Measurement of Transient Voltages in TVSS Systems

A properly-selected surge-rated series fuse causes no significant increase in TVSS clamping voltage.

Dan Dunlap and Bob Wilkins
Ferraz Shawmut
Newburyport, MA

A recent publication[1] has again raised the notion that use of a fuse to protect a TVSS system raises the clamping voltage. This idea comes partly from a misunderstanding of how fuses should be used in TVSS systems and results obtained with inaccurate measurements.

The problem of transient voltage measurement is discussed in this article, and techniques for avoiding large measurement errors are described.

Fuses for the protection of TVSS systems need to be surge-rated, *i.e.,* they must withstand the surge without melting. This article explains that a properly-selected surge-rated series fuse causes no significant increase in TVSS clamping voltage.

INTRODUCTION

Measurement of 8/20 μs surge currents is relatively easy and can be done accurately using a high-bandwidth Rogowski-type current transformer.

Measurement of the voltages produced by these currents is, however, a different matter. The voltages are normally too high for direct input to an oscilloscope so probe dividers are employed to reduce the voltage. Figure 1 shows a method which might be used with an ungrounded system. The voltage across the test object is taken to be the difference between the measured voltage on the two channels.

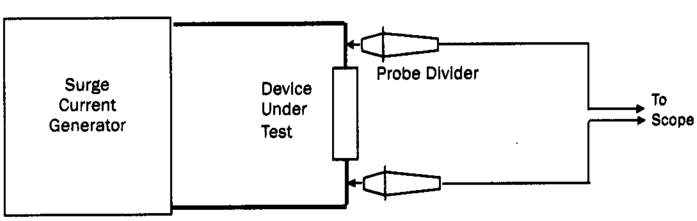

Figure 1. An incorrect method for measuring device voltage.

MEASUREMENT OF MOV CLAMPING VOLTAGE

Figure 2 shows a typical result of a surge test on an MOV, obtained using the measurement method shown in Figure 1. An MOV is principally a resistive circuit device, and the transient voltage should largely follow the manufacturer's published V-I characteristic with some dynamic variation.

However, the voltage wave in Figure 2 is significantly different, showing an initial voltage spike followed by a continuously drooping voltage during the rest of the surge.

Waveshapes such as that shown in Figure 2 are commonly found in published literature. Such data give a very poor estimate of the true MOV clamping voltage waveform. Since the MOV is a resistive element, the voltage should pass through zero at the same instant as the current, but the current zero in Figure 2 lags behind the measured voltage, indicating the presence of an inductive voltage error. The data shown is for a test with a relatively low peak current of 4.5 kA. For higher currents the

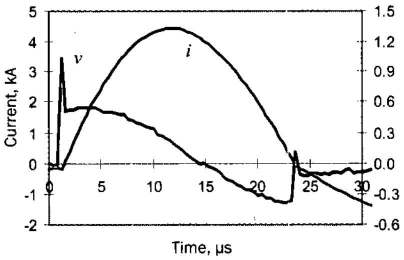

Figure 2. Typical results obtained with an incorrect voltage measurement method.

inductive error becomes even larger.

INDUCTIVE VOLTAGE ERROR

Figure 3 shows schematically an attempt to measure a resistive surge voltage V_R using a method like that shown in Figure 1. The surge current produces a magnetic flux ϕ which links the measurement loop (the area shown shaded) and an induced electromagnetic flux equal to $d\phi/dt$ is produced. The measured voltage is then

$$v_{MEAS} \quad v_R \quad \frac{d\varnothing}{dt}$$

$$v_R \quad L\frac{di}{dt}$$

where L is the inductance of the loop.

For MOV surge testing, di/dt is high (~ 1-10 kA/µs) and the induced voltage can be very high, sometimes completely dominating the measurement. This observation is particularly important for high test currents, and when the true resistive voltage drop is small.

The inductive voltage is responsible for the droop commonly seen in MOV voltage measurements. On the front of the current wave, di/dt is positive, so that Ldi/dt adds to the measured voltage, while on the tail, di/dt is negative, and Ldi/dt subtracts. In the presence of a significant inductive voltage, the true value of V_R is obtained only at the instant of peak current when di/dt = 0.

Reducing the area of the loop reduces the inductive voltage. With the probes positioned as shown in Figure 1, their physical size will not allow a small loop to be obtained. It is better to connect the leads as close to the device under test as possible, to twist them together to obtain flux canceling, and then to position the probes well away from the test circuit, at the far end of the leads. Figure 4 shows the improvement which can be obtained using this method for a test on a 150 V MOV. The lower (black) voltage transient was obtained with the leads as close to the MOV as physically possible. In the case of the upper (blue) voltage transient a loop area of about 2 in^2 was deliberately created by separating the twisted pair of leads. The increase in voltage and droop can be clearly seen.

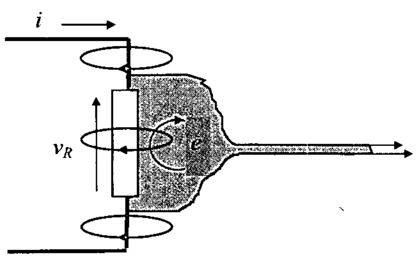

Figure 3. Inductive voltage in measurement leads.

THE NEED FOR SHIELDING

Even with twisted leads and the probes remote from the test object, there is still a significant inductive voltage, as evident in Figure 4. Further improvement must be obtained by shielding the measurement leads by enclosing them in a copper tube which shields the conductors from the magnetic field.

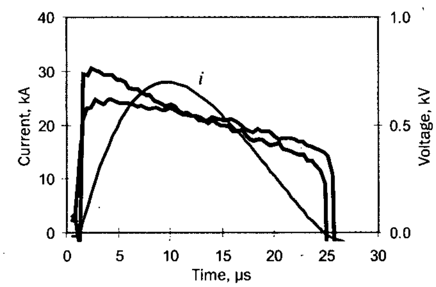

Figure 4. Effect of area of inductive loop.

An 8/20 µs impulse wave has a wide spread of spectral frequencies, principally in the range of zero to 20 kHz, but with significant higher frequencies as well. To obtain satisfactory shielding at all frequencies, including the lower ones, a shield thickness of at least 1 mm is needed. With such a shield, the inductive voltage error in the measurement loop can be eliminated almost entirely.

INITIAL VOLTAGE SPIKE

In addition to the measurement problems posed by magnetic field interference, there is also electrostatic coupling to the measurement leads, which is the cause of the initial voltage spike seen in Figure 2.

When the making switch in the surge generator closes, the voltage on its output side will change very rapidly indeed, and this change will be transmitted to the measurement leads by stray capacitances. The stray capacitances are small and will discharge very rapidly (*e.g.*, through the input impedance of the measurement system), and *thus* there will be a capacitive voltage spike produced. The magnitude of this spike will depend upon the layout of the system components and the interconnected network of capacitances between them and to ground. Sometimes this initial spike is mistakenly taken to be the clamping voltage of the MOV or TVSS system. Actually, it is a function of the measurement system. If the measurement leads were not there, the spike would not exist.

Electrostatically coupled interference voltages can be reduced by enclosing the device under test and measurement system within a Faraday cage, as described.[3]

RESULTS OBTAINED WITH SHIELDED SYSTEM

Figure 5 shows results obtained with the measurement points situated as close to the MOV as

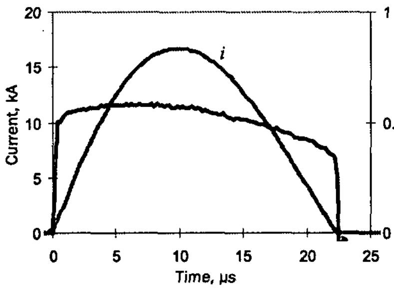

Figure 5. True clamping voltage waveform of an MOV.

possible, the leads twisted within a copper tube and then surrounded by a steel pipe, with the probes remote from the surge generator.

The initial voltage spike and inductive voltage are almost entirely removed, revealing the true MOV dynamic voltage response.

TESTS ON MOV WITH SERIES VSP FUSE

If a measurement arrangement similar to that shown in Figure 1 is used to measure the total voltage across a fuse in series with an MOV, a very large inductive error is produced because the loop area is increased by connecting the leads across the two components. The higher transient voltage which is then measured, is incorrect.

Figure 6 shows the total voltage across a surge-rated VSP fuse in series with an MOV, using the shielded measurement arrangement described in the previous section. The total voltage transient is almost the same as that shown in Figure 5. In fact, the peak voltage obtained is very slightly lower than that shown in Figure 5 and is caused by normal variations in MOV characteristics. This result shows conclusively that the addition of a series fuse has no significant effect on clamping voltage—not really surprising since the fuse resistance is very low.

EFFECT OF USING A NON-SURGE-RATED FUSE

In a TVSS system, the function of the fuse is to protect the system against the effects of an MOV failure by clearing the 60 Hz follow current. It should *not* operate during surge conditions.[4]

If a non-surge rated fuse is used, it may melt during the surge and may produce an arc voltage across its terminals which adds to the MOV clamping voltage (Figure 7). The fuse was not rated to withstand the applied surge and melted on the current wavetail, causing the total voltage to more than double. This occurrence is obviously undesirable and emphasizes the necessity of using surge-rated fuses for TVSS protection.

TESTS ON A COMPLETE TVSS SYSTEM

Before surge voltage measurements are made on a complete TVSS system, it is essential that errors in the measurement system are minimized by the shielding methods described above. The measurement

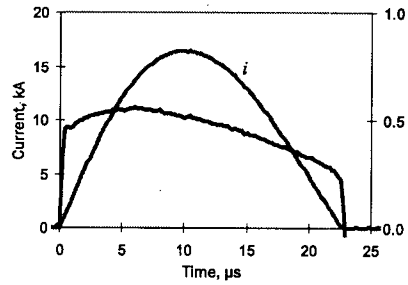

Figure 6. Clamping voltage with surge-rated fuse.

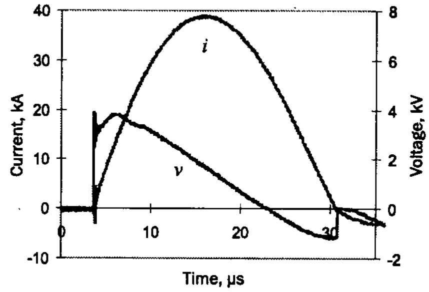

Figure 8. Test on a commercial TVSS system.

system must then be validated by checking that correct clamping waveforms for an MOV are obtained (See Figure 5).

Of course, in a real TVSS device the voltage at the terminals of the device will be higher than the MOV clamping voltage because of the inductance of the connections from the MOV to the device terminals which will normally include a VSP fuse. This "parasitic" inductance[3] is a function of the wiring and the board layout of the components in the device and is controlled by the skill of the TVSS designer.

Figure 8 shows the result of a surge test on a commercial TVSS product, using the shielded voltage measurement techniques described previously. The voltage waveform shows a typical inductive voltage droop. However, this droop is *real.* It is due to the total inductance of the TVSS system wiring loop and is not caused by the inductance of the measurement loop.

CONCLUSION

Great care is needed when measuring voltage transients in TVSS systems to eliminate errors caused by magnetically-induced voltages in the measurement loop and capacitively-coupled voltage spikes at switch-on.

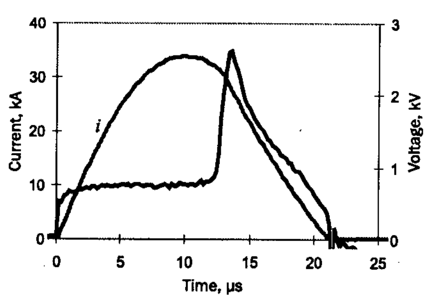

Figure 7. Effect of using a non-surge-rated fuse.

If properly-shielded measurement leads are used, true clamping voltages can be recorded, even for high currents and low-resistance devices. Measurements done in this way show that surge-rated VSP fuses cause no significant increase in the clamping voltage of a TVSS system.

REFERENCES

1. P.H. Wiley. "Repeated Surge Performance of Fused Surge Protective Devices." *Power Quality Assurance*, November 1999. 30–34.
2. I.M. Vitkovitsky. "High Power Switching." (Van Nostrand 1987).
3. F.D. Martzloff. "Driving High Surge Currents into Long Cables: More Begets Less." *IEEE Transactions on Power Delivery*, Vol. 12, No. 3, July 1997. 1176–1184.
4. R. Wilkins. "Protection of TVSS Systems." *Proceedings of Power Quality 99 Conference*, Chicago, November 1999. 390–397.

Note: the test results in this article were obtained using:

Oscilloscope – Tektronix TDS420A 4CH, 200 MHz, 100 MS/s

Voltage probes – Tektronix P6015A, with 10 ft. cable

Current Transformer – Pearson Electronics 1423, 1000 A: 1 V

DAN DUNLAP and BOB WILKINS can be reached at Ferraz Shawmut, Newberryport, MA, (978) 462-6662 or Dan.Dunlap@ferrazshawmut.com. ■