ETHERNET EQUIPMENT PORT VOLTAGE STRESS TESTS

The content of this document is of a general nature only and is not intended to address the specific circumstances of any particular individual or entity; nor be necessarily comprehensive, complete, accurate or up to date; nor represent professional or legal advice. The views expressed by the writer are solely those of the writer and do not necessarily represent official positions of IEEE PES SPDC.

© M J Maytum

Draft 2, 2013-11-18
CONTENTS

1 Introduction ................................................................................................................... 3
2 Insulation withstand voltage test .................................................................................... 3
  2.1 2,4 kV, 10/700 rational ..................................................................................... 4
  2.2 Recommendation ITU-T K.21 basic 1 kV, 10/700 test level ......................... 4
3 Insulation resistance test .......................................................................................... 4
4 Surge Protective Component (SPC) and Surge Protective Device (SPD) effects........... 5
5 SPC interaction with safety testing ............................................................................... 6
  5.1 Telecommunications port: mains environment testing ........................................ 7
  5.2 Telecommunications port: telecommunications network environment testing .............................................................................. 7
6 SPC interaction with equipment port surge testing ..................................................... 8
7 Summary ...................................................................................................................... 8
Annex A (informative) Further reading .......................................................................... 9
  A.1 ATIS Protection Engineers Group (PEG) presentations .................................... 9
  A.2 ITU-T Recommendations .................................................................................. 9
  A.3 E-learning centre at pes-spdc.org ..................................................................... 9
  A.4 Forthcoming IEEE Standards ............................................................................ 9

Figure 1 – Differential mode surge generated by asynchronous SPC operation on a common mode surge (© M J Maytum 2011, Damage to Equipment in the US, ITU-T Technical Session on Home Networks Geneva) ........................................................................ 5

Figure 2 – Insulation voltage overstress caused by SPD operation on a common mode surge (© M J Maytum 2011, Damage to Equipment in the US, ITU-T Technical Session on Home Networks Geneva) .......................... 6
ETHERNET EQUIPMENT PORT VOLTAGE STRESS TESTS

1 Introduction

Ethernet ports can be designed in two ways; with SPCs (Surge Protective Components) bridging the isolating transformer insulation or without SPCs and relying on the isolating transformer insulation alone to withstand common-mode voltage surges. How to test Ethernet equipment ports is often a subject of disagreement amongst engineers. There are several areas of disagreement and this document attempts to describe how these problems arise. The following document clauses expand on these topics:

clause 2 Insulation withstand voltage test: IEEE Std 802.3T-2012 - IEEE Standard for Ethernet offers a.c. or d.c. or impulse test voltage options for insulation testing. The impulse test voltage options have of several values of amplitude and two values of waveshape. At the transformer component level the highest to lowest possible peak impulse test voltage ratio is 2.4:1. An “IEEE Std 802.3T compliant” transformer qualification is not good enough for designers to know what the inter-winding impulse withstand voltage is.

clause 3 Insulation resistance test: The insulation resistance test is really a second check on the insulation after the insulation withstand voltage test (clause 2). The d.c. test level of 500 V ensures the insulation will withstand the highest expected level of local mains (230/240 V a.c.). There are variations on this test covered in clause 5

clause 4 Surge Protective Component (SPC) effects: When used in Ethernet systems SPCs can cause two types of port failure under common-mode surge conditions; PHY chip failure due to SPC common-mode to differential mode surge conversion and voltage overstress of the port transformer insulation.

clause 5 SPC interaction with safety testing: Safety testing covers the mains electrical environment and the telecommunications network electrical environment. These tests are not really suitable for modern Ethernet port equipment as the applied stresses are based on historical wire-line POTS (Plain Old Telephone System) values and not on what really occurs in wired LAN networks.

clause 6 SPC interaction with equipment port surge testing: Here again the majority surge resistibility standards and recommendations fail to comprehend the testing needs of the different Ethernet port design approaches.

clause 7 Summary: Provides brief details of how some manufacturers have responded to the short falls of clauses 5 and 6.

The main area of misunderstanding is for safety testing and whether surge protective components (SPCs) that directly or indirectly bridge the transformer insulation be removed for voltage withstand testing and insulation resistance testing.

2 Insulation withstand voltage test

Within the IEEE Std 802.3T-2012, including its normative references, there are many test voltage options:

a) 1500 V rms at 50–60 Hz for 60 s, applied as specified in Section 5.3.2 of IEC 60950 (listed 12 times)

b) 2250 Vdc for 60 s, applied as specified in Section 5.3.2 of IEC 60950 (listed in body 12 times)
c) A sequence of ten 2400 V impulses of alternating polarity, applied at intervals of not less than 1 s. The shape of the impulses shall be 1.2/50 µs (1.2 µs virtual front time, 50 µs virtual time or half value), as defined in IEC 60060. (listed in body 11 times)

d) An impulse test consisting of a 1500 V, 10/700 µs waveform, applied 10 times, with a 60 s interval between pulses. The shape of the impulses shall be 10/700 µs (10 µs virtual front time, 700 µs virtual time of half value), as defined in IEC 60950-1:2001 Annex N. (1x) (From 60950-1, 6.2 Protection of equipment users from overvoltages on telecommunication networks, 6.2.2 Electric strength test procedure, 6.2.2.1 Impulse test, for 6.2.1 b) and 6.2.1 c) configurations). (listed in body once)

e) An impulse test consisting of a 2400 V, 10/700 µs waveform, applied 10 times, with a 60 s interval between pulses. (Logically deduced by one SDO from d) and the normative IEC 60950-1, clause 6. Rational given in clause 2.1 of this document)

2.1 2,4 kV, 10/700 rational

In d) the 1.5 kV, 10/700 is the heritage of long distance line POTS (Plain Old Telephone System) values. A LAN electrical environment can be different to the POTS environment. In 60950-1, clause 6, 1.5 kV value is justified by:

"If the TELECOMMUNICATION NETWORK TRANSIENT VOLTAGE is not known, an assumed transient rating of 800 V peak should be used for TNV-2 CIRCUITS and 1,5 kV peak for TNV-1 CIRCUITS and TNV-3 CIRCUITS."

and

"It is assumed that adequate measures according to ITU-T Recommendation K.11 have been taken to reduce the likelihood that the overvoltages presented to the equipment exceed 1.5 kV peak. In installations where overvoltages presented to the equipment may exceed 1.5 kV peak, additional measures such as surge suppression may be necessary."

It is unlikely that Recommendation ITU-T K.11 measures will be taken on a LAN system. The equipment manufacturers on the referenced SDO group know from home networking field experience that a 1.5 kV, 10/700 level is a too low to ensure a reasonable field reliability of Ethernet ports. The next preferred impulse level is the 2.4 kV from item c). The IEC clause 6 statements allowed the SDO group to come up with a 2.4 kV, 10/700 rated level.

2.2 Recommendation ITU-T K.21 basic 1 kV, 10/700 test level

Recommendation ITU-T K.21 is a set of the resistibly tests for telecommunications equipment located at the customer premises. Ethernet isn’t mentioned at all in this document. Most people use Table 7 – Lightning test conditions for ports connected to internal cables for Ethernet tests. In particular, test 7.1 Unshielded cable with symmetric pairs. This has two levels of withstand; basic 1 kV 10/700 and enhanced 1.5 kV 10/7000 (same as list item d). The reason for mentioning K.21 is that one of the coming IEC 61643 standards on surge protective devices is going to standardise Ethernet as requiring only the basic level - 1 kV 10/700. This creates further confusion as to how Ethernet ports should be impulse tested; 1 kV, 1.5 kV or 2.4 kV?

3 Insulation resistance test

In IEEE Std 802.3T-2012 the requirement is:

There shall be no insulation breakdown, as defined in subclause 5.2.2 of IEC 60950-1:2001, during the test. The resistance after the test shall be at least 2 MΩ, measured at 500 V d.c.

The rational here is that a high resistance at 500 V d.c. means the insulation barrier will block any substantial current flow caused by the accidental conductor contact with the local mains
having voltages up to 230/240 V a.c. However, this IEC rational coupled with clause 2 items a), b) and c) does not comprehend telecommunications ports, see clause 5

4 Surge Protective Component (SPC) and Surge Protective Device (SPD) effects

Voltage limiting SPCs can be used in equipment ports to limit the voltage a conductor can reach relative to the equipment reference potential (the insulation is bridged by the SPC); in some cases the reference potential is the earthing/grounding system. SPDs can provide the same function when connected in-line with the LAN cable.

In the POTS era external SPDs and equipment port SPCs where regarded as a good thing to have as overvoltages were mitigated. Carrying over this philosophy to LAN systems has, in some cases, resulted in a large increase in equipment field failures. The reason for the failures is simple to understand.

POTS ports can have working voltage levels of up to 300 V peak to peak, but Ethernet ports operate with much smaller (differential) signal levels of a few volts. In addition, Ethernet PHY chips running at very low supply voltages are intolerant to quite low levels of overvoltage. When each conductor is “protected” by an individual bridging SPC, the operation of these SPCs is not synchronised. As the common-mode conductor voltages are limited at different times the common mode surge is converted to a large differential surge applied across the transformer primary due to the asynchronous SPC operation, which in turn applies a damaging voltage to the PHY.

The second failure mode occurs when common-mode protection is applied only at one end of the cable, see Figure 2. Without any SPD and with a 4 kV induced voltage the cable ends are at +2 kV and -2 kV respectively. When one SPD is added, its operation holds the cable voltage at that end to the local reference potential, doubling the voltage at the far end of the cable (4 kV). SPDs at both ends prevents the voltage doubling, but because the SPDs are

Figure 1 – Differential mode surge generated by asynchronous SPC operation on a common mode surge
(© M J Maytum 2011, Damage to Equipment in the US, ITU-T Technical Session on Home Networks Geneva)
likely to have differences in local ground potential rise (GPR) surges can be coupled into the cable by this mechanism.

**Figure 2 – Insulation voltage overstress caused by SPD operation on a common mode surge**
(© M J Maytum 2011, Damage to Equipment in the US, ITU-T Technical Session on Home Networks Geneva)

There are many field examples where people in good faith have fitted SPDs to the cabling and the equipment failure rate has shot up. Removing the SPDs returns the equipment reliability to the previous level. The soon to be published IEEE Std C62.36 contains test methods to measure the SPD common-mode to differential-mode impulse voltage conversion.

The SPD equipment failure explanation also applies to SPCs incorporated into the equipment Ethernet port.

### 5 SPC interaction with safety testing

Most safety standards are focussed on verifying the insulation voltage withstand of items connected to the mains, such as power transformers and motors. Insulation bridging SPCs
here can interfere with the voltage withstand verification of the insulation and hence it is allowed for the bridging SPCs to be disconnected. There is no need to define what the minimum limiting voltage of such SPCs is as it is necessary to make the SPC limiting voltage higher than the expected maximum peak voltage of the local mains.

Similarly for the insulation resistance test, any SPCs connected may reduce the measured insulation resistance and hence it is allowed for the bridging SPCs to be disconnected.

IEC 60950-1 Section 6 can be regarded as testing the insulation to a mains power port environment and to a telecommunications port environment.

5.1 Telecommunications port: mains environment testing

As the current capabilities of the previously referenced clause 2 test voltages a) through c) are unspecified, leaving the SPCs in place would likely cause SPC failure due to excessive current flow. Using tests formulated for the insulation of mains connected items are not appropriate for telecommunications ports that have their own insulation, see 5.2.

IEC 60950-1 clause 6.1.2 covers the separation of the telecommunication network from earth. IEC 60950-1 clause 6.1.2.1 Requirements is a subset of the earlier power port tests. Insulation voltage withstand testing (electrical strength test) is done at 1.5 kV rms (item a) of clause 2) and it is permitted to remove any bridging SPCs.

IEC 60950-1 clause 6.1.2.1 Requirements states:

Surge suppressors (SPCs) that bridge the insulation shall have a minimum d.c. sparkover (limiting) voltage of 1.6 times the RATED VOLTAGE or 1.6 times the upper voltage of the RATED VOLTAGE RANGE of the equipment.

For 230 V mains at maximum tolerance, this gives a minimum SPC limiting voltage requirement of about 425 V, reasonably close to the 500 V d.c. used for power insulation resistance measurement (clause 3). For the mains environment, compliance is tested for by applying the RATED VOLTAGE of the equipment or to the upper voltage of the RATED VOLTAGE RANGE to the telecommunications port with the bridging SPCs in place. With a 5 kΩ voltage source resistance, the resultant current shall not exceed 10 mA. This compliance test substitutes for the insulation resistance test (clause 3 of this document)

5.2 Telecommunications port: telecommunications network environment testing

At the time IEC 60950 was formulated there was a debate going on about signal ports. Many people considered there were two types of signal port; telecommunications ports (e.g. POTS) and Information Technology, IT, ports (e.g. Ethernet). The IEC 60950 section 6 title “Connection to telecommunication networks” really means that only telecommunications ports are covered. You will not find the term Ethernet mentioned or telecommunications ports with four twisted pairs. The section 6 tests are designed to test telecommunications ports but have shortcomings for IT ports. Recently this terminology conflict has been resolved by the merging the terms of teleCommunications ports and Information Technology ports into Information and Communications Technology, ICT, ports.

IEC 60950-1 clause 6.2 deals with the protection of equipment users from overvoltages on telecommunication networks. IEC 60950-1 clause 6.2.2 Electric strength test procedure has two test parts; clause 6.2.2.1 Impulse test and clause 6.2.2.2 Steady-state (a.c.) test. IEC 60950-1 clause 6.2.2.3 give the compliance criteria for the two test parts.

The IEC 60950-1 clause 6.2.2.1 impulse test from the joined port conductors to conductive equipment parts applies a 1.5 kV 10/700 10 times without any SPCs being removed. Shielded cables are not comprehended in this test.
The IEC 60950-1 clause 6.2.2.2 steady-state (a.c.) test from the joined port conductors to conductive equipment parts applies a 1.0 kV rms voltage and it is permitted to remove SPCs, provided the SPCs survive the impulse test of clause 6.2.2.1 when tested as components.

The IEC 60950-1 clause 6.2.2.3 requires that there shall be no insulation breakdown during the two tests. For the impulse test SPC operation is allowed. If the impulse test is not monitored for the operation of the bridging SPCs present, then a d.c. voltage insulation resistance test is performed. The SPCs are permitted to be removed for the insulation resistance test. The insulation resistance test is done at either 500 V d.c. (clause 3) or at a d.c. voltage test voltage of 90 % of the minimum SPC limiting voltage. The measured insulation resistance shall not be less than 2 MΩ.

6 SPC interaction with equipment port surge testing

Safety standards try to ensure the equipment is safe. Equipment functionality after a safety test is not important. Equipment standards require that equipment port can withstand a specified level of surge and be fully functional afterwards for field reliability. Such testing will leave any SPCs in place to check they can withstand the applied surge currents and their operation will not damage the equipment.

Ethernet ports can be designed in two ways; with SPCs bridging the insulation or without SPCs. When SPCs are used, common-mode surge generators that produce a defined amount of current through the bridging SPC are needed (similar to a telecommunications equipment port surge test). When SPCs are not used, common-mode surge generators that produce a defined amount of voltage on all the port conductors relative to the reference potential are needed (effectively an insulation voltage withstand test).

In the case of the ports with bridging SPCs there needs to be two types of common-mode test; one that tests for the condition where just one SPC hogs all the induced current (all conductors connected together) and the other that tests for the common-mode to differential mode conversion condition (each conductor separately fed).

Unfortunately telecommunications equipment standards and recommendations are currently in a catch-up stage after neglecting the testing of "IT" ports. The recent Recommendation ITU-T K.44 (05/2012) Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation has a small tutorial on the use of isolation transformers for common-mode surge protection, but this hasn't yet been translated into actual tests contain in the equipment Recommendations ITU-T K.20, K.21 and K.45.

7 Summary

Equipment manufactures want equipment to be both safe and reliable. Equipment safety and surge resistibility standards and recommendations lack sufficient treatment of Ethernet ports to achieve these goals. This has resulted in equipment manufacturers, particularly those making home networking optical network termination (ONT) boxes to develop their own company requirements. For example, one US manufacturer specifies 8 kV impulse voltage withstand for the Ethernet isolation transformer and a Japanese supplier has initially specified 13 kV impulse voltage withstand for the Ethernet isolation transformer.
Annex A
(informative)

Further reading

A.1 ATIS Protection Engineers Group (PEG) presentations

[1] The Ethernet Port Maze Parts 1 and 2

[2] Power Over Ethernet (POE) – What is it? How to Protect it?

[3] Ethernet Protection (Once it has Left the Building; Inside the Cell Site)


[5] Evolving Ethernet Applications and Protection

[6] Ethernet Protection

[7] A Comparison of Various Ethernet Protection Solutions

[8] Lightning Damage of the Home Network Ports

[9] IEEE Std. 802.3 Ethernet ports — Types, Surge Capability and Applications

[10] Ground or not to Ground Ethernet Protection


A.2 ITU-T Recommendations

[12] Recommendation ITU-T K.44 (05/2012), Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation see Appendix II

A.3 E-learning centre at pes-spdc.org

[13] Introduction to Surge Mitigation Techniques

A.4 Forthcoming IEEE Standards

[14] C62.69 Standard for the surge parameters of isolating transformers used in networking devices and equipment