHz. Surge arrester fails to turn on successfully during these nanosecond surges and its turn-on time is much longer than the front time of invading nanosecond surges [9]. Because the capacitive effect not permitting the arrester to turn on from in-action mode (non-conduction) into action mode (conduction) under nanosecond surges [10], [11]. So, a time delay occurs between the peak of residual voltage and current surge (current takes a peak earlier to voltage peak). Therefore arrester takes a delay in its initial response to conduct against nanosecond front times because of failure in the successful transition from in-action into action mode. These scenarios place a numeral interrogation that needs a strong answer/solution. Some of them are,

- Whether the enhancement of potential distribution is possible with arrester material composition?
- How the electric field varies between the stacks during the shortening of arrester length?
- How the small magnitude of stray capacitive affects the Arrester conduction performance?
- Whether the High gradient arrester material helps to reduce the stray capacitances?
- Does Rare Earth Elements are suitable for fast transients and enhancement of potential distribution?

Considering all the above, this work focuses to bring the answers using modified arrester material for Fabrication.

For reducing the stray capacitive effect, one of the effective methods is shortening the arrester column by modifying the material composition of ZnO arresters. The new chemical composition of the basic ZnO materials doped with rare-earth (RE) oxide assumes greater significance. Jiang *et al.* [12] reported that the Rare Earth doping can increase the electrical behavior of the ZnO surge based on its homogeneity and microstructure properties of the arrester blocks. Therefore, higher voltage gradient arrester blocks can be developed and it leads to miniaturization of the arrester. Moreover, this high gradient material with rare-earth additives leads to enhanced densification and smaller grain growth due to the stabilization of the fresh spinel phases attained at the grain intersections. This is also a reason for the augmented voltage gradient with attendant fall in the capacitive effect causing shortening of arrester length. The REE (Rare earth elements) fetch improved consequences when applied with ZnO-Bi_2O_3 based arrester compositions [4]. The rare earth elements like Scandium oxide (Sc_2O_3), Vanadium oxide (V_2O_5), and Gadolinium oxide (Gd_2O_3) are chosen to prepare a new high gradient non-linear arrester material. The microstructure of newly developed material is obtained and compared with conventional arrester material. The outcome of this work upkeep large scale deployment of ZnO arrester especially for high voltage application in Gas Insulated substation (GIS) with reduced arrester length (Compactness) and stray effect which leads to much effective against nanosecond wave shapes.

II. PERFORMANCE OF CONVENTIONAL ARRESTERS

The main scope of this fragment is to demonstrate the performance of the existing surge arrester. It helps to evaluate/compare the effectiveness of the proposed arrester composition in terms of arrester behavior, stray effect, and voltage distribution.

A. SIGNIFICANCE OF STRAY CAPACITANCE

It is a sound known point that the height/length of the arrester increases with its voltage rating. To demonstrate the increase of stray capacitive effect (C_s) with arrester height, a 330 kV (5 × 66kV) arrester having 5 stacks of 66kV voltage rating is considered and shown in Figure 1.

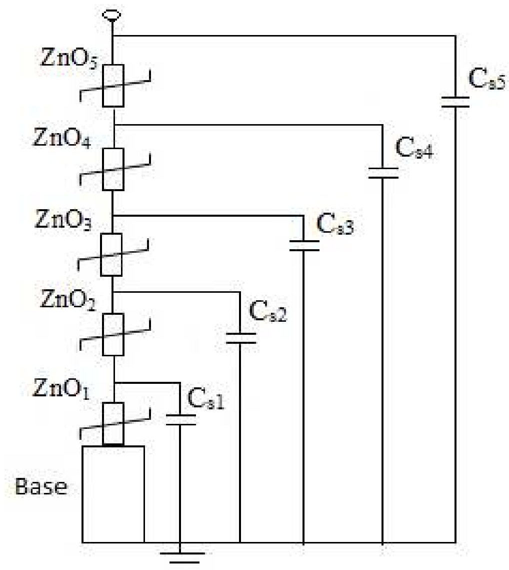


FIGURE 1. 5 × 66kV arrester showing only stray capacitance.

The stray capacitance of arresters for different voltage ratings/heights and maximum electric field (E_{max}) are computed using the finite element method and given in Table 1 [7]. This stray capacitance acts as a major role during the transition duration of the arrester.

TABLE 1. Stray capacitance and E_{max} for arresters of different voltage ratings (C_S–total stray capacitance).

Voltage Rating (kV)	Height (MM)	Stray Capacitance (C_s) pF	E_{max} V(pu/m)
1×66	2116	2.10	1.65
2×66	2732	4.58	1.72
3×66	3348	6.78	1.84
4×66	3964	8.86	1.99
5×66	4580	10.78	2.12

1) NON-CONDUCTION MODE

It is a known fact that the voltage and electric stress distribution along the arrester column become more non-uniform because of higher stray capacitance [7] causing a reduced lifetime of the arrester. Generally, grading rings are used to make voltage distribution more uniform. If the height of the arrester is shortened, then the stray capacitance is reduced accordingly and the reduction of the number of grading rings in the arrester may be achieved. The electric stress distribution along the arrester height of 66, 132, 198, 264, and 330 kV ratings are computed using finite element method based electrostatic field solver. Figure 2 shows the electrical field plot for a 330 kV arrester. The maximum field occurs across the topmost units. The electrical field or stress appearing across the arrester blocks plays a vital part in deciding the lifespan of the arrester. So the performance of the arrester during non-conduction mode is only based on the distribution of voltage across the arrester height.

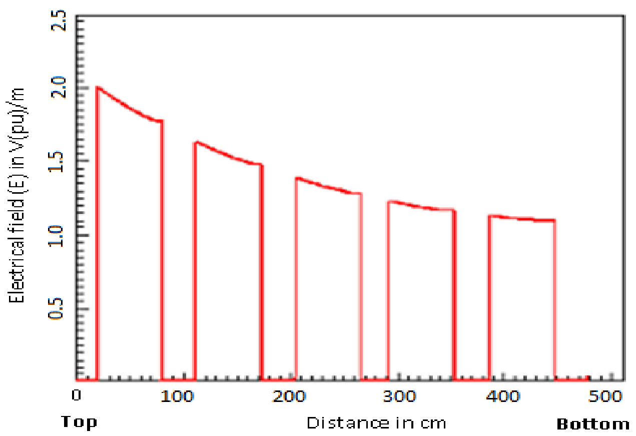


FIGURE 2. Electrical field plot along 330kV arrester.

2) CONDUCTION MODE

During conduction mode, voltage distribution becomes more non-uniform when the arrester is open to different over-voltages against various constituents. This non-uniformity upturns with the steepness of the current transients, since capacitance takes a major part especially under very fast transient overvoltages. Moreover, there is a notable delay in the initial response of the surge arrester, and this delay increases with the steepness of the arrester. Therefore, arresters may fail to operate especially under very fast transient overvoltages. So, during in-action mode, in adding to non-uniform voltage distribution, there is a delay in its initial response of the residual voltage, instigating failure of operation arrester especially under very fast transients. So, it becomes necessary to reduce the stray capacitance effect [7].

Since the height of the arrester depends on the voltage gradient of the arrester material, the appropriate chemical composition is chosen and new arrester material is prepared. The microstructure of newly developed arrester material is analyzed because the average grain sizes of the ZnO block regulate the voltage gradient of the resistor blocks. To compare the increase in voltage gradient of new arrester material, the microstructure of conventional arrester is analyzed.

B. MICROSTRUCTURE OF CONVENTIONAL ARRESTER

The cross-sectional view of conventional arrester assembly (M1) consists of a series arrangement of ZnO (metal oxide) blocks is shown in Figure 3 (a) and a single metal oxide arrester block is shown in Figure 3 (b).

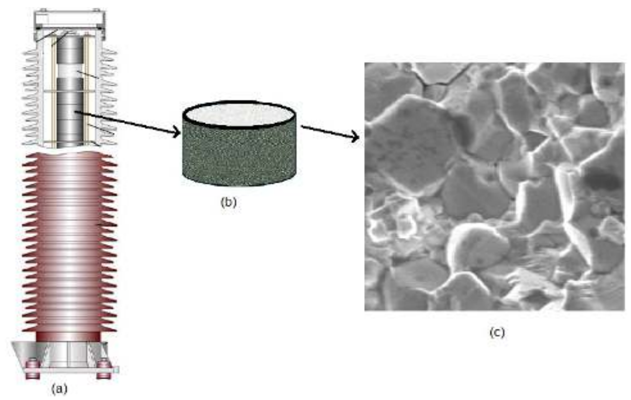


FIGURE 3. (a) Cross-sectional view of arrester assembly (b) Metal oxide block (c) Microscopic image of conventional arrester block (M1).

The microstructure of the conventional arrester element is observed under a scanning electron microscope (Tescan-Vega 3) after magnifying thousands of times and the observed image is shown in Figure 3 (c). From that, the average sizes of the grains are computed using equation 1.

$$d = \frac{1.56L}{MN} \tag{1}$$

L represents the random line length, M indicates magnification, and N represents intercepted lines in grains.

Daniel Qi Tan et al have given grain size for commercially available arresters, ranging from 2-15 μm [10] and Fukano et al [11] have reported as 12.1 μm. This grain size decides the voltage gradient of the arrester block. Generally, the voltage gradient of conventional ZnO varistors used for surge arresters in high voltage systems is about 200V/m [11]–[15]. But in this study, the average ZnO grain sizes and voltage gradients for commercial arresters are found to be 12.53μm and 140V/mm (Figure 3 (c)) respectively. The larger grain size exhibits the poor performance of the arrester. An appropriate approach to reduce the length of the metal oxide arrester is the usage of high gradient material to increase the voltage gradient as well as to mend the potential distribution along the arrester length.

C. PERFORMANCE OF ARRESTER AGAINST DIFFERENT SURGES

1) ARRESTER MODEL

The frequency-dependent arrester model endorsed by the IEEE working group (WG) [16]–[19] is taken for this study. This model consists of dual non-linear resistors parted by the

RL filter. For the slow rising current surge, the impedance of the RL filter is very low and thus A0 and A1 are practically connected in parallel. While for a high rising time, the impedance of the RL filter takes a significant role and A0 derives more current than A1. Since the capacitance of the arrester takes a major part for very fast transient [7], [19] and therefore block (C_b) and stray (C_s) capacitance are included in the IEEE WG model to analyze the arrester behavior especially under very fast transients as shown in Figure 4.

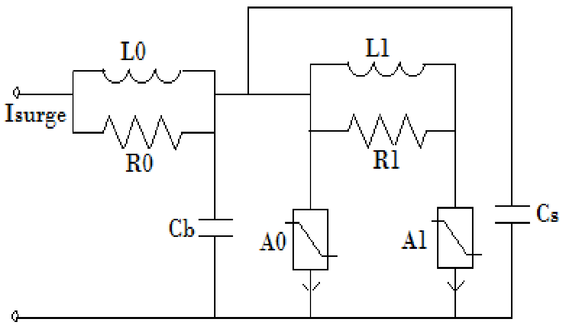


FIGURE 4. Modified IEEE arrester model.

The parameters of the model such as resistors (R0 and R1) and inductances (L0 and L1) are computed based on the formulation proposed by IEEE WG. The computation procedure of both capacitances is given in equations 2 and 3.

$$C_b = \left(\frac{k1 \times 30 \times r^2}{d} \times N\right) nF \tag{2}$$

where d represents the height of arrester, r indicates the radius of arrester block and N represents the parallel columns.

$$Cs = (k2 \times 0.004 \times d)\, nF \tag{3}$$

The terms k1 and k2 symbolize the factor of arresters. This model is designed in the EMTP RV platform to study the performance of ZnO arresters for different ratings against various constituents of surges.

2) GENERATION OF NANOSECOND SURGES FROM GIS

The Switching operation of GIS generates maximum magnitude of transients up to 2.4p.u and it results in disquiets to the end-users in Extra High Voltage (EHV) and Ultra High Voltage (UHV) systems. Moreover, their frequency lies in the range of 14.67 to 43.38MHz. Its wave shapes take a front time of about 5ns. Sometimes, its magnitude reaches its higher value compared with lighting surges especially in EHV and UHV systems [20], [21].

3) DYNAMIC BEHAVIOR AGAINST MICROSECOND SURGES

The above model is simulated for different ratings of conventional surge arrester (M1) for microsecond current surges. From the simulation, the residual voltage (U_r) and conduction time (t_c-time took to accomplish the peak of residual voltage) are observed and shown in Table 2.

TABLE 2. Simulated Ur and t_c for 330kV arrester.

Surge waveforms	U_r(kV)	t_c(μs)	% of Delay
30/60μs, 2kA	679.01	27.90	-7.0
8/20μs, 10kA	775.84	1.920	-76.0
1/10μs, 10kA	866.43	0.250	-75.0

a: RESIDUAL VOLTAGE (U_r)

The voltage-clamped across the arrester terminal during the conduction of surge is known as residual voltage or clamping voltage. During invading of the surge, the voltage across each grain exceeds, breaks the potential barrier, and allows a current start to flow into ZnO grain. To accomplish the complete successful conduction of arresters during the surge, the potential breakdown takes place completely as early as possible to warrant the successful suppression of the current surge. This operation is justified from the incidence of the peak of residual voltage earlier to a current peak which is shown in Table 2.

b: CONDUCTION CHARACTERISTICS (T_c)

Surge arresters act as a capacitor during in-action mode [20]–[22]. During a surge, the capacitance must be vanished out as soon as possible and turn on the arrester into a resistive mode to suppress the surge positively. Furthermore, time taken to diminish the capacitive effect need to be less than the t_f of the current surge to ensure the successful conduction of the arrester. In this line, the time taken to grasp the peak of residual voltage is called conduction time (t_c). Table 2 represents the figured value of conduction time of 330kV rated arrester, in which the residual voltage attains a peak ($t_c = 27.90\mu s$) before the current peak ($30\mu s$) during invading of switching surge. Likewise, the same trends are observed during the invading of lightning and steep surges. This shows the successful operation of arrester during microsecond current surges because of highly negative delays.

c: ARRESTER ENACTMENT AGAINST NANOSECOND SURGES

By contrast with the operation of the arrester against microsecond surges, the dynamic behavior of the arrester during the invading of the nanosecond surge is not yet given a clear vision on it. This fact throws a bad light on the successful arrester operation against all types of current surges, especially nanosecond surges. To shows this, the simulation study is carried out with conventional arrester against nanosecond current surges.

A current surge of 2kA, 5ns is applied to 330kV rated conventional arresters. From the simulation, residual voltages and conduction times are observed and shown in Table 3. The 330kV rated arrester (M1) takes 10.56ns (t_c) to break the potential barrier completely. On the other hand, the current

TABLE 3. U_r and t_c of arresters (M1) for 2kA, t_f = 5ns current surge.

Parameters	Values
U_r(kV)	743.03
t_c (ns)	10.56
t_d(ns)	+5.560

surge takes a peak in 5 ns and therefore arrester fails to conduct the surge. In other words, the incidence of the residual voltage after the current surge peak. Therefore, there is a delay (t_d) in its reaction (time lag) for successful conduction of arrester about 5.560ns for 330kV arresters (Figure 5).

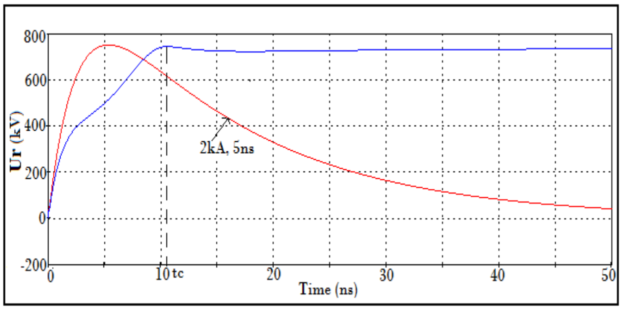


FIGURE 5. U_r and current surge waveforms of 330kV.

Above all, it seems pertinent that the surge arresters are not operating successfully against nanosecond surges because of its capacitance effect. In light of this evidence, the stray capacitance must be reduced and this can be possible by using high gradient material causing a reduction in its height, resulting in the reduction of delay in its response.

III. HIGH GRADIENT MATERIAL

Metal oxide arrester blocks are polycrystalline ceramics encompass of ZnO with added minor additives namely Bi_2O_3, Sb_2O_3, Co_2O_3, Cr_2O_3, MnO_2, etc [14]. The height and diameter of the sintered disc denote the voltage and current rating respectively. Generally, high gradient arrester blocks are designed by adding RE elements to the basic constituents of the composition. Shingo Shirakawa et al [15] stated that a high gradient arrester block increases the reference voltages about twice or thrice and contributes great compactness and better protection performance [22]–[26]. Consequently, the height of the arrester reduces greatly to attain a less stray capacitive effect. The conceivable course of succeeding high gradient arrester is an amendment of material composition and its molarity, sintering process, and advanced material processing.

A. ROLE OF RARE EARTH ELEMENTS AND SINTERING PROCESS

The inherent weakness and insufficiency of the conventional sintering method lead to the higher temperature gradient from outer to the interior portion of the arrester block with the attendant non-uniform sintering process. Jingzhong Zhaoa et al [26] proposed that it could be replaced with the microwave sintering process-an a pioneering measure with the lowest sintering time to acquire improved outcomes. Further, it is renowned as a process involving lesser temperatures and sooner transfer of heat energy. All these factors aid to avoid the necessity for preserving higher dwelling time during the microwave process. Moreover, it can fetch the uniform transmission of the temperature for the whole volume of the discs; this stage aids the higher densification of grains. The greater densification at lower sintering temperature consequences in reduced grain sizes, lesser leakage current, and reduced amount of block capacitance. Thus the combined influence of Sc_2O_3 doping, an adaptation of microwave sintering, and lower holding time aid to diminish the capacitive effect.

B. PREPARATION

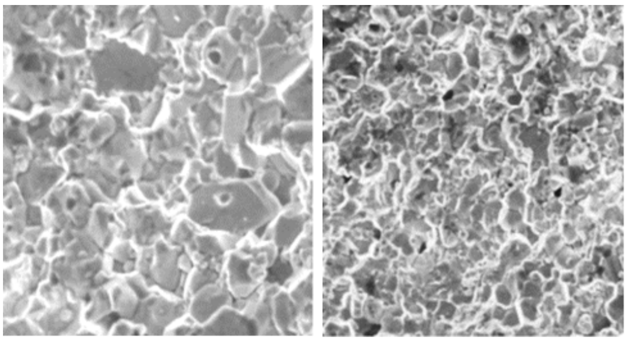
The arrester/varistor discs were developed with reagent raw materials which contained ZnO in main proportion and a minor quantum of Bi_2O_3, Sb_2O_3, Co_2O_3, Cr_2O_3, MnO_2, and Sc_2O_3 (S1) The powders were balanced, positioned in nylon jar with balls (zirconia) and refined by using HEBM in wetting medium [27]. The percentage of material to balls was selected as 1:10. After grinding for 10 hours, the mixtures were calcined at 600°C for two hours. The calcined precipitates were pulverized with Agate-mortar after applying 2wt% of Poly Vinyl Alcohol. Then the precipitates were granulated using 100 mesh screen sieve. The primed mixtures were now positioned in a die and then in a double axial Compressing machine and subjected to pressing. 150Mpa pressure was applied and compacted the powders to discs. The wet/green cylindrical discs had a density of around 55% of its theoretical density. Then the samples were made set for the sintering process. Then the samples were exposed to sintering courses. Lastly, the essential dimensions of the arrester samples had been accomplished by employing lapping and grinding machines. The complete process of the arrester sample had been finalized; finally, it took the shape of an innovative genetically modified ZnO arrester. The various processes involved in the production of genetically modified arresters discs are exhibited in Figure 6.

FIGURE 6. The production process of arrester blocks.

Similarly, for S2, the same procedure is followed with different compositions namely ZnO with additives namely Bi_2O_3, Sb_2O_3, Co_2O_3, Cr_2O_3, MnO_2, V_2O_5, and Gd_2O_3. The addition of Vanadium oxide increases the density of the arrester block even at low temperature and Gadolinium oxide inhibits the grain growth during sintering because of a strong pinning effect. The sintering temperature of both S1 and S2 is 1000°C. The behavior of developed blocks is compared with conventional arrester collected from the manufacturer (M1).

C. MICROSTRUCTURAL PROPERTY

The microstructural images of developed arrester blocks are observed and shown in Figure 7.



(a) (b)

FIGURE 7. SEM images of (a) S1and (b) S2.

From this image, the variations in grain sizes among the arrester blocks (S1 and S2) are observed and its average sizes are obtained as 5.56μm and 4.96μm respectively. These values are much lesser than the conventional arrester (12.53μm) and so attain a higher voltage gradient. The voltage gradient of S1 and S2 is found to be 550V/mm and 605V/mm respectively. As a consequence, the ZnO grain sizes converted smaller and the voltage gradients of ZnO arrester blocks are enriched.

IV. PERFORMANCE OF DEVELOPED ARRESTERS

A. COMPACTNESS

The consequence of higher gradient arrester material S1 and S2 is the compactness of the arrester assembly. With reference to the height of the conventional arrester, the sample S1, and S2 concede a reduced arrester assembly height of about 4-5 times because of its greater voltage gradient. The comparison between the conventional arrester and developed samples is shown in Figure. 8.

Because of the reduction in height of the arrester using new high gradient material, the stray capacitance of the arrester assembly may be reduced significantly.

B. STRAY CAPACITANCE AND ELECTRIC FIELD

The stray capacitances of conventional arresters are compared with newly developed arrester samples S1 and S2 which are shown in Table 4 (for 330kV). The sample S1 and S2 have

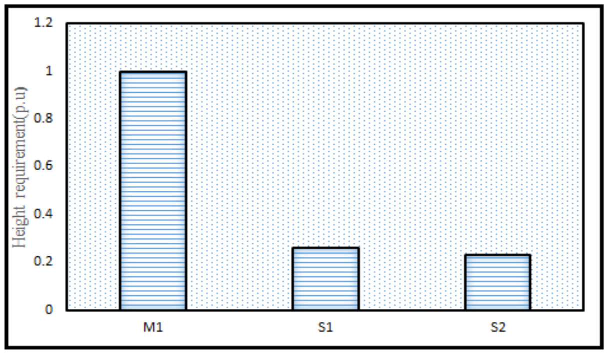


FIGURE 8. Comparison of required height in per unit.

TABLE 4. C_S and Emax (V/p.u.) of the samples.

Parameters	Conventional	S1	S2
Stray Capacitance (Cs)pF	10.78	4.36	4.12
E_{max} V(pu/m)	2.12	6.74	7.15

the least stray capacitance effect due to its higher gradient with high compactness.

Further, the values of E_{max}(V/p.u) have great improvement in both the samples S1 and S2. The improved version of the arrester has a great tendency to improve the voltage distribution across the arrester column and promotes the enhanced conduction performance during an operation against nanosecond surges.

C. PERFORMANCE OF DEVELOPED ARRESTER

1) MICROSECOND SURGES

The electrical parameters of fabricated samples (S1 and S2) for the ZnO arrester model are calculated with the estimated height of the arrester assembly (330kV). Subsequently, simulation is carried out by applying a microsecond current surge as given in Table 5.

TABLE 5. U_r and t_c of S1 and S2 for microsecond surges.

Surge waveform	S1			S2		
	U_r (kV)	t_c (µs)	% of Delay	U_r (kV)	t_c (µs)	% of Delay
30/60µs, 2kA	657.23	27.82	-7.2	655.98	27.82	-7.2
8/20µs, 10kA	749.11	1.919	-80.81	746.53	1.919	-80.81
1/10µs, 10kA	843.81	0.210	-79.0	839.49	0.210	-79.0

From the table, it is noted that the conduction time of the newly developed samples is the same. This is due to the absence of the influence of the stray capacitance effect against microsecond surges. Hence, the developed arrester performs well against microsecond surges similar to the conventional one. The residual voltages of the samples are nearly the same. However, S2 shows reduced residual voltage magnitude against microsecond surges compared with S1and conventional arrester.

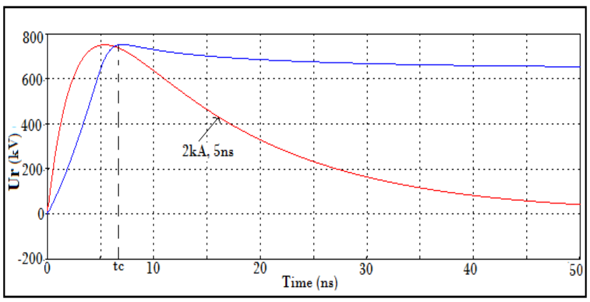
2) NANOSECOND SURGES

Subsequently, simulation is carried out by applying a nanosecond current surge (2kA, 5ns). From the waveform, the residual voltage, conduction time, and delay time are computed and shown in Table 6.

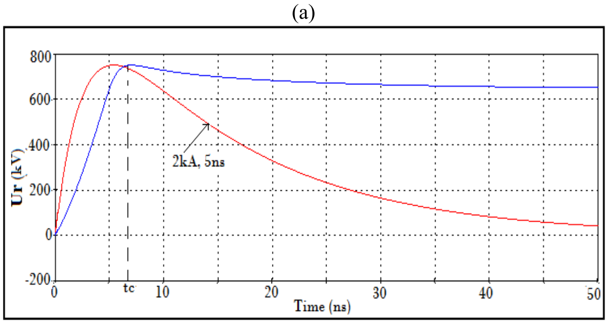
TABLE 6. U_r and t_c of S1 and S2 for 2kA, t_f = 5ns surge current.

Rating	S1			S2		
	U_r (kV)	t_c (ns)	t_d (ns)	U_r (kV)	t_c (ns)	t_d (ns)
132kV	314	5.91	+0.91	314	5.91	+0.91
198kV	462	6.22	+1.22	461	6.20	+1.20
330kV	751	7.03	+2.03	749	6.97	+1.97

It is seen that there is a notable reduction in delay in its response to arresters (S1 and S2) compared with conventional arrester (M1). This is because of a decrease in stray capacitive effect. Owing to this, incoming surge with 2kA, 5ns charges the arrester (capacitive effect) quickly, and subsequently, the breakdown of potential barrier happens quickly. Hence clamping of voltage takes a peak much faster than conventional arrester M1. Figure 9 gives the time gap (t_d) between the residual voltage and current surge peak for 330kV arrester against 2kA, 5ns current surge. Summarizing the results of the above, it is shown that the high gradient arrester reduces the delay in the arrester's response.



(a)



(b)

FIGURE 9. U_r and current surge waveforms of 330kV arrester (a) S1and (b) S2.

V. DISCUSSIONS

The primary objective of this work is to enhance the performance of the arrester against nanosecond surges by reducing the stray capacitance magnitude using RE oxides. Notably, the total height requirement of the arrester is reduced about more than twice due to the higher voltage gradient of newly developed arrester blocks. It is a known fact that the voltage distribution along the arrester column affects with arrester height. This height reduction of the developed samples would directly improve the voltage distribution along the arrester length and forms a secondary objective for this work. Due to this, the electric field of both the samples is enhanced particularly for Sample S2.

Also, these high gradient samples result in a lower magnitude of stray capacitance compared with the conventional one. It enhances the arrester performance against nanosecond surges. Because the lower magnitude of stray capacitance improves the transition time of the surge arrester. Both the samples tend to reduce the delay time for successful arrester operation against nanosecond surges. The percentage decrease in delay for S1 and S2 with respect to conventional arrester (M1) is computed. It is perceived that the delay percentage for 330kV arrester is decreased by 80.94%. On paralleling both samples, S2 affords better protection for nanosecond applications because of its reduced percentage delay.

In a nutshell, a higher-rated arrester with high gradient material consequences a condensed height requirement of the arrester and its stray capacitive effect. As a sign of this outcome, there is an improvement in its response which triggers the transition speed from in-action mode to action mode of the arrester especially against nanosecond surges along with better voltage distribution across the arrester length. This high gradient material might be used for a large scale design of ZnO arrester for Gas Insulated substation (GIS).

Moreover, the development cost of this proposed arrester might be more due to the doping concentration of Rare Earth oxide as it stakes higher cost among the other doping and additives with ZnO. Moreover, the special design of housing and supporting structures are recommended for this design. However, Gas insulated substations have a higher investment cost due to its encapsulated scheme with the special design of costlier power components which is connected to it. In order to protect this costlier system against very fast surges, the development and design cost of the arrester is not a concern because protection has to be taken place at any cost but optimally. Also, there are RE elements that are cheaper in the market, and experiments are undergoing to find the optimal ratio of RE, sintering time, dwelling time, dopants, and additives.

VI. CONCLUSIONS

The height of the ZnO arrester used in high voltage applications is abridged by modifying the chemical composition of the arrester material. Two different high gradient arrester materials are established using rare earth oxides. Further, the microstructures of the newly developed materials are examined. There is a reduction of grain sizes and found to be as 5.56μm and 4.96μm for two different materials. The respective voltage gradients are 550V/mm and 605V/mm. From this, the height requirement per unit is estimated and compared with the conventional ZnO arrester. There is a reduction of height about 4 - 5 times compared with conventional arrester assembly. Thus, the developed ZnO high voltage gradient arrester material adequately abridges the length of the arrester and the effect of stray capacitance may be reduced and leads to improve the arrester conduction performance and voltage distribution. Though this work gives a better outcome, large scale deployment of arrester assembly needs to be implemented to ensure the accuracy of its aftermath that may be discussed in future works.

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