The Need for "Substation Hardened" Ethernet Switches

Marzio P. Pozzuoli
RuggedCom Inc. – Industrial Strength Networks
Concord Ontario Canada

Introduction

Trends in electric utility automation, specifically substation automation, have converged upon a common communications architecture with the goal of having interoperability between a variety of Intelligent Electronic Devices (IEDs) found in the substation. This initiative was begun back in the late 1980s driven by the major North American utilities under the technical auspices of EPRI (Electric Power Research Institute). The resulting standard which emerged is known as the Utility Communications Architecture 2.0 (UCA2.0). This architecture, which is now being adopted worldwide by utilities and IED vendors alike, has as its underlying network technology - Ethernet.

1.0 Ethernet in the Substation

The proliferation of Ethernet capable IEDs used for substation automation has increased markedly in the past several years. There are currently nine vendors of protective relaying devices alone offering fiber optical Ethernet communications with their IEDs. Vendors of meters, RTUs and PLCs used for substation automation, mirror this trend. However, a key technological obstacle which hinders the full scale embrace of Ethernet by end users is the availability of 'substation hardened' Ethernet Switches (i.e. Switched Hub) which are necessary to provide the Ethernet network backbone into which all networked IEDs connect.

2.0 What Does It Mean to be 'Substation Hardened'?

"If you're going to connect your mission critical substation IEDs to a substation Ethernet LAN - shouldn't that LAN be as rugged as the IEDs connected to it?" This has been a common concern heard amongst engineers involved in substation automation.

2.1 Fiber Instead of Copper

Back in 1997, the Electric Power Research Institute (EPRI), commissioned a series of tests [1] conducted by engineers from American Electric Power to look at the viability of using Category-5 (CAT-5) unshielded and shielded twisted pair copper cable for connectivity in an Ethernet based substation network. The CAT-5 cabling was subjected to fast electrical transients in accordance with IEC 1000-4-4, the precursor to IEC 61000-4-4. This was done since it represented likely conditions in a substation during a fault (i.e. a power system short circuit) condition when the substation network would be required to perform at its *'real-time, mission critical'* best. The results of this testing clearly showed that copper cables, shielded or unshielded, were unsuitable for performing real-time control over the substation LAN. To quote the summary conclusions of the report:

"These tests clearly demonstrate that shielded and unshielded twisted pair cables are not suitable as LAN media UCA substation automation. The results clearly show that fast electrical transients have an adverse impact on ethernet communications using these cables. While protocols at various layers can mitigate the adverse effects, these cables does not exhibit the immunity to fast electrical transients required to support protective "tripping" over the LAN. It is recommended that a fiber optic media be used to connect all Intelligent Electronic Devices engaged in protection in a UCA substation." [1]

Fiber optical media is the only reliable media for networking IEDs in a substation.

2.2 Too hot, too cold…and no fans allowed!

The environmental conditions found in substations can straddle the extremes of the surrounding climatic conditions. As is often the case, the substation control room or IED kiosk may be sheltered from the elements (i.e. wind, rain and snow) but there are often no climatic controls with respect to temperature or humidity. Thus IEDs within theses environments must be capable of operating reliably across a wide range of temperatures and humidity. To add further to the challenge; using cooling fans is undesirable because of the low reliability of rotating mechanical parts. While fans may be acceptable in an office LAN they are most definitely unacceptable in a substation LAN which is the backbone of a mission critical protection and control system. Substation IEDs, such as protective relaying devices have operating temperature ranges:

1. -25 to 55°C in accordance with IEC 60255-6 (1988) or
2. -40 to 85°C in accordance with IEC 60068-2-1&2.

Typical commercial grade Ethernet switches have operating temperatures from 0 to 45°C with the aid of cooling fans. This is more than acceptable for the office environment but a far cry for what is required in the substation environment.

Ethernet switches for the substation need to operate in the same temperature range as protective relaying IEDs.

2.3 Enough EMI to fry an egg!

Substation IEDs are required to withstand a variety of electromagnetic interference phenomena. ANSI/IEEE C37.90.1&2 and IEC 60255 define a variety of type withstands tests designed to simulate EMI phenomena such as inductive load switching, lightening strikes, electrostatic discharges from human contact, radio frequency interference due to personnel using portable radio handsets, ground potential rise resulting from high current fault conditions within the substation and a variety of other EMI phenomena potentially encountered in the substation by protective relaying IEDs. These devices have to be able to withstand continuous EMI fields of 35 V/m without ‘misoperation’. Compare this to the IEC 61000-4-6 standard for radiated EMI immunity for devices in “industrial” environments which is only 10 V/m! Commercial Ethernet switches don’t even comply with the industrial requirement let alone the substation.

Ethernet switches for the substation need to pass the same EMI type tests as protective relaying IEDs.

3.0 The Arrival of the IEC 61850-3 Standard

In January 2002, the International Electrotechnical Commission (IEC) released a new standard entitled *IEC 61850-3 “Communications networks and systems in substations”* to specifically address the general environmental and electromagnetic interference (EMI) immunity requirements for network equipment used in substations. In particular, section *5.7 EMI Immunity states that “The general immunity requirements for the industrial environment are considered not sufficient for substations. Therefore, dedicated requirements are defined in IEC 61000-6-5…” [2]*

3.1 A Closer Look at IEC 61850-3

The IEC 61000-6-5: “Generic Standards – Immunity for power station and substation environments” outlines the EMI immunity requirements. The details of these requirements and test procedures are given in the parts of the IEC 61000-4-x series. Figure 1 shows the relationship between IEC 61850-3, IEC 61000-6-5 the IEC 61000-4-x series and other referenced standards.

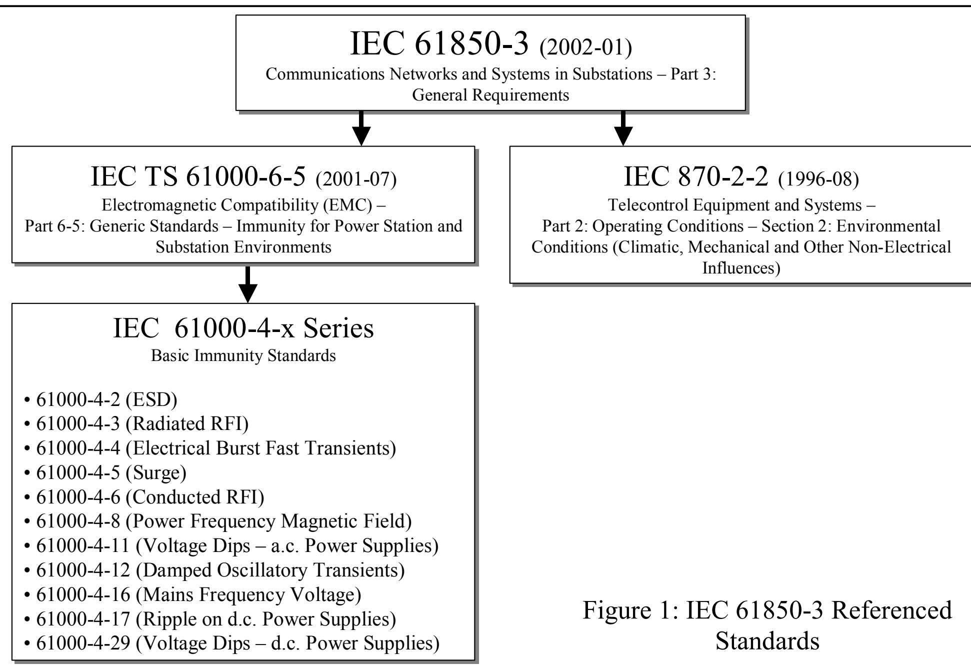

Figure 1: IEC 61850-3 Referenced Standards

IEC 61000-6-5 defines port categories and the corresponding applicable standards. A ‘port’ is defined as a *“particular interface of the specified equipment* *with the external electromagnetic environment".*[2] There are five port categories defined:

1. Enclosure Port
2. Signal Port
3. Low Voltage a.c. Input Power and Output Power Ports
4. Low Voltage d.c. Input Power and Output Power Ports
5. Functional Earth Port

Each port type has a corresponding list of IEC 61000-4-x EMI Immunity standards which must be met. Table 1 lists the required test standards and levels for each port type.

Table 1: IEC 61000-6-5 EMI Test Levels

Referenced Standards	IEC-61000-6-5 LEVELS				
	Signal Port Types				
	Enclosure Ports	*Signal Ports (In field)*	*a.c. Input Power Ports*	*d.c. Input Power Ports*	*Earth Port*
IEC-61000-4-2 ESD	3 (8kV Air, 6kV Contact)				
IEC-61000-4-3 Radiated RFI	3 (10 V/m)				
IEC-61000-4-4 Fast Transients		4 (2kV/1kv)	4 (2kV/1kv)	4 (2kV/1kv)	4 (2kV/1kv)
IEC-61000-4-5 Surge		3 (2kV/1kv)	4 (4kV/2kv)	3 (2kV/1kv)	
IEC-61000-4-6 Induced RFI		3 (10 V)	3 (10 V)	3 (10 V)	3 (10 V)
IEC-61000-4-8 Magnetic Field	2 (3 A/m)				
IEC-61000-4-11 Voltage Dips a.c. Power			30% for 1 cycle		
IEC-61000-4-12 Damped Oscillatory		2 (1kV/0.5kv)	3 (2.5kV/1kv)	3 (2.5kV/1kv)	
IEC-61000-4-16 Mains Freq.		4 30V Cont. 300V for 1s		4 30V Cont. 300V for 1s	
IEC-61000-4-17 a.c. Ripple				10%	
IEC-61000-4-29 Voltage Dips d.c. Power				30% & 60% for 100ms	

IEC 870-2-2 *"Telecontrol equipment and systems – Part 2: Operating conditions – Section 2: Environmental conditions (climatic, mechanical and other non-electrical influences)"* addresses the atmospheric environment which defines four classes of locations:

1. Class A: air-conditioned locations (indoor)
2. Class B: heated and/or cooled enclosed conditions
3. Class C: sheltered locations
4. Class D: outdoor locations

The majority of IEDs in substations will be in "Class C" locations. Class C locations are further sub-divided into four classes: C1, C2, C3 and Cx. Operating temperature ranges for each of the classes are as follows:

1. Class C1: -5 to 45°C
2. Class C2: -25 to 55°C
3. Class C3: -40 to 70°C
4. Class Cx: Special

For IEDs in substations classes C2, C3 or Cx (-40 to 85°C) will be required.

4.0 How Rugged is RuggedSwitch™?

RuggedSwitch™ is family of fiber optical Ethernet switches designed to operate in -40 to 85°C temperatures. Originally developed prior to the emergence of IEC 61805-3, the family was designed to withstand the same type tests as protective relaying devices. Tests defined in ANSI/IEEE C37.90.1&2 and IEC 60255 for protective relaying IEDs were adapted for the RuggedSwitch™ family of network devices. Table 2 shows how RuggedSwitch compares to IEC 61850-3 (IEC 61000-6-5). In fact, by having designed to the same type test standards as protective relaying IEDs the RuggedSwitch™ family exceeds, in several instances, the levels defined in IEC 61000-6-5.

Table 2: IEC 61000-6-5 EMI Test Levels vs. RuggedSwitch™

Referenced Standards	IEC-61000-6-5 LEVELS					RuggedSwitch™ LEVELS (All Signal Port Types)
	Signal Port Types					
	Enclosure Ports	***Signal Ports (In field)***	*a.c. Input Power Ports*	*d.c. Input Power Ports*	*Earth Port*	
IEC-61000-4-2 ESD	3 (8kV Air, 6kV Contact)					✸ 4 (15kV Air, 8kV Contact)
IEC-61000-4-3 Radiated RFI	3 (10 V/m)					✸ X (35 V/m) IEEE C37.90.2
IEC-61000-4-4 Fast Transients		4 (2kV/1kv)	4 (2kV/1kv)	4 (2kV/1kv)	4 (2kV/1kv)	4 (2kV/1kv)
IEC-61000-4-5 Surge		3 (2kV/1kv)	4 (4kV/2kv)	3 (2kV/1kv)		✸ 4 (4kV/2kv)
IEC-61000-4-6 Induced RFI		3 (10 V)	3 (10 V)	3 (10 V)	3 (10 V)	3 10 V = 140db(uV)
IEC-61000-4-8 Magnetic Field	2 (3 A/m)					✸ 4 (40A/m Continuous) 1000 A/m for 1s
IEC-61000-4-11 Voltage Dips a.c. Power			30% for 1 cycle			30% for 1 cycle
IEC-61000-4-12 Damped Oscillatory		2 (1kV/0.5kv)	3 (2.5kV/1kv)	3 (2.5kV/1kv)		✸ 3 (2.5kV/1kv)
IEC-61000-4-16 Mains Freq.		4 30V Cont. 300V for 1s		4 30V Cont. 300V for 1s		4 30V Cont. 300V for 1s
IEC-61000-4-17 a.c. Ripple				10%		10%
IEC-61000-4-29 Voltage Dips d.c. Power				30% & 60% for 100ms		30% & 60% for 100ms

✸ RuggedSwitch Exceeds 61850-3 (61000-6-5) test levels

5.0 Conclusions

Ethernet equipment for the substation should be as 'rugged' as the substation IEDs connecting to it. The substation Ethernet LAN will be an integral part of a mission critical protection and control system which must perform reliably in real-time when a fault condition occurs. In order to ensure reliable performance Ethernet switches should have the following characteristics:

1. Fiber Optical media for immune connectivity and security
2. –40 to 85°C operating temperature
3. Compliance with the following type test standards:
    a. IEC 61850-3 or
    b. ANSI/IEEE C37.90.1&2 and IEC 60255

<u>About the author:</u>

Marzio Pozzuoli is the founder and president of RuggedCom Inc. Prior to founding RuggedCom he was the Technology Manager at GE Power Management (1994 – 2001) where he developed protective relaying systems and substation automation technology. He graduated from Ryerson Polytechnical Institute, Toronto, Ontario in 1986 with a Bachelor of Electrical Engineering Technology. He holds multiple patents and has published several technical papers and articles on technology and substation automation. He is also an active member of the IEEE.

References:

[1] "*UCA Substation Integrated Protection, Control and Data Acquisition - Electro-Magnetic Immunity Tests of Shielded Twisted Pair Copper Cable for 100 Mbps Ethernet" (Final Report - January 31, 1997)*

[2] *"IEC 61850-3: Communications networks and systems in substations – Part 3: General Requirements" (Section 5.7 EMI Immunity)*