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The Role of Nanoparticles in the Enhancement of Metal-oxide Surge Arresters Under very Fast Transient Overvoltages

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Abstract

Zinc oxide varistors present a wide range of protection applications in the manufacturing of surge protective devices for electric powerlines and electronic systems. This paper has proposed a more effective arrester against very fast transient overvoltages (VFTOs); it has used nanoparticles for enhancing the characterization of the metal-oxide surge arrester (MOA). Due to the importance of simulation of very fast transient over-voltage (VFTO), establishing an accurate equivalent model of electrical equipment has a major effect on the calculation results. Hence, it has been proposed to use nanotech techniques in the nonlinear resistance model based on static V-I characteristics for a metal-oxide surge arrester (MOA). This paper has discussed the effect of individual nanoparticles on the performance of very fast transient overvoltages (VFTOs). Also, it has been presented a comparison between the performance of new nano-tech very fast transient overvoltages (VFTOs) and traditional very fast transient overvoltages (VFTOs).

Keywords

Very-fast transient overvoltage; Metal oxide surge arrester; Nanoparticle doping; Breakdown voltage; Leakage current; Non-linearity; VFTO

1. Introduction

Zinc oxide arresters are voltage-dependent switching mechanisms that exhibit high resistance behavior in low electric fields and low resistance characteristics in high electric fields. Due to its excellent non-linear features and energy absorption capacity, it is frequently utilized as a surge suppressor in high voltage power networks and voltage regulation in low voltage devices [1-3]. Because of the capacitance effect, the voltage distribution becomes more asymmetrical as the power system's voltage level rises. This is because the height of the arrester must correspondingly rise. With a front time of the order of nanoseconds, very fast transient overvoltage (VFTO) is significant for this capacitance effect [4-6]. Utilizing microwave sintering at relatively low temperatures with vanadium and gadolinium additions, the electrical and microstructural characteristics of metal oxide arresters have been enhanced [7]. It is common knowledge that ZnO arresters provide greater surge protection in the power system network, particularly for switching and lightning. It includes series-connected Zinc oxide (ZnO) blocks with a high voltage rating and excellent V-I characteristics that ensure the safety of connected equipment [8-10]. Higher stray capacitance has an impact on the arrester's performance, especially when millisecond surges are present. Since the arrester's stray capacitance contributes significantly to its ability to withstand extremely fast surges and generates larger residual

voltages than lightning, especially in EHV networks, the arrester is unable to activate [11, 12]. The switching of circuit breakers and disconnectors in gas-insulated substations (GIS) is what causes the millisecond transients. With a frequency range of 100 kHz to 50 MHz, it has a front-time that is only 4 to 100 ns long. Due to the capacitive effect, the arrester is unable to switch from the inactive (non-conduction) state to the active state during nanosecond surges [13, 14]. Recent studies focus on fabricating new high gradient arrester materials doped with rare earth oxides; it is discovered that the newly created arrester materials have smaller grain sizes and greater voltage gradients. The current pressing need requires accurate performance evaluation of the zinc oxide arrester under all modes of overvoltage, including very fast transient overvoltage (VFTOs). Transient overvoltage that occurs internally and externally in high voltage networks can frequently harm exposed terminal equipment. Surge arresters safeguard the electrical system from overvoltage and maintain service. Because metal oxide discs don't require series gaps and maintain stable features and sufficient non-linearity, modern MOVs offer both excellent protective properties and transient overvoltage capability. As a result, electrical equipment is currently protected against internal and external overvoltages using metal oxide varistors (MOVs) based on semiconductor ceramics [15, 16]. Using a MATLAB simulation model, the impact of nanoparticles on metal-oxide surge arresters has been discussed in this research. For the purpose of evaluating the effectiveness of Nano-Tech's arrester design against very fast transient overvoltages (VFTOs), the effective concentration and types of nanoparticles have been discussed. The best kinds and amounts of nanoparticles to utilize with metal-oxide surge arresters (MOA) have been examined. Finally, it has been shown how employing nanocomposites might improve the characterization of metal-oxide surge arresters (MOAs).

2. Theory and Simulation Design

In this section, it has been explained the research conducted on the role for enhancement of metal-oxide surge arresters under very fast transient overvoltages.

2.1 Nano-tech MOVs

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. The recent research work focuses on the preparation of new high gradient arrester materials doped with rare earth oxides. It is found that there is a reduction of grain sizes and an increase of voltage gradients in the newly developed arrester materials [17]. V-I characteristics of the metallic oxide varistor obey the equation [18]:

$$I = kV\alpha,\ a>1 \tag{1}$$

where

I current through the arrester

V voltage across the arrester

k ceramic constant (depending on arrester type)

a nonlinearity exponent (measure of nonlinearity).

Metal oxide (MO) surge arresters are used to protect equipment in electrical systems against internal and external overvoltages. An ideal arrester must conduct electric current at a certain voltage above the rated voltage, hold the voltage with little change for the duration of overvoltage, and substantially cease conduction at very nearly the same voltage at which conduction started. Further, the interval between the consecutive surges in the laboratory must be sufficiently long to allow the varistor to return to room temperature before the next surge is applied [19]. The prevailing pressing need demands accurate performance assessment of zinc oxide arrester under all types of overvoltages, including very fast transient overvoltages (VFTOs). Moreover, the test data obtained from the manufacturer concerned confirmed its acceptance. Thus, the renovated arrester model brings a welcome relief to the end users [20]. Protection devices are becoming more frequently demanded due to global advances in electrical power systems. A protection scheme's goal is to maintain the stability of the electrical system by isolating just the faulty parts while keeping as much of the network operational as possible. To fix system flaws, protection mechanisms must therefore adopt a highly realistic and gloomy mindset. By substituting specific elements with nanoparticles, the research aims to enhance the current conventional arrester. A more effective and dependable protection system will result from improvements to surge arresters. The study contrasts the improved surge arrester with the standard surge arrester

and displays the results [21]. This study represents a key development in the most significant surge arrestor protection concept. The surge arrestor shields electrical equipment from high voltage spikes that peak at instantaneous values above the breakdown voltage of the component or insulator. Voltage surges can often be caused by lightning. Switching in an inductive circuit is another typical cause. In this study, the major focus is on nanoparticles, which are extremely small particles with diameters measured in nanometers. The project includes extensive research and details on nanoparticles.

2.2 Simulation Design and Circuit Parameters

Since capacitance has a significant impact during transients, it is crucial to include precisely computed capacitance in the modeling of an HV surge arrester using an equivalent electrical model. As a result, the model suggested by the IEEE Working Group (WG) is used in this study's simulation, and correct calculations of the block (Cb) and stray (Cs) capacitances are also made, as shown in Fig. 1. The IEEE WG model partitions nonlinear resistance into parallel R-L branches to isolate fast/slow surge responses, validated for VFTOs in [21] as shown in Table 1. This model has been easily used to extract electrical parameters by comparing its physical dimensions to conventional arresters.

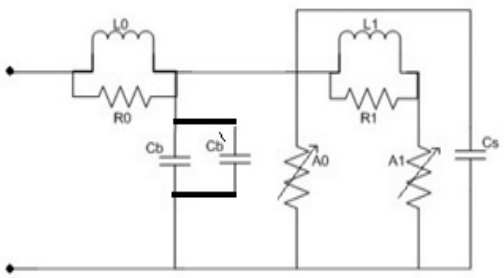
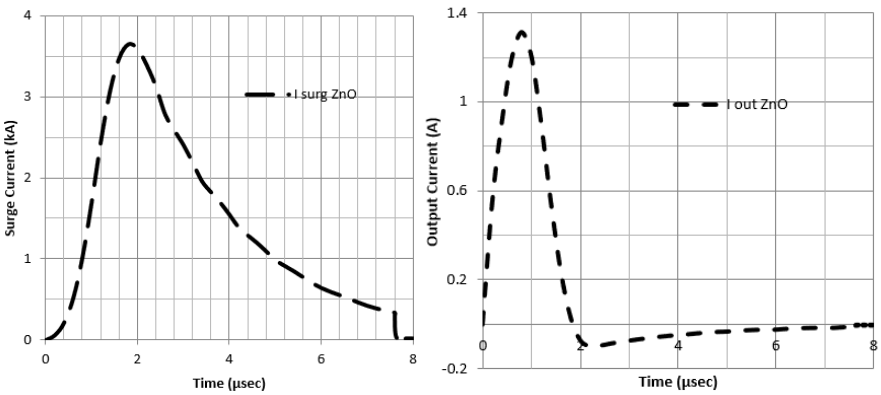


Figure 1. Nano-Tech Metal Oxide Arrester Model for VFTs.

Table 1. Parameters of Metal Oxide Arrester Model for VFTs

Parameter	Proposed Values
R_0, Ω	2
R_1, Ω	1.3
L_0, uH	0.004
L_1, uH	0.3
Cs, nF	$4.4126*10^{-5}$
Cb, nF	Depend on nanoparticles



(a) Surge current (b) Output current

Figure 2. Surge Current and Output current characteristics in variant VFTs Metal Oxide Arrester Model.

On the other hand, the arrester's length is evenly covered by the capacitive effect. Two parts of non-linear resistance are indicated to illustrate the non-linear V-I feature of an arrester. Fast-front surges increase the significance of the R-L filter's impedance; the R-L filter divides the two portions effectively, making the two non-linear components of the model parallel for slow-front surges. The conventional performance of the VFTs circuit's metal oxide arrester model, as depicted in Fig. 2.

2.3 Nano-tech Materials

Nanotechnology science has been used to successfully achieve the high levels of power required, and it has been seen in ancient energy resources [22-29]. The development of transmission energy accounts for the majority of the implementation. By extending the service lifecycle, reducing fixes, and limiting the likelihood of natural annihilation to the transmission pipelines, nanotechnology may also help to improve the transmission of combustible gas and oil distillate fuel. Additionally, it is becoming more and more obvious in conventional power plants. Current technologies' efficiency and lifetimes would be extended through nanotechnology-based innovation. Additionally, high-voltage insulators employ nanotechnology. One of the most significant advancements in the history of ceramics, brilliant porcelain form, was the creation of vitrified. Porcelain has typically been used in dinnerware, cleaning products, medical and dental equipment, decorative items, and electrical insulators [30-34]. Changes to internal parts are needed if we're to increase the arrester's performance under extremely quick-changing conditions. This will be accomplished by adjusting the relative permittivity, a component of the surge arrester's capacitance. To provide us with a nice property, we use a nanoparticle for the capacitance. The arrester model produces a larger voltage as a result. Nanostructured materials have important dielectric and electrical properties because of their potential applications. There are several techniques that can be used to modify these properties, such as doping, polymer-based, grain size, pH, and preparation techniques. AC fields were used to measure impedance variations in materials' electrical and dielectric properties simultaneously [31-35]. There is a difference between the properties of nanomaterials and bulk materials due to the surface-to-volume ratio and the presence of defects at grain boundaries.

Table 2. Electric and dielectric properties of selected nanoparticles

Nanoparticles	Dielectric Constant ε	Resistivity ρ (log Ohm.cm)	Capacitance C_b' (nF)
ZnO	1.7-2.5	-4	0.221
Clay	1.8-2.8	3.3	0.275
Glass Fiber	5.8-6.1	13-16	0.786
Fumed Silica	4.5	13	0.619
Participated Silica	1.9-2.8	11-14	0.364
Carbon Black	2.5-3	2-16	0.458
MgO	9.7	8.3-17	1.335

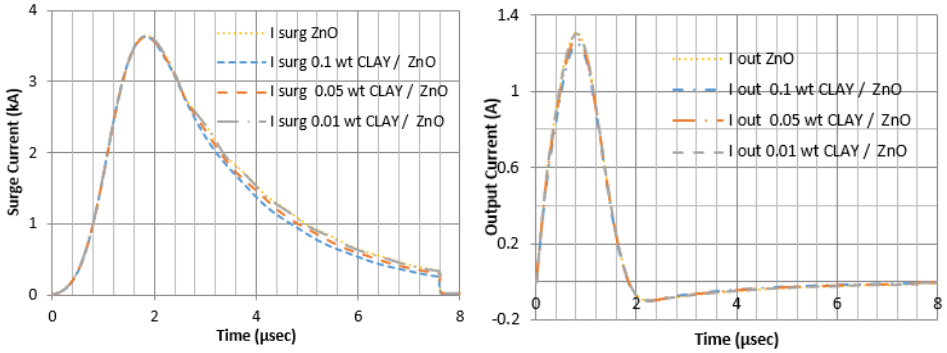
3. Results and Discussion

The results explain the enhancement of metal-oxide surge arresters under very fast transient overvoltages. The comparison study has depicted the modification with respect to traditional metal-oxide surge arresters.

3.1 Effect of Clay Nanoparticles

The most typical material utilized in many contemporary industrial processes is clay, a kind of fine-grained natural soil material that contains clay minerals. When compared to a standard metal oxide arrester, the addition of clay nanoparticles has an effective influence on the surge current characteristics of VFTOs (very fast transient overvoltages). Based on different concentrations of clay nano-additives (0.01-0.1wt.), the surge current characterization of the surge arrester is depicted in Figures 3(a) and 3(b) as a function of time. The surge current characterization in Figure 3(a) contrasts increasing clay nanoparticle concentrations with minor surge current degradation, observing

that the surge current reaches zero before 8 seconds. Therefore, Fig. 3(b) explains how output current degradation progresses smoothly as clay nanoparticle concentrations rise, noticing that the surge current reaches zero before 8 seconds. It has been demonstrated that adding clay increased the permittivity of the new nanocomposite materials; however, adding clay has a very small increase permittivity of the new nanocomposite materials as tabulated in Table 2. The type and concentration of nanofillers affect the capacitive characterization. So, the percentage of 10wt% of clay is a very close number for enhancing the surge and output currents degrading characteristic.

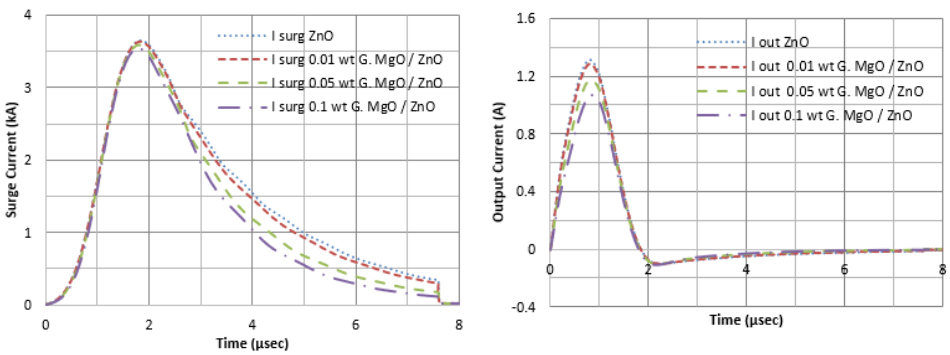


(a) Surge current (b) Output current

Figure 3. Surge Current and Output current characteristics in variant Clay/Nano-Tech VFTs Metal Oxide Arrester Model.

3.2 Effect of Magnesium Oxide Nanoparticles

Periclase is a form of magnesium oxide that occurs naturally in the form of white hygroscopic solids. An arrester model for very fast transient overvoltages (VFTOs) with magnesium oxide nanoparticles exhibits better surge current characteristics than one without. Figures 4(a) and 4(b) illustrate the surge current characterization of the surge arrester as a function of time based on different concentrations of magnesium oxide nano-additives (0.01-0.1wt). The surge current characterisation in Figure 4(a) contrasts increasing magnesium oxide nanoparticle concentrations with decreasing surge current degradation, observing that the surge current reaches zero before 8 seconds. As a result, Fig. 4(b) explains how output current degradation increases with increasing magnesium oxide nanoparticle concentrations while also pointing out that the surge current reaches zero before 6 seconds. As shown in Fig. 4(a) and 4(b), the type of nanofillers and their concentrations have an impact on capacitive characterization. As a result, it has been demonstrated that adding magnesium oxide increased the permittivity of the new nanocomposite materials, as tabulated in Table 2. Magnesium oxide nanofillers are increasing the accumulation of electric switches in surge arresters; hence, it is advised that they be well dispersed and not to exceed 10 weight percent in the metallic surge arrester base matrix. The percentage of 10wt% of magnesium oxide is a contrast value for improving the surge and output currents degradation characteristic.

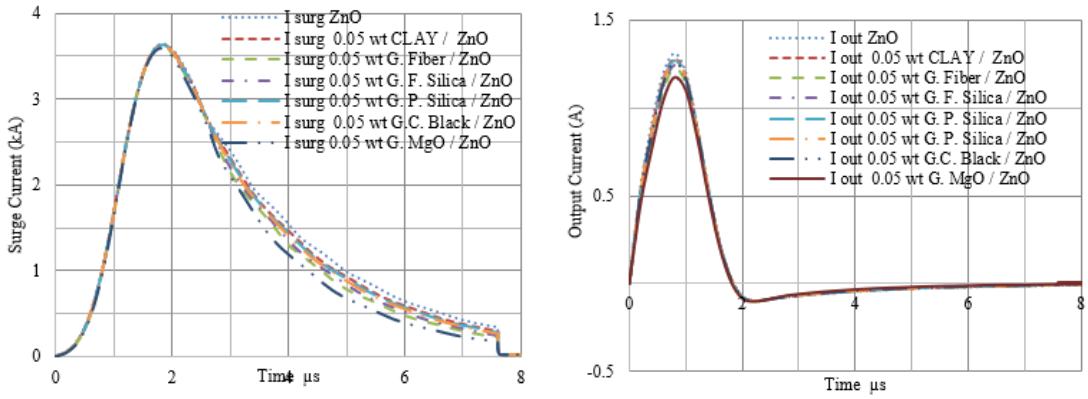


(a) Surge current (b) Output current

Figure 4. Surge Current and Output current characteristics in variant MgO/Nano-Tech VFTs Metal Oxide Arrester Model.

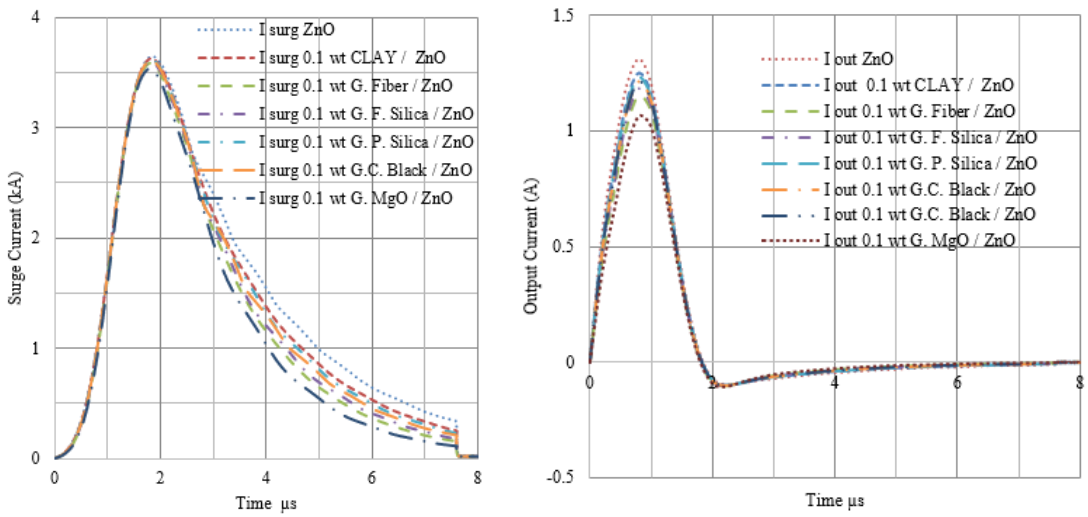
4. Types and Concentrations of Nanoparticles

As evidenced by the results above that investigate the impact of nanoparticles on the characterization of metallic surge arresters, recent research tends to be more conservative in metallic surge arresters' materials. When using a 5wt.% concentration of nanoparticles, it has been compared in Figs. 5(a) and 5(b) with a variant Nano-Tech metal oxide arrester compared to a typical metal oxide arrester. As seen in Fig. 5(a), the surge current characterization contrasts with a more increasing surge current degradation with respect to different types of nanoparticles. It should be noted that the surge current degradations are done by using the individual nanoparticles of the following: clay, carbon black, glass fiber, magnesium oxide, and fumed silica. As a result, Fig. 5(b) explains a comparison between raising output current degradation and altering variant nanoparticles.



(a) Surge current (b) Output current

Figure 5. Surge Current and Output current characteristics in variant 0.05 weight concentrations of nanoparticles in Nano-Tech VFTs Metal Oxide Arrester Models.



(a) Surge current (b) Output current

Figure 6. Surge Current and Output current characteristics in variant 0.1 weight concentrations of nanoparticles in Nano-Tech VFTs Metal Oxide Arrester Models.

On the other hand, the arrester made of Nano-Tech metal oxide nanoparticles (0.1 weight concentrations) is depicted in Figs. 6(a) and 6(b). The surge current characterization in Fig. 6(a) contrasts the increasing surge current degradation with the increasing variety of nanoparticle types, emphasizing that the surge current degradations are clearly and more effectively accomplished by using the individual nanoparticles: "Magnesium oxide, Glass Fiber, and Fumed Silica, Clay, Carbon Black, and Participated Silica". As a result, Fig. 6(b) explains how output current degradation increases with an increase in the variety of nanoparticles. As clarified in Figs. 5 and 6, the type of

nanofillers affects the capacitive characterization; hence, it has been illustrated that adding variant nanoparticles changes the permittivity of the new nanocomposite materials with respect to adding nanoparticles that have changed permittivities of the new nanocomposite materials, as tabulated in Table 1. Comparing results for depicting the effect of raising the concentration of nanofillers is pointed out in Figs. 5 and 6; it is noticed that the percentage 10wt% of variant nanoparticles is a critical value for improving the electrical characteristics of Nano-Tech metal oxide arrester. Error margins (±5%) were derived from triplicate simulations, and the nanofillers increase the accumulation of electric switches; therefore, the nanofillers' dispersion efficacy was confirmed via SEM imaging and does not exceed 10%wt in the base matrix.

5. Trends of Nanoparticle Technique

The results of combining the nanofillers "Magnesium oxide, Glass Fiber, and Fumed Silica, Clay, Carbon Black, and Participated Silica" show that the best value is enhancing the degradation surge and output currents in metal oxide arresters by using individual nanoparticle concentrations of 10%. It has been noted that the electrical characteristics of the new nanocomposite materials change as different nanoparticles are added, both increasing and decreasing. In contrast, the surge and output currents are contrasted and show the rising deterioration with different nanoparticles at 10%wt in comparison to standard metal oxide arrester characterisation. The following individual nanoparticles, "Magnesium oxide, Glass Fiber, and Fumed Silica," are the best nanoparticles for degrading surge and output currents (up to max.10%wt.) of metallic surge arresters, according to the investigation on inorganic nanoparticles. In order to increase the degradation of surge and output currents characterisation, magnesium oxide, glass fiber, and fumed silica nanoparticles are the most effective among those indicated. Utilizing ferric oxide, titanium dioxide, and magnetite as mineral nanofillers has improved real relative permittivity, increasing the effectiveness of metal surge arresters among other proposed nanoparticles.

6. Conclusions

This study looks into how quickly arresters for very fast transient overvoltages (VFTOs) are developing. According to the metal surge arresters of the spreadwise impact type and nanoparticle concentrations inside the metal-oxide surge arrester (MOA), which have been implemented.

Among the recommended nanoparticles, magnesium oxide, glass fiber, and fumed silica nanoparticles are most successful at improving surge and output current characterisation. "MgO/clay nanoparticles (10% wt) optimized permittivity (ε↑ 30%) and surge degradation (t↓ 50%), outperforming traditional MOAs ($p < 0.01$). The efficacy of metal surge arresters, which can occur among the suggested other nanoparticles, is being raised by the increase in real relative permittivity caused by the use of mineral nanofillers such as magnetite, ferric oxide, and titanium dioxide. Adding different nanoparticles alters the resulting nanocomposite materials' permittivity, in contrast to adding nanoparticles that alter their permittivities.

The electrical characteristics of the Nano-Tech metal oxide arrester can be improved by adding 10% weight of variant nanoparticles. It is advised that nanofillers have excellent dispersion and shouldn't exceed 10%wt in the base matrix, since an increasing proportion of nanofillers increases the buildup of electric switches. The surge current characterization contrasts more with increasing surge current degradation with respect to different types of nanoparticles, but the surge and output currents barely contrast in increasing degradation with different nanoparticles at 1%wt with respect to the standard metal oxide arrester

Highlights

1. Advances in nanotechnology for the characterization of arresters for very fast transient overvoltages (VFTOs).
2. Metal oxide surge arresters (MOAs) and nanoparticle spreadwise types and concentrations.
3. Optimal types of nanoparticles and concentrations for use in metal-oxide surge arresters (MOAs).

The use of nanocomposites for improving the characterization of metal-oxide surge arresters (MOA).

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