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THE RESPONSE OF MOV AND SiC ARRESTERS TO STEEP-FRONT LONGER DURATION CURRENT PULSES

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ABSTRACT

An 80 m section of 138 kV transmission cable is used to produce pulses with voltages of several hundred kilovolts, currents greater than 20,000 A and risetimes equal to approximately 50 ns. This line pulser is used to test the response of MOV and gapped SiC surge arresters to steep-front, high current, 1.4 microsecond duration pulses. The typical arrester voltage during a pulse consists of a very strong initial "overshoot" voltage spike, followed by a nearly constant "residual" voltage which lasts to the end of the pulse. The "overshoot" voltage is believed to be related to the inductance of the arrester/divider circuit; this voltage increases linearly with peak current and is about the same for the MOV and SiC arresters. The "residual" voltage indicates the protection offered by the arrester due to its voltage clamping action and is larger for the SiC arrester. Replacing the arrester by a similarly sized aluminum tube allows the inductive portion of the response to be removed, and the true arrester response is then seen to be quite fast.

Introduction and Test Procedure

Fast transient voltages are now recognized to be present on electric power systems, and recent publications (1,2,3) have investigated the ability of arresters to control these transient overvoltages. All papers reveal the overvoltage resulting from the response of the arrester inductance to the large rates-of-change of current through the arrester during these steep-front transients. Schmidt, et al (1) and Ozawa, et al (3) carry out their measurements on individual block-size MOV samples and show that the inductive effect can be largely eliminated by taking the current return circuit through a central hole in the block. They then propose non-linear R-L-C equivalent circuits to model the arrester block.

We wish to extend this activity to full-sized, commercial arresters, as begun in our 1989 paper (2), to compare MOV and gapped SiC arresters, and to note the effect during steep-front pulses which extend beyond the initial inductive overshoot period. To carry out the intended measurements, the 1989 test concept, using a coaxial cable to deliver the steep-front pulse to the arrester, was continued, but a new, longer, higher voltage coaxial cable was obtained for these tests. The test facility is shown in the Figure 1 circuit diagram and in the Figure 2 photograph. Note that the line-pulser cable is now an 80 meter length of polyethylene-insulated, coaxial 138 kV transmission line with calculated characteristic impedance equal to 42 ohms, wave propagation velocity equal to 2.0E8 m/s, and dimensions: 3" OD x 1.1" ID. The 3000/3 ohm resistive divider has measured step response of approximately 30 ns. The Pearson 20 kA current transformer measures the arrester current. A LeCroy 6880 1.2 gs/sec digitizer is employed to record the voltage and current signals. When the total load beyond the peaking gap is a resistance equal to the characteristic impedance of the pulsing cable, the measured pulse rises in about 50 ns, as shown in Figure 3.

All arrester tests were conducted with commercial 9 and 10 kV distribution arresters, connected to the input of a terminated section of 15 kV distribution cable. As can be seen in Figure 2, the pulsing cable, the load cable, and the voltage divider are all connected directly to the top end of the arrester, and a very short lead is used between the bottom end of the arrester and the copper sheet ground circuit.

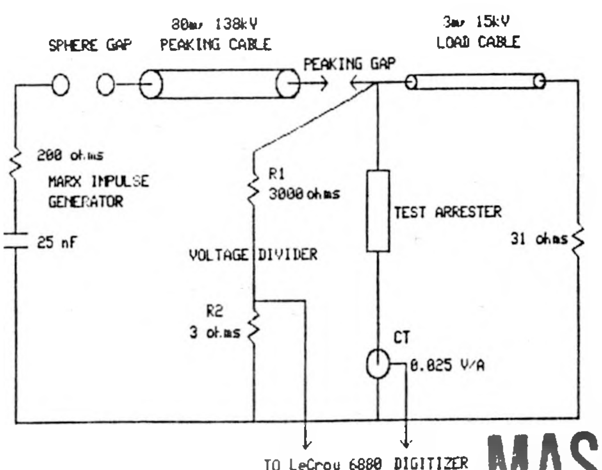

Figure 1 Circuit diagram of the steep front pulser.

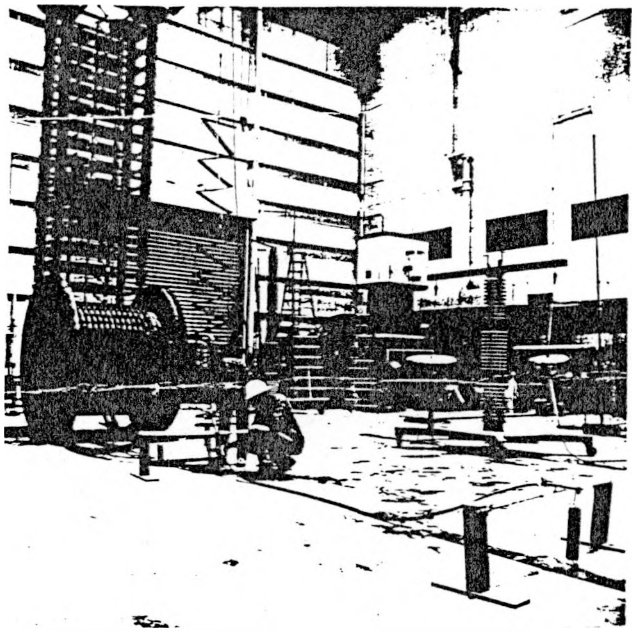

Figure 2 Photograph of the steep front pulser, showing test cable and its termination in lower foreground, test arrester, cable terminator and current transformer being adjusted by engineers, 80 m 138 kV peaking cable on large reel, 3 MV Marx generator in left background, and 3000 ohm/3 ohm divider in right background.

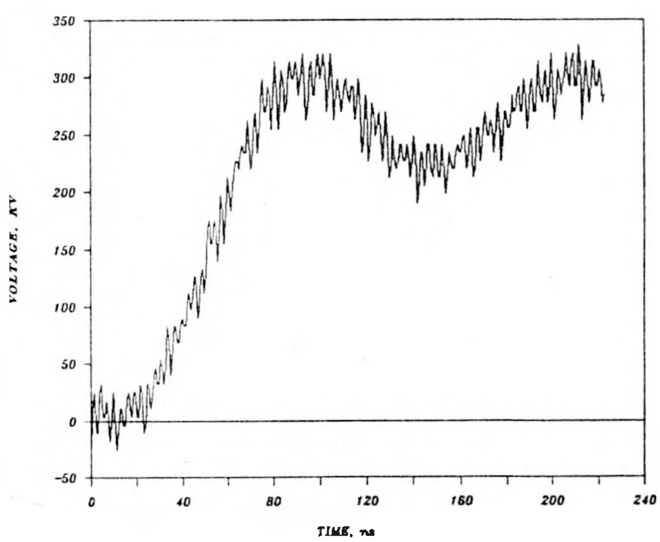

Figure 3 The front end of the pulse from the 138 kV peaking cable switched directly into a matching resistive termination.

Measurements

Figures 4-7 show typical current and voltage traces for the MOV and SiC arresters, for peak currents of approximately five and 20 kA. The current pulses are characterized by a steeply rise initial section, followed by a more-or-less steadily rising portion up to the peak value and then a rapid drop at the end of the pulse. The voltage has the initial "overshoot" peak cited in earlier references, followed by a nearly constant "residual" voltage value to the end of the pulse. The durations of the pulses are relatively long (approximately 1.4 microseconds).

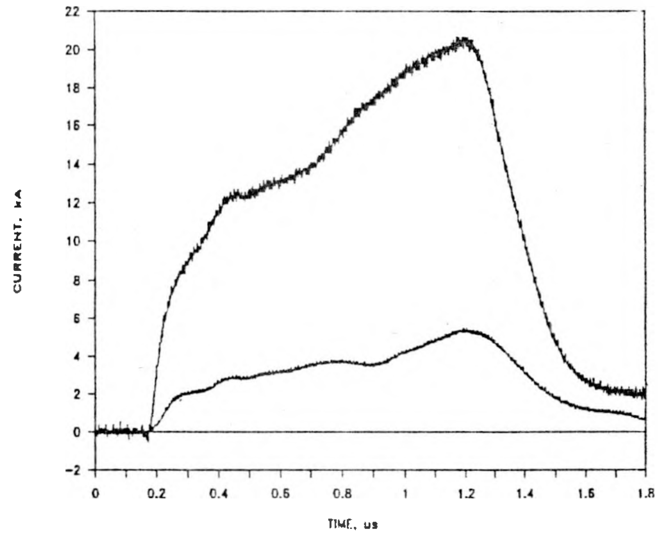

Figure 4 Current waveshapes for the 9 kV MOV arrester at approximately 5 and 20 kA peak.

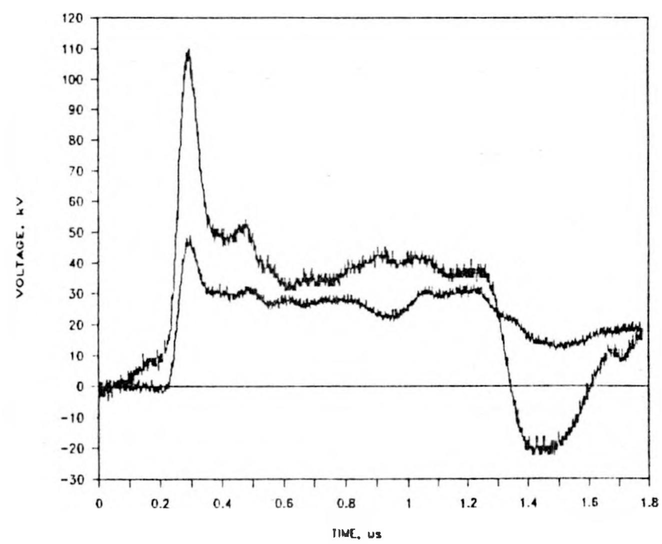

Figure 5 MOV arrester voltages during the 5 kA and 20 kA current pulses shown in Figure 4.

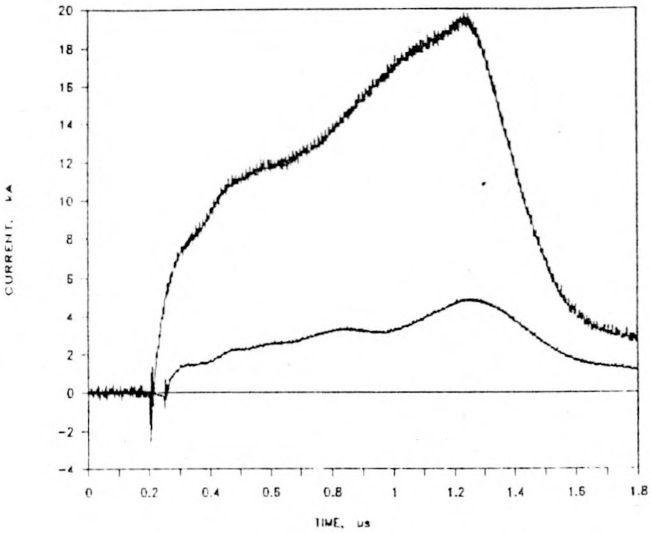

Figure 6 Current waveshapes for the 9 kV SiC gapped arrester at approximately 5 and 20 kA peak.

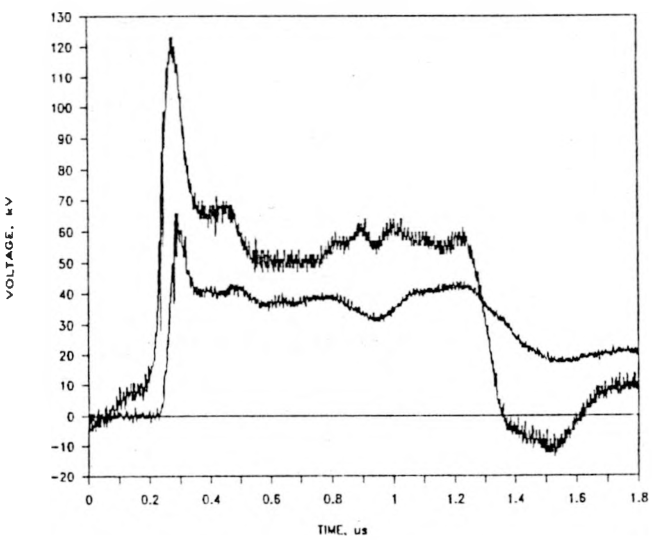

Figure 7 SiC arrester voltages during the 5 kA and 20 kA current pulses shown in Figure 6.

This type of test was performed on two MOV and one SiC 9 kV arresters, for peak currents from one to twenty kiloamperes. Figures 8 and 9 plot the peak "overshoot" voltage and the "residual" voltage (relative to the residual voltage) versus peak current. Figure 8 shows that the overshoot voltage increases linearly with peak current, independent of type of arrester. Actually, the overshoot voltage should be shown as a function of the peak di/dt at the front of the wave, but this current slope is difficult to measure precisely within the noise which is present on the signal. The slope is presumed to be proportional to the peak current. The overshoot voltage is ascribed to the effective inductance of the arrester circuit. If indeed the slope is proportional to peak current, then Figure 8 indicates that the inductances represented by the MOV and SiC arresters are equal. This agrees with the theory that arrester inductance depends on conductor geometry rather than type of arrester material.

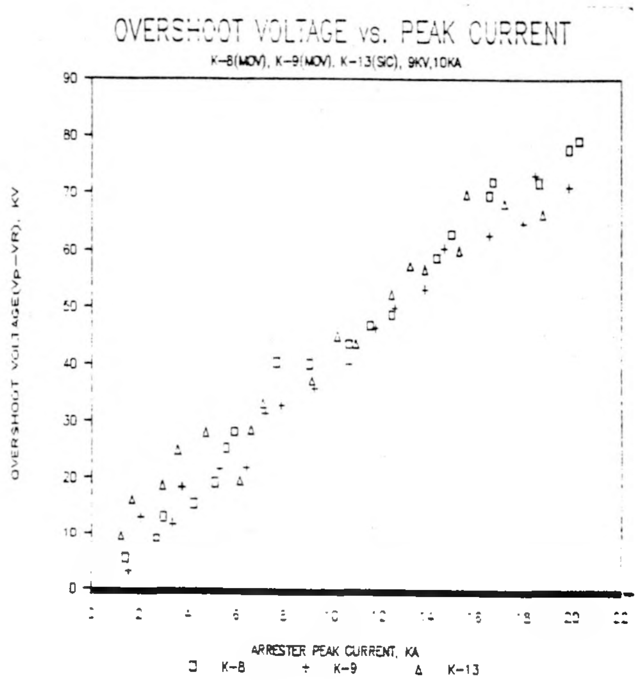

Figure 8 Overshoot voltage versus peak arrester current for two 9 kV MOV arresters and one 9 kV SiC arrester.

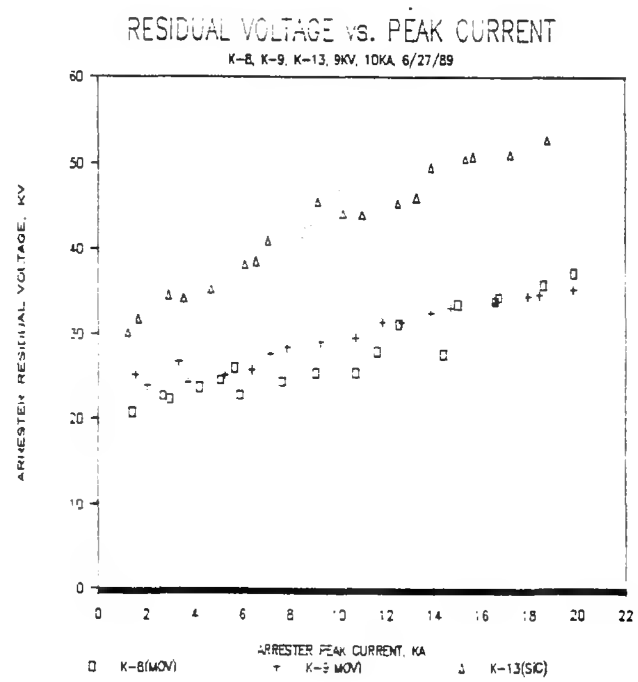

Figure 9 Residual voltage versus peak arrester current for two 9 kV MOV arresters and one 9 kV SiC arrester.

The relatively level "residual" voltage region can be ascribed to the protective action of the arrester active material. Figure 9 indicates that the 20 kA residual voltage is about 35 kV for the MOV arrester and 52 kV for the SiC arrester. This is in comparison to approximately 28 kV and 40 kV for the 20 kA 8x20 standard lightning discharge voltage for the MOV and SiC arresters.

In contrast to the "overshoot" voltage, the "residual" voltage (Figure 9) is higher for the SiC arrester. Both types of arrester show linear dependence of residual voltage on peak current, with the MOV unit having possibly a lower rate of rise of voltage with current.

Whereas References 1 and 3 separated out the inductive effect by taking the current return lead through the center of the arrester blocks, this study accomplished the same objective by substituting a thick-walled aluminum tube for the arrester. The length and outside diameter of the tube were approximately the same as the test arresters so that the equivalent inductances would be about the same. Figures 10 and 11 show the resulting current and voltage traces for peak current of 10 kA. The shape of the current trace is very closely similar to the current waveform with an arrester in place. The overshoot voltage, about 35 kV, is also nearly the same as with an arrester in the circuit (Figures 5 and 7), but the "residual" voltage now is approximately zero.

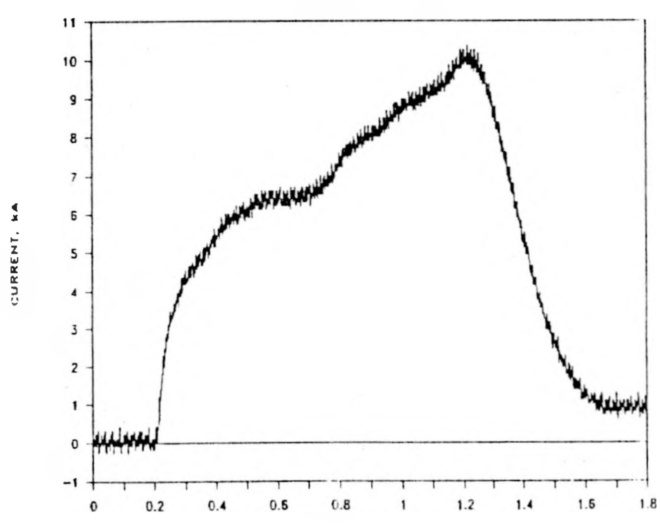

Figure 10 Current waveshape for the aluminum tube replacing the arrester in the the Figure 1 circuit, at approximately 10 kA peak.

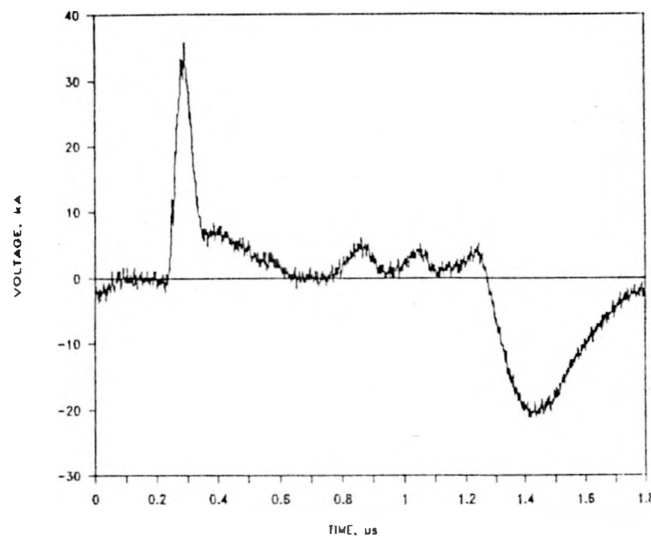

Figure 11 Voltage across the aluminum tube during the 10 kA current pulse shown in Figure 10.

If the response of the aluminum tube, for a given peak current, is subtracted from the arrester response at that same peak current, the inductive effect should be removed, leaving the voltage component due to the non-linear arrester material. This result is plotted in Figure 12. The rise time of the blocks in the arrester is seen to be about 60 ns, or slightly greatly than the risetime of the pulse itself. This result reveals that the conclusions of References 1 and 3, namely that the MOV material responds rapidly to rapidly changing voltages, holds also for complete commercial arresters.

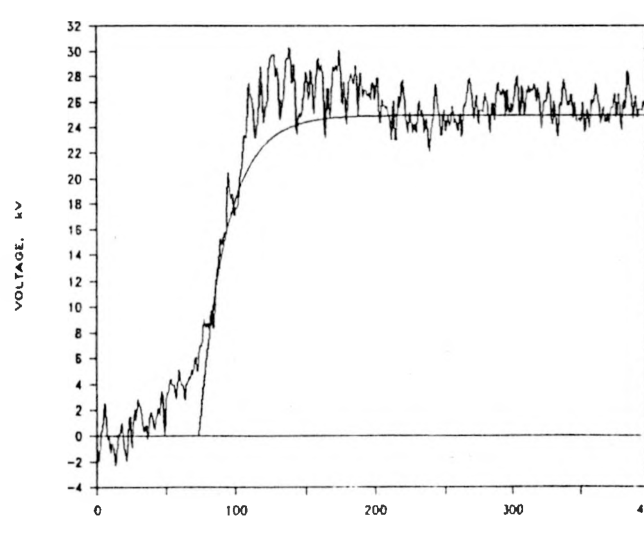

Figure 12 Aluminum tube voltage (Figure 11, extrapolated to kA equivalent peak current) subtracted from the kA MOV voltage pulse in Figure 5.

Model

These measurements lead to a simple empirical model for an arrester during a steep-front impulse. This model consists of an inductance in series with either a non-linear resistance or a current-controlled voltage source. The inductance has the magnitude equal approximately to 0.3 microhenry (ratio of overshoot voltage to di/dt). The current controlled voltage source magnitude is equal to the "residual" voltage and is taken from Figure 9.

Conclusions

1. A cable pulser has been developed which will deliver high-current, steep-front pulses to commercial arresters.

2. Commercial 9 kV MOV and SiC distribution arresters have been tested with this pulser, up to 20 kA peak.

3. The voltage response of these arresters to these current pulses consists of a sharp "overshoot" voltage, reaching ~~40~~ 120 kV peak at 20 kA peak, followed by a relatively level "residual" voltage region, which depends on current magnitude. The residual voltage is higher for the SiC arrester. This residual voltage holds up for the relatively long duration (about 1.4 microseconds) of the pulse.

4. The "overshoot" voltage is shown to be due to the inductance of the arrester. This inductive effect is mathematically removed by subtracting out the response of a metal conductor which has the same shape and size as the arrester. In this way, the rapid turn-on characteristic of the arrester material is observable.

5. A simple empirical model for the arrester during steep-front pulses, consisting of an inductance in series with a current-controlled voltage source, is proposed.

6. Filtering should be applied to these waveforms in order to be able to explore in more detail the relationships of current and voltage for both the gapped and ungapped arresters. These measurements should also be applied to a wider variety of arrester ratings.

Acknowledgements

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