PRACTICAL LIMITATIONS OF BACK FILTER DESIGNS FOR VOLTAGE AND CURRENT SURGE TESTING

Introduction

The requirement for surge testing equipment while it is operating on ac power lines is now becoming widespread. To satisfy this need, specifications for this purpose are being issued. One major specification is IEEE Standard 587-1980, which describes three basic waveforms applied to the Equipment Under Test (EUT) while it is simultaneously energized from an ac power line. In order to prevent the surge waveforms from reaching equipment on the ac power line other than the EUT, and in order to prevent severe loading on the surge generator, a back filter is required between the ac power lines and the EUT. Problems of isolating the ring wave and the discharge current waveform are fairly straightforward. However, significant problems are encountered when employing a back filter in conjunction with an open circuit waveform if no restrictions are placed on the amount of ac current flowing to the equipment under test. This article describes the nature of the problem and a suggested approach for testing under this condition.

The Need For A Back Filter

Filtering is required for two reasons:

1. To attenuate the pulse signal fed back to the power lines to prevent damage to devices other than the EUT on the power line and;
2. To prevent loading of the surge generator so that the desired voltage can be generated across the EUT input.

Figure 1 shows a simplified basic diagram of a standard filter. In this figure two inductors are shown (each having a value of $\frac{L}{2}$), indicating that filtering is provided in both ac lines. To achieve the desired filtering and provide an adequate impedance for the surge generator so as not to severely attenuate or distort the surge to the EUT, the total value of L should be high. However, a high inductance causes an excessive drop in the voltage to the EUT if the line current required by it is high. To minimize the voltage drop across L, its value should be small. This would require a very large value of C to achieve the surge attenuation back into the ac line. However, a low L and high C result in very heavy loading on the surge generator, and unless the surge generator source impedance is extremely low, amplitude reduction and waveform distortion (primarily rapid decay) will result. If the generator is being used in a mode intended for high surge current, this decay will be acceptable since the surge generator source impedance is low. However, if the surge generator is used in a high impedance (or open circuit) mode, then the effects on waveshape and amplitude are severe. (See Figure C2, "Voltage into High-Impedance Test Piece; $1.2 \times 50 \mu S$ 10kV Maximum" of IEEE Standard 587-1980 which suggests a generator source impedance of 250 ohms for the high-impedance mode.)

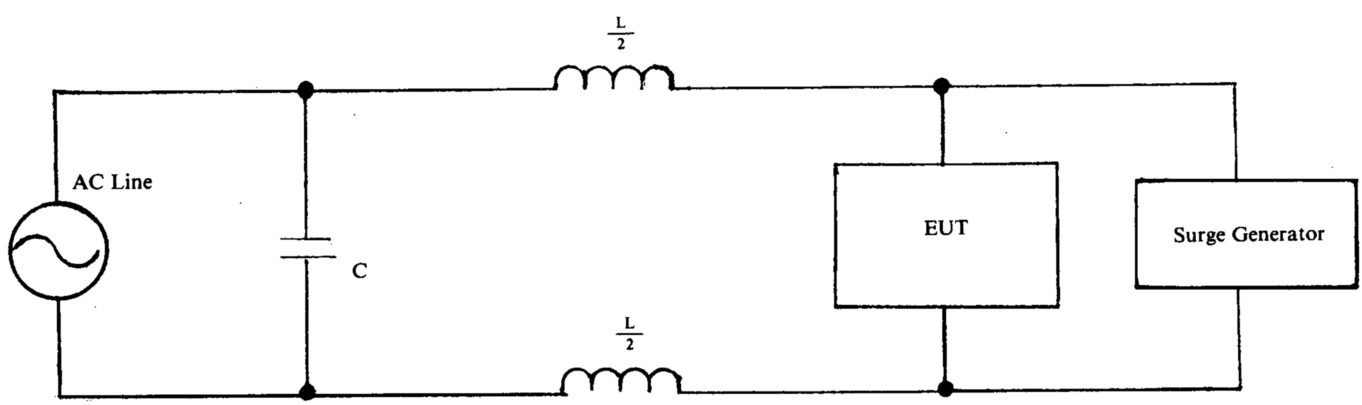

Figure 1: Standard Filter

The above considerations present contradictions and a dilemma for the designer of the back filter. Consideration has been given to the use of various types of filters employing a series element other than a "simple inductor." Such approaches lead to additional problems. For example, if the impedance of the inductor is changed dynamically so as to increase during the time the pulse is present and decrease at other times, good isolation is achieved. However, aside from the test being difficult and costly to design and construct, a distortion or drop-out of the ac waveform could occur during the surge time and thereby invalidate the test.

Practical Back Filter Values

Some realistic values for a back filter can be considered. Referring to Figure 1, it can be seen that for maximum attenuation, both $\frac{L}{2}$ and C should be high. However, for considerations pointed out earlier, very real limitations exist, particularly regarding the values of the inductance. It should be recognized that the impedance of the EUT can be purely resistive, purely inductive, purely capacitive, or complex. Also, it can be non-linear, linear or any combination of these conditions. Furthermore, the load can be dynamically changing and non-constant. Assuming the *simplest* condition wherein the load is constant, linear and resistive, and given a condition where the EUT requires 20A RMS from a 120V RMS, 60Hz line, the impedance of the EUT would be 6 ohms. For isolation purposes, the value of the inductance must be at least 1mH. In this case, X_L is equal to approximately 0.38 ohms. As can also be seen with a current of 20 amperes, this results in a voltage drop of 7.6 volts which represents a 6.3% drop in the ac voltage to the EUT. It should be noted that this drop is in addition to that of the allowable variation in the supply voltage. For example, if the line is 10% low, then after the drop through the inductor, the EUT voltage would be greater than 16% below nominal voltage. With a constant load, this drop could be compensated for by stepping up the line voltage, but if the load fluctuates, the poor regulation of the filter can cause voltage fluctuations to occur as well. Furthermore, if the load is not linear, other complications severely exacerbate the problem. In practice, values of higher current, higher inductance, and higher ac line frequency further aggravate the problem.

Suggested Solution

A compromise approach is suggested in which the best back-filtering is achieved consistent with the other requirements. This approach employs a back filter providing a low series inductance for those modes of surge testing that require high surge currents. However, the back filter provides a high series inductance for that mode of surge testing requiring high surge voltages into a high impedance or open circuit condition.

To ease the operator problems, the back filter can be made to automatically change the value of series inductance when the surge generator is switched from a high current mode operation to a high impedance mode operation. Apparently this type of operation poses only one minor disadvantage; since the 6kV, $1.2 \times 50\mu S$ waveform is used solely in a mode of operation designed for high impedance circuits, the only time the back filter could affect the normal flow of current would be when the surge voltage has caused a breakdown in the EUT, causing it to change from a high impedance to a low impedance circuit. In this case, the back filter may provide some limiting of the "follow-on" current from the ac line. However, this would occur only after a breakdown occurred. In such a rare instance, separate tests could be made to determine the effects of follow-on current.

Appendix

The reasons that the back filter design is relatively difficult in this application as compared to many others is primarily due to the combination of the following factors:

1. The relative closeness in the surge pulse period to that of the ac power line period (for 60Hz the period is approximately 8.3mS whereas the equivalent pulse period may be greater than 0.1mS). This problem increases with higher ac line frequency.
2. The high values of load current required by many of the EUTs (frequently equal to, or greater than 20A RMS).
3. The high value of peak surge voltage (6,000V peak).
4. The need to maintain a very small voltage drop across the backfilter.

This article was written for ITEM by William Milwitt, President, Velonex, Santa Clara, CA.