
Photo: KEYSTONE

New approaches to surge protection

Walter Schmidt, Felix Greuter

Nobody expects to be left in the cold and without light every time there is a lightning storm, although such storms can cause nightmarish overvoltages in the power grid. Protection that works perfectly doesn't usually grab the headlines. But how exactly do supply systems survive such massive surges and keep the power flowing to our homes?

Surge arresters are one key element. Another is 'insulation coordination', in which the insulation properties of all the power system equipment are configured in such a way that it cannot be damaged by overvoltages. These surges occur, quite literally, at lightning speed, and the insulation has to be massively dimensioned to cope with them. Apart from taking up valuable space, this adds cost.

New insulation technologies now offer the possibility of integrating overvoltage limitation capability directly in the protected equipment. Ultimately, the insulation itself may be endowed with surge arrester properties. New technologies will radically reduce insulation requirements, lowering the cost and increasing the functionality of future systems.

For a long time, spark gaps and silicon carbide arresters offered the best means of bleeding off all kinds of surges in power systems. Over the last two to three decades, however, these rather unpredictable devices have given way to the zinc-oxide (ZnO) varistor-based surge arrester. Such arresters are the prominent protection feature of today's insulation schemes. Thanks to good control of the properties of their metal-oxide (MO) resistors, ZnO arresters provide much better protection than the older technologies.

The surges that the varistor-based arresters have to handle can be considerable, arising as they do from massive events such as lightning strikes or switching transients. It is the job of the arrester to divert these sudden current pulses to ground so they do not damage expensive equipment.

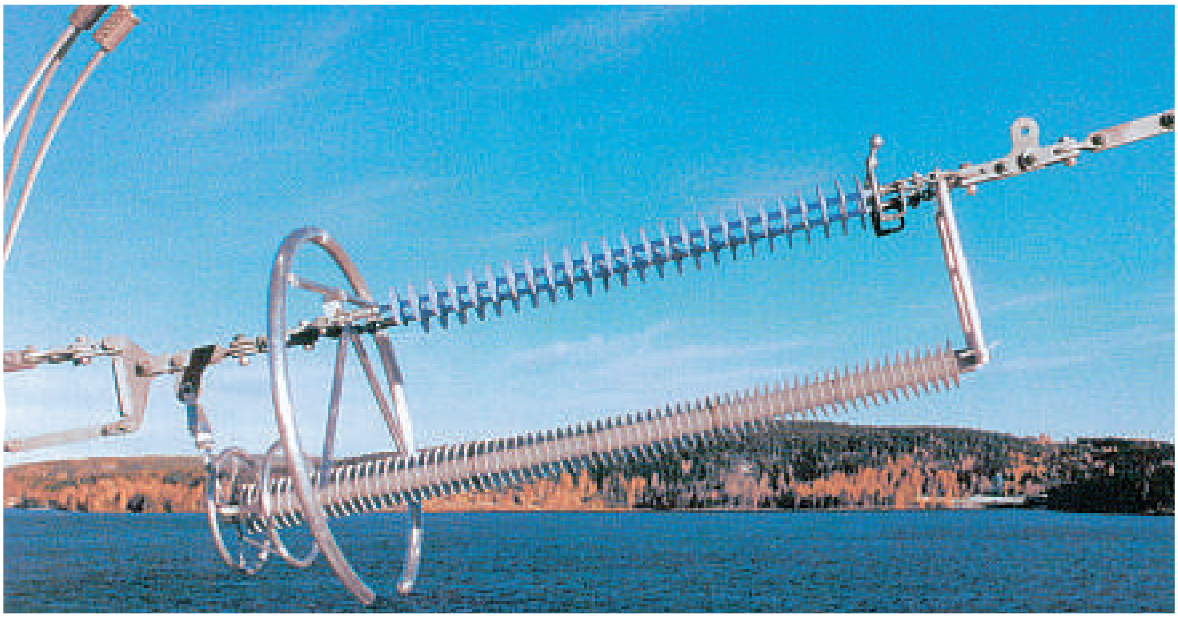
The arrester must also be positioned with care. Grid reflection points are an important consideration, since current surges can be reflected, thus gaining in destructive power. Another critical factor is the steepness of the wave. Steep waves are more easily reflected and, as the arrester can only handle them when they occur in the close vicinity, they limit the length of line being protected.

New approaches to insulation coordination are emerging in which the arrester is combined with the equipment to create novel design configurations. These solutions feature flexible polymeric insulation with modern MO resistors [1,2]. A typical application providing efficient line protection combines a suspension insulator and arrester, as in the case of ABB's PEXLINK product family 1 [3]. Similar applications have been proposed for other equipment, eg disconnectors [4], transformers [5] and breakers. These offer new economic potential in medium- and high-voltage systems.

Insulation coordination

In a broader sense, insulation coordination refers to all measures taken to avoid damage being caused by overvoltages in an electrical system. This is underlined by the IEC definition of insulation coordination as 'the correlation of insulation of equipment with the characteristics of the protective devices such that the insulation is protected against overvoltages'. In such a context,

1 Line surge arrester across a 400-kV tension insulator string. A disconnector is at the high-voltage end, to the left.



surge arresters form the traditional ‘first line of defense’.

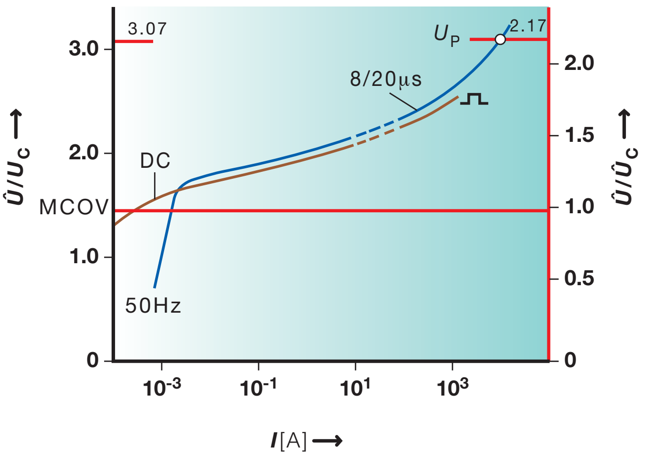
MO surge arresters have excellent protection characteristics, as the example given in 2 shows. The current-voltage characteristic, which is highly nonlinear, has its origin in microscopic grain boundary phenomena in the ceramic semiconductor [6].

For MO arrester applications, certain key parameters in respect of the protection characteristics must be known:

- *Maximum continuous operating voltage U_c* (MCOV): This voltage is selected such that it lies sufficiently below the knee point of the characteristic, where the power losses are low, most currents are purely capacitive, and a continuous insulating operation is guaranteed. However, the arrester can be operated at elevated *temporary overvoltages* (TOV) for limited periods of time (seconds-hours). For example, the AC rated voltage U_r specified by IEC ([7], for ≥10 s) is typically 25% higher than U_c, the actual figure being dependent on the arrester’s thermal design.
- *Residual voltage* or *protection level U_p* for standardized current impulses in the range of <100A to >100kA. Often U_p is normalized to the peak-value $\hat{U}_c$ of the MCOV (sometimes also to the rms value), being referred to then as the *protection ratio R* of the arrester. These impulses simulate critical surges, such as:
  – The most frequent lightning strikes (nominal current impulse of I_N = 2.5-30 kA, 8/20 µs, $R \approx$ 1.7–2.2).

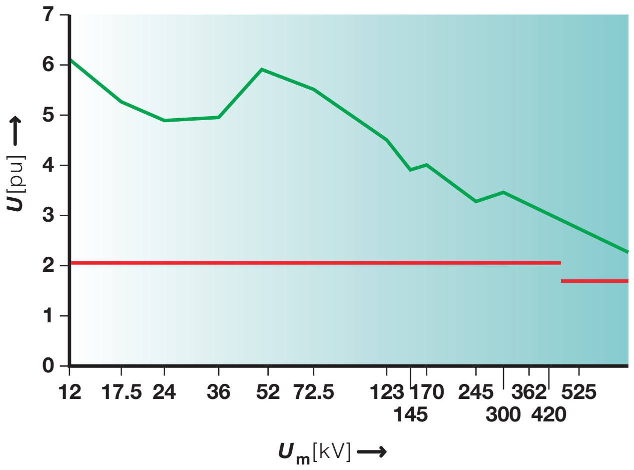
2 **Protection characteristics of a modern distribution-type surge arrester**

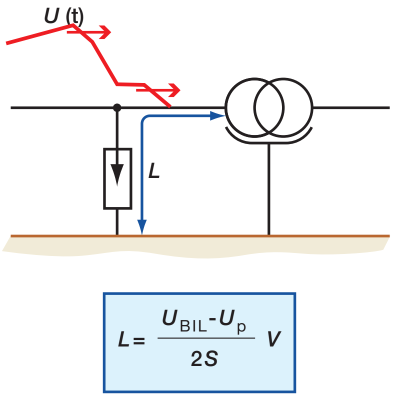
$\hat{U}/U_c$	*Residual voltage U_p (peak), normalized to rms value of maximum continuous operating voltage U_c*
$\hat{U}/\hat{U}_c$	*Residual voltage U_p (peak), normalized to $\hat{U}_c$*
I	*Current*



3 **Basic insulation level (BIL) required by the standards for testing insulation structures for different system voltages. Modern surge arresters offer much lower lightning impulse protection levels (LIPL).**

U	*Basic insulation level (1 pu = $\sqrt{2}$xU_m/$\sqrt{3}$)*
U_m	*Effective phase-to-phase voltage*





$$L = \frac{U_{BIL} - U_p}{2S} V$$

4 **Top: Interaction of surge arrester with incoming traveling wave *U(t)***
Bottom: Calculation of protective length *L* with full wave reflection. While the protective distance increases with decreasing residual voltage U_p, it decreases with higher wave steepness *S*. For remote lightning strokes, a steepness of about 1200 kV/µs is typical.

L	*Protection range, in m*	
U_{BIL}	*Basic insulation level of apparatus (eg, transformer), in kV*	
Up	*Protection level of arrester, in kV*	
S	*Steepness of surge wave (approx 1200 kV/µs)*	
V	*Velocity of wave propagation*	
	Overhead line	*approx 300 m/µs*
	Cable	*approx 150 m/µs*

- The rare direct lightning strike on an arrester (high current impulse of 65–100 kA, 4/10 µs, $R \approx 2.5$–2.9).
- Switching operations by a circuit-breaker (switching impulse currents of ~125–3000 A, 30/60 µs, $R \approx 1.5$–1.8).

The actual residual voltages depend primarily on the current amplitudes and, to a lesser degree, on the steepness of the pulse 2.

To choose the right surge arrester it is necessary to know the expected impulse currents, the insulation strength of the electrical components in the system, and the grounding and temporary overvoltage conditions. A lightning impulse coordination current I_N is defined for the expected impulse activity; for most networks this is typically 10 kA, but a value of up to 40 kA may be selected for the highest voltage levels. The insulation levels required today by the standards are summarized in 3 for different system voltages U_m. This figure only gives the lowest values specified by IEC, since the higher BIL values for a given phase-to-phase voltage just reflect different safety margins. For comparison, typical lightning impulse protection levels for modern MO surge arresters are also given for a situation in which good grounding conditions allow $\hat{U}_c$ = 1 pu (for non-solidly-grounded networks U_c may have to be increased to the value of U_m).

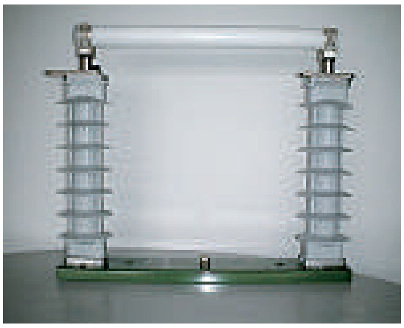
From 3 it is evident that today there are large safety margins between the equipment's required insulation strength and the protection offered by modern surge arresters. This is particularly true for the lower system voltages (up to 170 kV).

Arresters with low protection levels and field-proven reliability have been available for many years, and the time has come to reconsider the present practice of insulation coordination. Recent progress in material technology has opened up new opportunities, not only for reducing the over-dimensioned

Table 1: Comparison of different arresters. The very low protection levels of the polymer-housed arresters (types MWK and POLIM-D) result in better protective distances.

Range	*Relationship* U_p *8/20µs /* U_c *(peak)*			
U_c kV	POLIM-D class 1	MWK class 2	Others on market class 1	Others on market class 2
3–24	2.48		2.7 to 3.3	
4–36		2.17		2.5 to 3

5 Fuse–disconnector. The post insulator on the left has a surge arrester of type MWK integrated in it; the insulator on the right is a conventional one.



6 Suspension line insulator-arresters, combining mechanical support and the surge protection in a single device

insulation but also for locating the surge arresters elsewhere in the network.

The protective distance

Arrester protection is only provided over a limited protective distance *L*. This parameter depends strongly on the arrester protection level, or residual voltage U_p, and on the steepness *S* of the traveling surge wave. Its value is calculated with the equation in 4, and assumes the worst case of full reflection at an open end.

Since arresters do not all offer the same protection level, the protective distance will also vary. *Table 1* shows differences between the available arresters. It is seen that the protection values are especially low for the polymer-housed arresters of types MWK and POLIM-D. Their better protective distances make them superior to the other commercially available products.

The closer an arrester is to the apparatus, the better the protection it provides. The logical conclusion of this is that, to provide the very best protection, the arrester should be closely combined with the apparatus or even integrated directly in it.

Integration of arresters in apparatus

With the overvoltage protection now based on an integrated rather than a remote arrester, some obvious benefits arise. Not only is protection better and more efficient, especially where fast transients are concerned; such combinations are also more economical due to smaller space requirements and a saving in installation and logistical effort.

This kind of integration has already been successfully implemented, eg in transformers, where the arrester is submerged in oil in the tank [8]. Also known are combinations with HV disconnectors and MV fuse-disconnectors. In the fuse-disconnector shown in 5 one of the post insulators has been replaced by a high-performance MWK surge arrester. This has resulted in more efficient surge protection, reduced the space taken up and made installation easier. Other possibilities are integration in line insulators or in measuring transformers. 6 shows a suspension line insulator-arrester of type POLIM-S in which the mechanical support function and the surge protection are combined in the same device. Close-proximity combinations of arresters and HV bushings have also been realized for more efficient transformer protection [5] and for a gas-insulated HV bushing [9]. The fully integrated MV arrester-bushing shown in 7 combines an ordinary class 2 surge arrester with an outdoor bushing to form a single plug-on component. Such solutions have been made feasible by the development of new, tube-like MO elements that allow extremely compact concentric integration without affecting the functionality of either the protection device or the bushing.

The effect of such integration on the equipment's electric field characteristics

7 Integration possibilities: The 24-kV arrester (center-left) and outdoor bushing (left) can be combined into one compact arrester-bushing (center-right), which can be plugged on to a standard DIN termination (right).

is critical and has to be considered in the design. The mutual influence of adjacent parts on field distribution, for example, has to be carefully investigated.

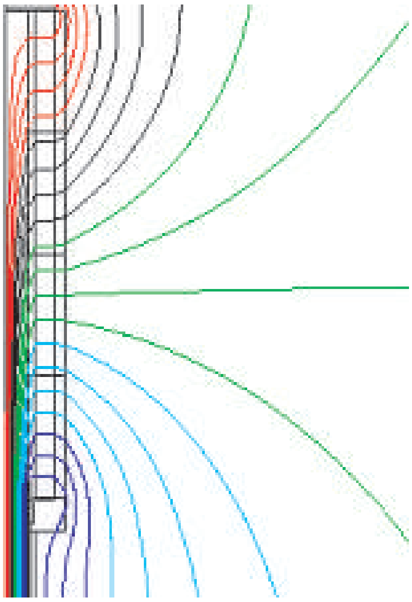
Field calculations and tests have shown that optimized, highly integrated solutions are possible. 8 shows, for example, the field plot for a cable termination with an integrated surge arrester. This example demonstrates the even field distribution displayed by MO elements simultaneously providing the function of electric field grading and surge absorption in the integrated device.

One potential disadvantage of integration is that the functionality of the apparatus containing the arrester may be compromised by an arrester overload. However, the probability of such an event is reduced by selecting a higher energy absorption capability, eg IEC class 2 instead of class 1. In the example shown 6, IEC class 3 arresters have been selected to greatly reduce faults and provide the highest possible availability even when there is high lightning density. Testing of the insulation strength is, of course, also affected by the integrated arrester, and new test criteria are required as a result;

Table 2: Proposals for new insulation coordination: dynamic insulation with integrated arrester function

U_m	Service stress	*Protection system*			
		Insulation	Interactive arresters		Insulation
kV	1 pu (peak) kV	Today's IEC BIL kV	Solidly grounded U_p kV	Non solidly grounded kV	New 'BIL' proposed kV
12	9.8	60/75	20	≤ 34	<50
24	19.6	95/125	40	≤ 66	<80
36	29.4	145/170	65	≤ 105	<120

8 Electric field distribution for a highly integrated 24-kV arrester termination



this is addressed, for example, in IEC 60694.

Where surge protection is heading

The trend we see today of increasing integration of arrester and equipment insulation functions will intensify in the coming years. The cost savings and increase in equipment performance and availability will be irresistible to operators, especially in a climate of deregulation and privatization. When protection schemes develop from today's practice of protecting only critical points in the system toward a network with widely distributed protection, insulation coordination can be revised and standards corrected downwards. *Table 2* proposes a way in which the system insulation could be reduced toward a 'new BIL' in such a new interactive or dynamic insulation configuration. Clearly, for solidly grounded networks or systems featuring fast ground fault interruption, radical reductions could be realized. The voltage would never be higher than the residual voltage of the interactive insulation and protective distance problems would no longer be of any concern. As integration progresses, the borderlines between insulation and protection will fade and, inevitably, the insulation material itself will perform surge arresting functions.

Such developments are not unrealistic and research work is already under way. For example, new polymer composites based on microvaristors [10], and which can be molded to any shape, can have their microcontacts and structure tailored to obtain highly nonlinear characteristics that extend into the high current regime needed to handle impulse currents. This may be a first step towards a dynamic, self-protecting insulation capable of dramatically changing our present approach to insulation coordination.

Authors

Walter Schmidt
ABB Switzerland Ltd
High Voltage Technologies
CH-5430 Wettingen
Switzerland
walter.schmidt@ch.abb.com

Dr. Felix Greuter
ABB Switzerland Ltd
Corporate Research
CH-5405 Baden-Dättwil
Switzerland
felix.greuter@ch.abb.com

References

[1] **W. Schmidt:** New Polim medium–voltage surge arresters with silicone insulation. ABB Review 2/96, 32–38.
[2] **T. Skytt, H.E.G. Gleimar:** Changing of the guard: Polymer replaces porcelain for surge arresters. ABB Review 1/02, 43–47.
[3] ABB publ. SESWG/A 2110E PEXLINK Ed 2, 1999.
[4] **V. Hinrichsen, et al:** CIGRE 2000, paper 33–104.
[5] **W. Schmidt:** Metal-oxide: An almost ideal surge arrester. Bull SEV/VSE 7/1998, p .13.
[6] **F. Greuter, et al:** The metal-oxide resistor – at the heart of modern surge arresters, ABB Review 1/89, 35–42.
[7] IEC 60071 part 1 (1993) and 2. Insulation coordination.
[8] **M. Kobayashi, et al:** Built–in type ZnO arresters for distribution pole transformers. CIGRE SC 33-95 and CIGRE Working Group 33.11TF 03. Application of Metal Oxide Surge Arresters to Overhead Lines.
[9] Siemens Infosheet 3ED2, 03/2000: Combined arrester-bushing for gas-insulated switchgear.
[10] **R. Strümper, P. Kluge-Weiss, F. Greuter:** Smart varistor composites. Advances in Science and Technology, Intelligent materials and systems, 1995, vol 10, 15–22.