EMP and Transient Suppressed Mains Filters

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INTRODUCTION

The transient suppressed mains supply filter, incorporating protection arrangements for EMP, lightning and other line induced transients, has been around for some time. Because of the ruggedness and the transient absorption qualities of mains power supply circuitry, the benefits of a transient suppressed filter for the EMP protection of mains supply lines have been questioned. These queries include the exact form which the transient suppressor component should take, where it should be placed with respect to filter and load, and whether one is actually necessary.

The well-known shape and amplitude of the model nuclear EMP of 50 kV/m electric field strength, rise time of <10 ns, and duration of 300-600 ns, is modified quite significantly when the waveform is induced into a *long* power line. Generally, it is considered that the principle effects of the line are such that the rise time is lengthened to about half a microsecond, the amplitude of the induced current applied to the load is of the order of 5 kA, and the duration is more likely to be 10 microseconds. These changes are caused primarily because the shape and amplitude of the induced EMP is dependent on so many factors other than the field strength of the EMP, particularly the situation and the environment in which the cable and load are sited, and the quality and effectiveness of the load matching arrangements.

The precise degree of protection offered by EMP mains filters is rarely defined well enough for correct interpretation by a system designer.

The electromagnetic field produced by lightning, on the other hand, is totally unpredictable, as no two lightning strikes are the same. A standard has to be defined, however, to provide equipment manufacturers with appropriate design parameters. Some examples of pulse shapes and waveforms which components and complete systems should be immune to are:

- 10 microsecond rise time, 700 microsecond duration, current of >300 A;
- 10 microsecond rise time, 1000 microsecond duration, current up to 500 A; and
- 8 microsecond rise time, 20 microsecond duration, current up to 5 kA.

The purpose of any mains filter is to rid the line of the induced transient, and thus limit the frequencies which are allowed to pass. This increases the rise time and reduces the amplitude of the transient, providing the energy handling capability of the components in the filter is adequate. Filters could be used, therefore, to slow down the EMP, so that a surge arrestor fitted across the load has sufficient time to ionize or strike, and shunt away most of the energy before it reaches the input circuits of the equipment being protected. However, the majority of EMP or transient suppressed filters have the suppressor arrangements fitted at the front or source end where they absorb most of the energy before application to the filter and the equipment circuitry. The positions of the protection arrangements are therefore relevant.

EMP protected mains filters, currently being produced as standard products, provide various degrees of protection against EMP, lightning and other transients. Unfortunately, the precise degree of protection offered rarely is defined clearly enough for interpretation by a systems designer. For a given filter range by a specific manufacturer, the degree of protection is often determined by the cost of the complete product. It is quite likely, therefore, that when a particular range of EMP protected filters is more expensive than another, the cost difference can be the key to the degree of protection provided.

This article has been written to detail tests which were undertaken to clarify some of these uncertainties, and it attempts to put into perspective the different forms of EMP or transient suppressed mains filters which are generally available.

TEST SETUPS, TEST EQUIPMENT AND ITEMS UNDER TEST

The filter used as the test piece had basic parameters of 250 V ac, 50/60 Hz, single phase, 60 A. One version was fitted with a varistor only, and another version was fitted with a gas discharge tube as the primary protection, and a delaying choke and varistor as the secondary protection.

One test setup utilized a pulse forming network (PFN), consisting of a capacitor charged to a specific value by a dc charging source, to provide the test transient inputs. In this arrangement, the energy contained in the applied pulse is determined by the amplitude of the charging voltage and the value of the capacitor (Energy = $1/2\ CV^2$). Two PFN's were used in the tests. One consisted of a 1-μF capacitor charged to 3 kV from an appropriate charging source, and providing about 4.5 J of energy. The other was a 13.4 μF capacitor charged to 3 kV by the same source, and providing 60 J. The 60 J output was a positive-going pulse having a rise time of 1.2 microseconds. The short-circuited current waveform was an exponentially decreasing sinusoid of frequency approximately 300 kHz, and the maximum peak amplitude was about 5 kA.

The tests on the filter, in its two versions, were conducted at different times. Circuit diagrams of the two versions, connected as a standard product, are shown in Figure 1.

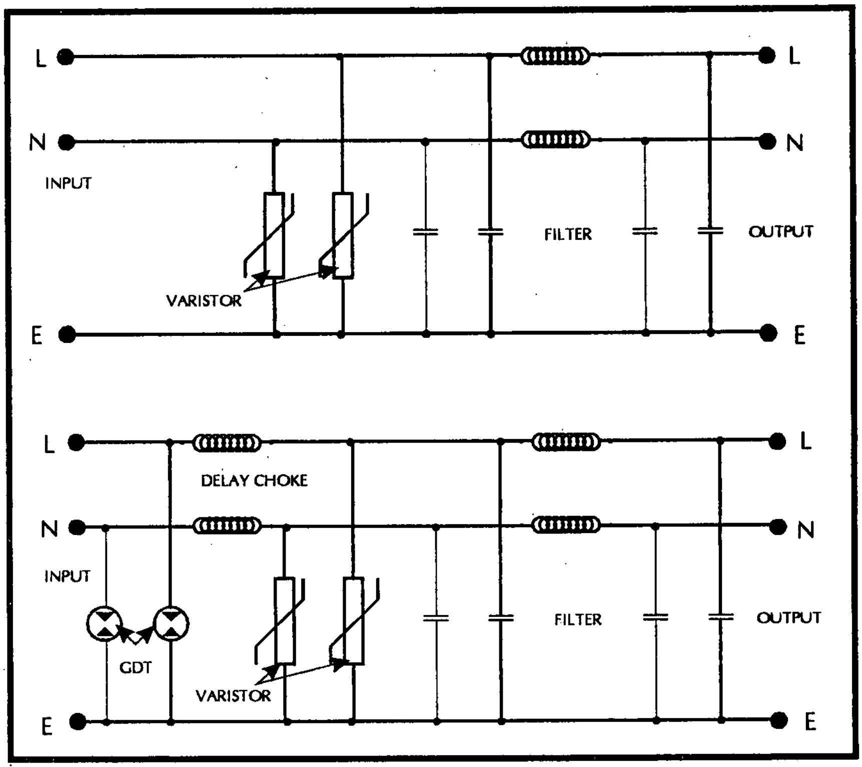

FIGURE 1. Filter fitted with Varistor Protection Only (Top), and Filter Fitted with Both Primary and Secondary Protection (Bottom).

The varistor used in these models of mains filters has the following parameters:

Maximum continuous ac rms voltage = 275 V
Maximum continuous dc voltage = 369 V
Transient energy = 140 J
Peak current (1 pulse) = 6.5 kA
Typical capacitance (1 MHz) = 900 pF
Clamping voltage (8/20 microsecond) = 740 V

TESTS OF THE EMP PROTECTED MAINS SUPPLY FILTER

With a 5-ohm load connected across the filter output, and with no protection at all fitted, application of the test pulse produced the waveform shown in Figure 2. Figure 3 is the output of a filter protected by a single varistor connected across its input. Figure 4 shows the filter output under the same test conditions but with the varistor connected across the output, i.e., across the load.

Application of the test pulse to the test piece having both primary and secondary protection, i.e., gas discharge tube, delay choke and varistor, gave the response shown in Figure 5. With the same test waveform applied, the response of the same test piece, but with the varistor disconnected, is shown in Figure 6.

Tests carried out using the second test setup were conducted on the filter fitted with full EMP protection only, i.e., fitted with GDT, choke and varistor. The test pulse waveform was applied to the input. The filter input (output of protection arrangements) and the filter output were monitored with the delay choke both in and out of circuit.

Figure 7 shows the output of the transient protection arrangements. Figure 8 shows the same output with the delay choke disconnected. Figures 9 and 10 show the output of the complete filter under the same test conditions.

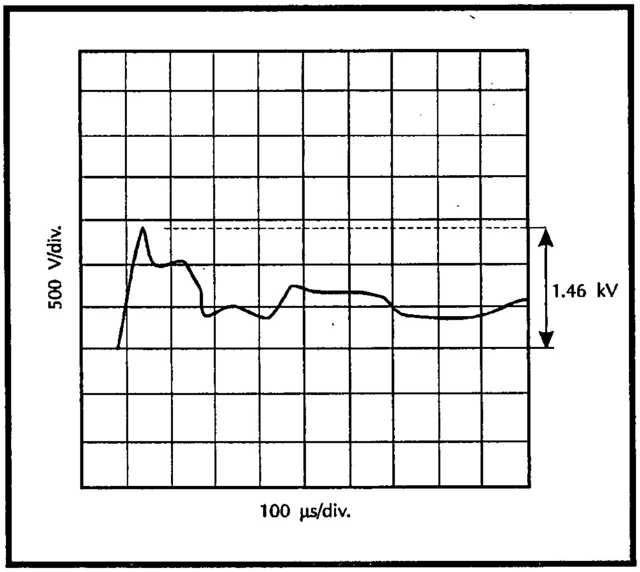

FIGURE 2. *Filter Output with No Protection Fitted, and Connected to a 5-Ohm Load.*

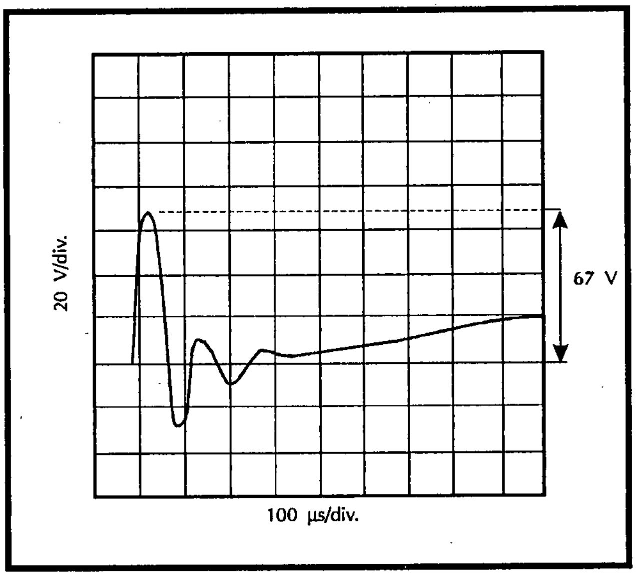

FIGURE 3. *Filter Output with Varistor Connected Across the Input, and a 5-Ohm Load Across the Output.*

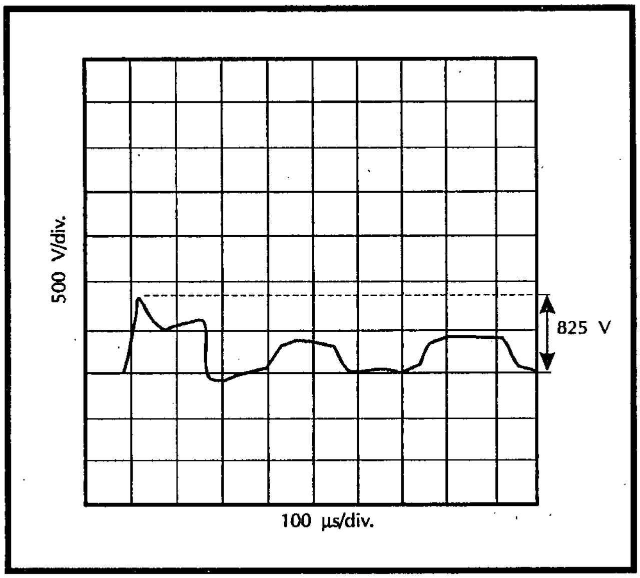

FIGURE 4. *Filter Output, with Varistor Connected and 5-Ohm Load Connected Across the Output.*

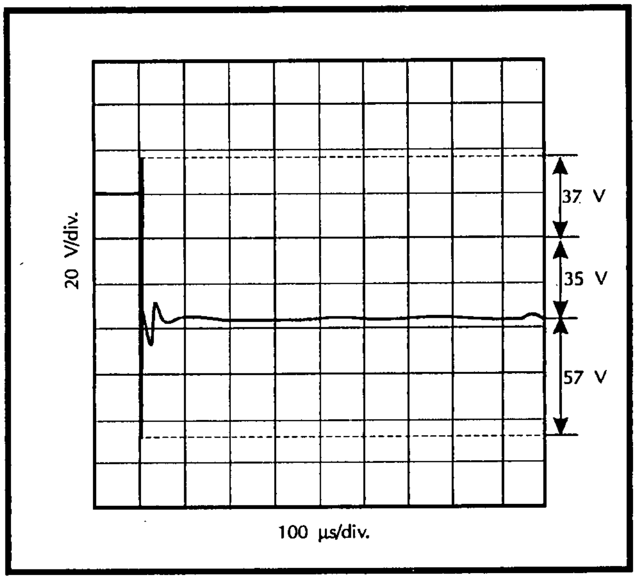

FIGURE 5. *Response of Filter Fitted with Full EMP Protection.*

TEST RESULTS

Examination of Figures 2 through 4 shows quite clearly the benefit of having a varistor fitted as a transient suppressor, and its ability to eliminate the maximum amount of energy when it is fitted at the front or source end. Figures 5 and 6 illustrate the importance of having a second stage of protection, particularly the action of the secondary protection in bringing the eventual line voltage level down to that which would be more acceptable to potentially vulnerable circuitry. Selection of the secondary protection component allows almost any line voltage level to be chosen. Notably, under these two separate test conditions, the excursions at the output are about the same amplitude, but have a different reference.

Figures 7 through 10 show the effect of the delay choke on the eventual output applied to the equipment being protected.

CONCLUSION

The waveforms achieved show that the transient suppression arrangements protect the filter as well as the circuits connected to the load end of the filter. Indeed, it could be said that with the protection components at the filter output, the filter is *protecting* the transient protection arrangements, bringing the input waveform down to a much more manageable size.

The action of the delay choke is also made clear, indicating that the arrangement is much more efficient with it in the circuit. The attenuation level of the

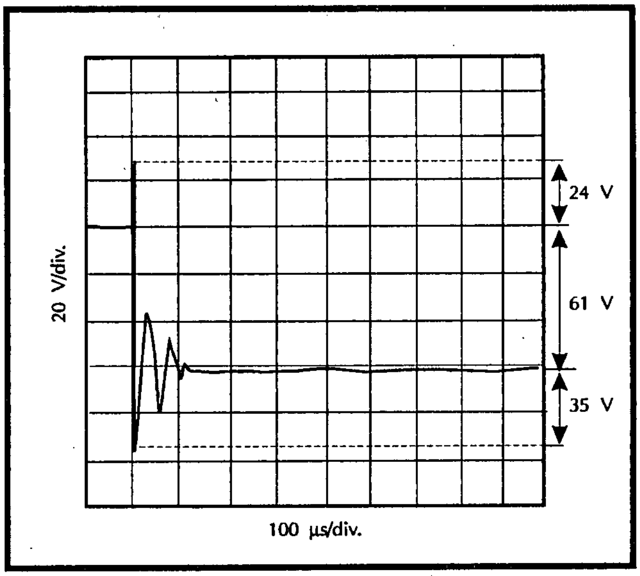

***FIGURE 6.** Response of Filter Fitted with Full EMP Protection, But with Varistor Disconnected.*

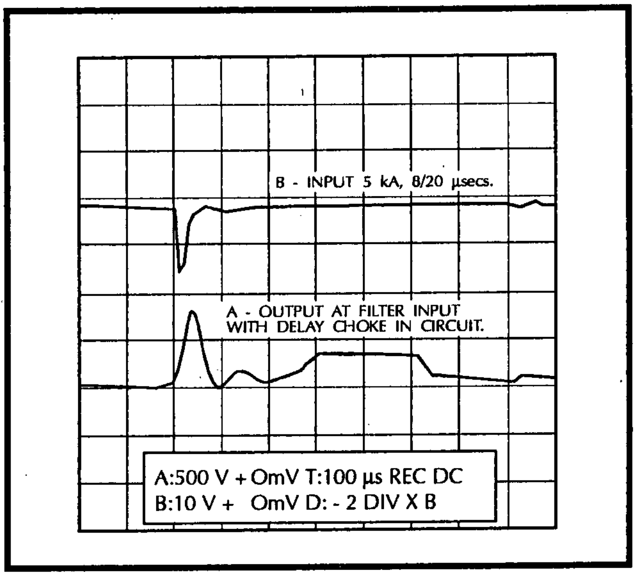

***FIGURE 7.** Output with Delay Choke in Circuit.*

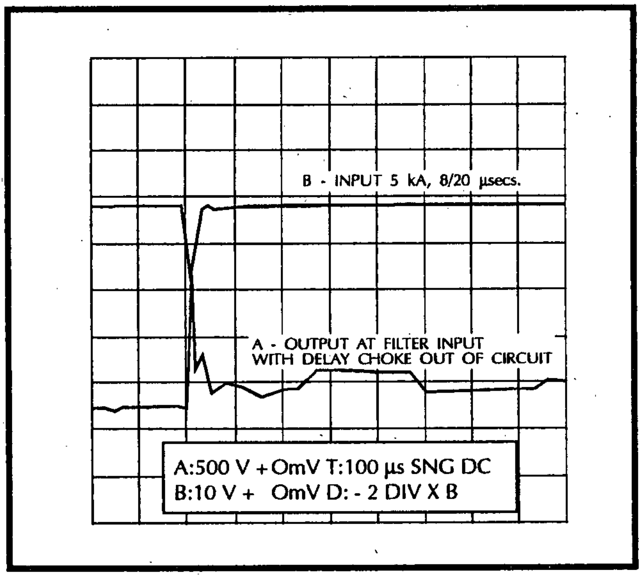

***FIGURE 8.** Output with Delay Choke Out of Circuit.*

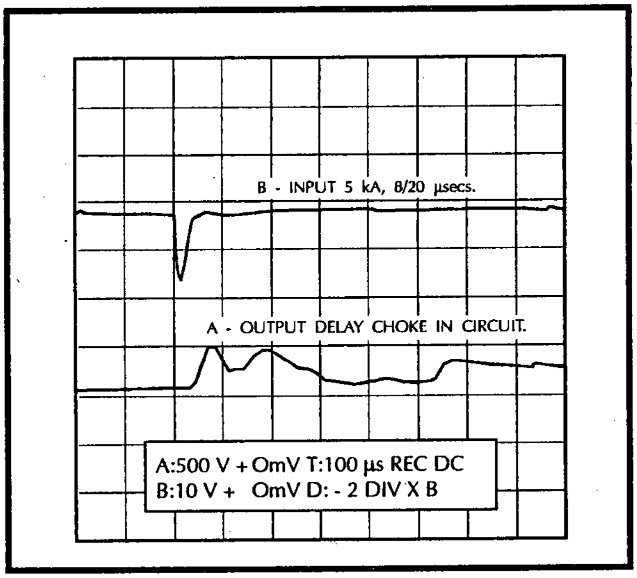

***FIGURE 9.** Complete Filter, Choke in Circuit.*

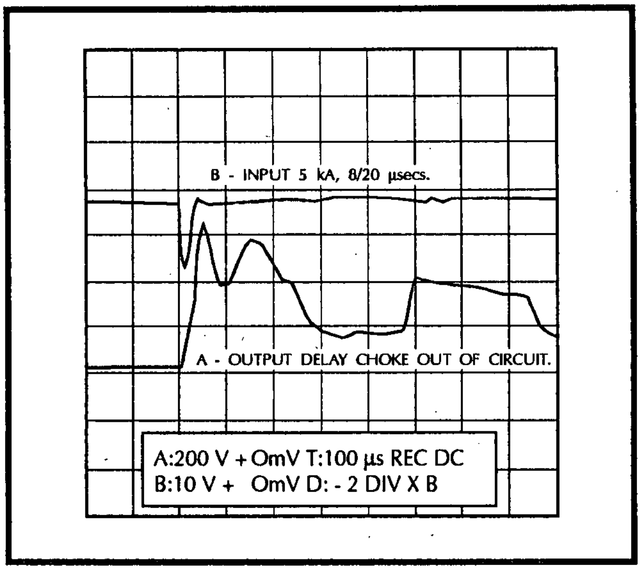

***FIGURE 10.** Complete Filter, Choke Out of Circuit.*

transient given by the filter is also obvious. It indicates that if the components in the filter could accommodate the input energy under these test conditions, special protection arrangements may not be necessary. It should be noted, however, that the components making up the filter would need to be tested and selected for each specified threat.

Choosing, selecting and testing the filter components in this way will be expensive with a very high discard rate. On the other hand, fitting protection components to a standard filter could be a fairly simple action, and allows the same filter to be used in an EMP or transient environment.

The advantages of the two protection arrangements tested are in the different energy handling capacities and these aspects were not very obvious. However, the results clearly indicate that protection can be provided which will limit the line voltage to almost any level.

Because of the small tolerances in series volt drop with mains supply filters, the delaying impedance used in the EMP and transient protection arrangements must take the form of an inductance, and it must be capable of carrying the full current of the load. The inductance will therefore be physically large and relatively expensive to manufacture. The cost difference of the filter with varistor protection only, and the one with GDT *plus* choke *plus* varistor, could be significant, and may very well play a part in deciding on the form the protection arrangements must take. Typically, the filter with both primary and secondary protection could be twice the cost of the one fitted with varistor protection.

Finally, an important point which should be considered when selecting an EMP lightning protected filter which utilizes varistors is the number of transients or pulses which the selected item is capable of absorbing. Examination of the varistor parameters used in the standard product shows that the stated current carrying capability is meaningful only when a specific number of pulses are applied. If the threat is a 6.5 kA transient, then the varistor is guaranteed by the manufacturer as being capable of withstanding it for one shot only. Application of 10 pulses of an agreed duration brings the current carrying capability down to 2 kA.

Once again, therefore, to obtain the correct and most cost-effective solution to EMP requirements, the threat must be very clearly defined, and expert advice and guidance must be sought on the optimum solution.

ACKNOWLEDGEMENTS

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