POWER LINE COMMUNICATION AND AC MAINS SURGE PROTECTIVE DEVICES

SUMMARY
This document looks at the degradation power line communication (PLC) caused by the capacitance of metal-oxide varistor (MOV) based AC mains surge protective devices. Various mitigation measures are discussed.
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1 Introduction

Power line communication (PLC) is most commonly known for domestic property local area network (LAN) extension over the AC mains wiring when the WiFi coverage is inadequate. Figure 1 shows a typical setup.

![Figure 1 – Example PLC LAN extension over AC mains wiring](image)

The Router Ethernet LAN connects to a PLC adaptor port. This adaptor exchanges data via the AC mains wiring with another remote PLC adaptor, whose Ethernet port is connected to a remote terminal. The remote PLC adaptor may have multiple Ethernet ports.

2 Overview

PLC has many names such as power-line carrier, mains communication, power-line telecommunications and power-line networking (PLN). It makes the conventional power service into a multiservice, carrying both the original power and data. The data spectrum can be roughly classified as narrowband, mediumband and wideband.

Narrow band frequencies are typically below 500 kHz, making it suitable for low data rate monitoring and control. The frequency band has certain usage allocations; such in Europe energy providers use the 3 kHz to 95 kHz band for such things as SMART energy meters. The low transmission frequency allows long distance communication as the attenuation caused by the power distribution network is tolerable. Even at this low frequency, there have been reports that SMART energy meter data bursts have disrupted digital subscriber line (DSL) Broadband connections.

Medium band extends up to about 12 MHz and is intended mainly for devices classified as the Internet of things (IoT).
Wideband frequencies extend up to about 100 MHz. Typically the high frequency bands start at 1.8 MHz to avoid interference with amplitude modulated (AM) radio transmissions. Other frequency slots sensitive to emissions are the amateur and frequency modulated (FM) radio bands. See IEEE standards 1901 series and Recommendation ITU-T G.9972 for information on mains power line communications.

3 Customer premises PLC

3.1 External
The relatively short distances involved allow wideband or high speed PLC to be used. Domestic PLC has been used in Japan over distance up to 200 m feeding 5 to 10 houses. At the house a filter and impedance matching filter is typically used. There are several issues with such an arrangement, the most notable being security.

3.2 Internal
High speed PLC adaptors within the house need the appropriate data port surge protection, see Luis Guilherme da S. Costa et al. Figure 2, based on an IEEE C62.42.3 example, shows a PLC adaptor AC mains surge protection using silicon PN-junction diodes.

![Figure 2 – Example of a PLC adaptor AC mains port circuit](image)

The multiservice AC mains provides both the PLC adaptor powering and PLC data. The data signal is coupled via a capacitor and the input surge voltage is limited by a bidirectional breakdown diode. A further bidirectional breakdown diode limits the receiver voltage signal amplitude, while the transmitter drive is voltage limited by rail-to-rail diodes.

4 AC mains SPDs

4.1 Surge withstand levels
Depending on the level of surge on the AC mains, IEC 60664-1 recommends preferred overvoltage category test levels of I, II or III. These levels are equivalent to 1.2/50-8/20 generator peak voltage and current levels of 1.5 kV, 0.75 kA (I), 2.5 kV, 1.25 kA (II) and 4.0 kV, 2.0 kA (III). Other viewpoints exist as to the test levels such as in standards UL1449 and IEC 61643-11.

4.2 SPD Capacitance
It has been found in domestic environments that mains SPDs and MSPDs can severely disrupt PLC communication. The reason is that most of these SPDs use high capacitance metal-oxide varistors (MOV) and their shunt capacitance attenuates the PLC signal. The various AC mains SPD standards tend to omit capacitance requirements. These requirements should be specified to indicate AC mains SPDs are compatible with PLC. There are several solutions to the attenuation problem. One would be to remove problem SPDs in the PLC
transmission path. Another would be to use SPDs that are PLC compatible. The next clause looks at some techniques to reduce capacitive loading.

5 Reducing SPD capacitive attenuation

5.1 Conventional MOV capacitance and operation

An MOV based SPD can have a capacitance in the nF region, which at 100 MHz represents a reactance in the order of 0.5 Ω. This impedance would shunt the AC mains wiring transmission impedance, which is generally somewhere between 10 Ω and 100 Ω (Nicholson and Malack) depending on frequency and distance.

The basic test circuit uses a 1.2/50-8/20 surge generator having a charge voltage of 6 kV to produce an initial dv/dt of 10 kV/µs. The generator load is a series circuit consisting of an MOV and any capacitance reducing components. Figure 3 shows the test circuit and Figure 4 the corresponding waveforms. The waveforms shown are for particular component characteristics and are intended to illustrate possible performance examples.

![Figure 3 – Single MOV protection circuit](image)

![Figure 4 – Example waveforms of Figure 3](image)

Figure 4 shows the applied surge causes an MOV peak current of 2.2 kA (green trace) and a peak voltage of 1.1 kV (blue trace).

5.2 Series air-cored inductor

The MOV capacitance can be decoupled by using a series inductance in the L and N SPD terminals. At the lower limit of 2 MHz an inductance of 20 µH represents a series decoupling reactance of 300 Ω.
Figure 5 – Series inductor and MOV protection circuit

Figure 6 shows the applied surge causes an MOV peak current of 1.45 kA and a peak voltage of 1.0 kV. The peak front protection voltage is 3.8 kV (red trace). While allowing PLC operation, this is not a satisfactory surge protection voltage.

5.3 Series saturating core inductor

If a saturating core inductor was used, under surge conditions the core would saturate and the inductor would become a much lower value of impedance. In this example, the inductor has an unsaturated core inductance of 20 µH and a core saturated inductance of 0.5 µH.

Figure 7 – Series saturating inductor and MOV protection circuit

Figure 8 – Example waveforms of Figure 7
Figure 8 shows the applied surge causes an MOV peak current of 2.2 kA and a peak voltage of 1.1 kV. The peak front protection voltage is 1.6 kV, rapidly dropping after that as the core saturates. Using a saturating core series inductor allows PLC operation and achieves a reasonable surge protection voltage.

5.4 Series gas discharge tube (GDT)

An alternative approach would be to use a low capacitance GDT (gas discharge tube) in series with the MOV elements. Typically the addition of a series GDT will reduce the circuit resultant capacitance from nF to pF.

Figure 9 – Series GDT and MOV protection circuit

Figure 10 shows the applied surge causes an MOV peak current of 2.2 kA and a peak voltage of 1.1 kV. The peak front protection voltage is set by the GDT 10 kV/µs sparkover voltage level, which is 1.05 kV (red trace). At lower currents the GDT sparkover voltage will exceed the MOV peak voltage. By using a GDT in series with the MOV results in low resultant circuit capacitance allowing PLC operational compatibility and a satisfactory surge protection voltage.

Figure 11 shows the first 200 ns of Figure 10. Due to the high MOV capacitance, very little voltage is developed across the MOV during the front time until GDT sparkover occurs at 105 ns (blue MOV voltage trace is overlaid by the green current trace). After sparkover, the MOV capacitance charges up to the 600 V MOV clamping level in a period of 8 ns. During the MOV capacitance charging time, a 52 A peak current spike occurs in the circuit current.
6 Multiservice surge protective devices (MSPDs)

The power SPD section of the MSPD could be similarly treated for PLC compliance. It would be useful to have a power outlet socket that is decoupled from the MOV protection for use with PLC adaptors. MSPDs are available with integrated PLC functions that provide a LAN socket or sockets on the MSPD.

7 Summary

The best two approaches for PLC compliance from the presented circuit examples are either a series saturating inductor or a series GDT. Table I summaries the results.

Table 1 – Comparison surge levels in circuit configurations of Figures 3, 5, 7 and 9

<table>
<thead>
<tr>
<th>Configuration</th>
<th>MOV peak current – kA</th>
<th>MOV peak voltage – kV</th>
<th>Peak front protection voltage – kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOV</td>
<td>2.2</td>
<td>1.1</td>
<td>–</td>
</tr>
<tr>
<td>MOV + linear inductor</td>
<td>1.45</td>
<td>1.0</td>
<td>3.8</td>
</tr>
<tr>
<td>MOV + non-linear inductor</td>
<td>2.2</td>
<td>1.1</td>
<td>1.6</td>
</tr>
<tr>
<td>MOV + GDT</td>
<td>2.2</td>
<td>1.1</td>
<td>1.05</td>
</tr>
</tbody>
</table>
Bibliography

IEEE 1901-2010 – Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications

IEEE 1901.2-2013 – Standard for Low-Frequency (less than 500 kHz) Narrowband Power Line Communications for Smart Grid Applications

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