Planning for the Successful Integration of Substation Communications

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***Abstract*—There are many benefits to building an integrated network for substation communications including cost effectiveness and the ease of adding new systems to an established network. To achieve these benefits, planners must understand and define a long term strategic architecture. This architecture must provide flexibility, performance, reliability and manageability. It must take into account the varied needs of different networking applications. These include control systems such as SCADA, measurement systems including metering, protection signalling among power systems, and other emerging requirements such as security video surveillance. Without an overall network plan, an established network may inhibit rather than help the implementation of future systems. This article outlines many of the requirements of an integrated network and the tools available to planners to plan and implement a successful integrated substation network.**

***Index Terms*—Substation, network, Ethernet, 61850, architecture, serial, communications, switching, reliability, performance.**

I. Introduction

THE ideal strategic substation network has the capacity and flexibility to support many different applications at the same time. These may have widely differing requirements. Applications include protection signalling, control automation, metering and other systems requiring communications within the substation and beyond. Successful implementation of such a multi-purpose network requires a comprehensive vision of the target architecture. This architecture guides each successive project as the network evolves. Implementers must meet immediate project needs while avoiding missteps that create obstacles to future evolutionary growth.

Standards and technologies such as IEC 61850, Ethernet switching and IP communications provide the framework for the strategic integrated substation network. The 61850 standards address the demanding requirements of protection signalling and data processing applications coexisting on a common network. Implementers must understand the mechanisms defined in 61850 and in Ethernet to meet strict physical reliability and network performance requirements and must also understand the requirements and limitations of a wide array of applications.

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Despite the emerging primacy of Ethernet as the medium of choice for local communications, in many substations legacy control systems and other serial communications requirements exist. The 61850 architecture involves distributed protocol gateways to convert legacy interfaces to 61850 information standards. Other serial-IP approaches are also available today to link existing centralised legacy systems to remote devices over an Ethernet infrastructure.

Security – both physical security and cyber security – has become an important issue in networking. An Ethernet infrastructure can support physical security initiatives by integrating video surveillance systems and access control systems on a common network. Power-over-Ethernet (PoE) can simplify camera and access system deployment. The network can support cyber security by supplying protections at many levels both for the systems and devices attached to the network and also for the secure management of the network infrastructure itself.

This paper takes a broad view of the challenges inherent in substation system integration. It assesses current and emerging requirements for substation networking with the goal of effectively integrating the communications infrastructure across such diverse applications as protection signalling, process control, metering, remote administration, video surveillance and voice/VOIP. The paper discusses a strategic architecture for local and wide area substation networking and proposes practical implementation guidelines. These will enable project planners to proceed with greater confidence that they can both meet immediate project needs and also prepare for a cost-effective and flexible path forward into the future.

II. Network Integration

The alternative to an integrated network is the implementation of multiple different networks running separately in the same substation. Traditionally, SCADA networks are separate from metering. Different control systems historically have often used differing data protocols, forcing additional network separation. Protection signalling was isolated from other communications largely because the extreme low latency and guaranteed performance requirements of protection events could not be assured in a shared network. Video surveillance, if implemented at all, was usually on a separate CCTV analogue network.

In contrast, a successful integrated network allows one core set of network devices, fibre facilities and network support people to serve many different applications. When multiple projects will share the new network, an immediate benefit will be reduced cost for equipment and facilities. The larger economic benefits come from reduced cost and delay in adding additional systems to the substation in the future, and also in reduced cost of ongoing operations, including training and maintenance. Also, with a larger scaled network serving more applications, it is easier to justify added features in the network to increase reliability and security as additional benefits.

The key success factors for an integrated network design are: (1) Flexibility to adjust and grow the topology as requirements change, (2) Performance, especially Quality of Service techniques, to enable effective prioritisation among competing applications and to meet critical requirements of the most important protection and control systems, and (3) Reliability, for critical protection systems, and also because so many different systems are relying on the same infrastructure.

III. Target Architecture

IEC 61850 and other initiatives identify Ethernet as the basic networking technology upon which to build an integrated substation network architecture. There are many factors encouraging rapid deployment of Ethernet as the core technology for substation networks. IP/Ethernet provides a broadly supported technology for system interconnection across many system suppliers. It leverages mass market component volumes to create a cost-effective, high-performance network. Ethernet lends itself to fibre-based connectivity that is important in electrically noisy industrial environments. Ethernet also supports ring, dual-star and mesh topologies that are highly resilient against single-point network faults, thus improving system reliability.

A complete view of the emerging substation network (as depicted in Fig. 1 below) uses high capacity Ethernet switches at the core of the network, and then surrounds this core with edge and access layers for Ethernet devices, serial devices and wide area network (WAN) connections.

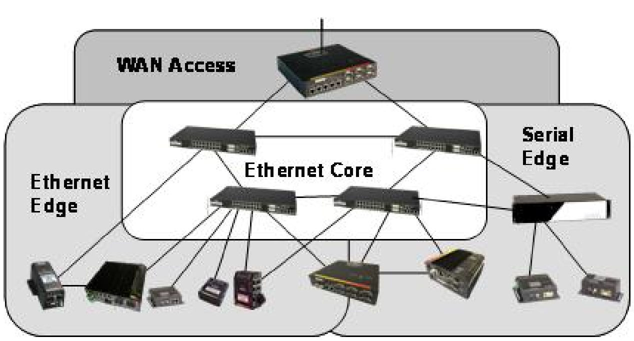

Fig. 1. Illustration of core/edge/service layers of an integrated network.

This distributed architecture directly addresses the critical success factors for substation network integration: flexibility, performance and reliability.

A. Flexibility

The major element of flexibility is the ability to adjust to both network growth (i.e., scalability) and changes in functional requirements (i.e., versatility). A key to scalability is establishing a hierarchy in the network so that the implementers can add switches to the network without disruption. With the hierarchy in Fig. 1, capacity for additional end devices can be added to the periphery of the network by adding additional edge switches tied into the common core. Similarly, the core of the network can be augmented without disrupting the edge.

As the infrastructure of choice now and for the future Ethernet will be the context in which new requirements will be added; that is, new standards will assume the use of an Ethernet infrastructure and will be designed to fit comfortably in that structure.

The technology for the network core can be relatively stable. Gigabit Ethernet is sufficient for most substations and high capacity rack-mount Ethernet switches are available with multiple Gigabit trunks.

At the edge of the network, there will be a wider diversity of requirements. It is important to be able to consider a broad range of edge devices to meet varying needs. One major consideration is the requirement for a range of physical interfaces, such as 10/100 and 10/100/1000 copper Ethernet, different sorts of fibre connectors including SFF, SFP and more traditional ST and SC connections, special-purpose interfaces such as for Power-over-Ethernet, and non-Ethernet serial protocols. One element of flexibility is to be able to employ a broad product line of different Ethernet switch types for the edge, all compatible with a common core. Another approach is to select highly modular edge switches that can be purchased with a wide variety of interfaces on the same switch.

One additional enabler of smooth growth is careful attention to networking standards. Standards permit a mixed vendor environment if a single vendor cannot meet all needs over time. Standards must apply to both basic connectivity of Ethernet devices and also other key enabling technologies such as Quality of Service, VLANs and SNMP network management.

B. Performance

A major challenge for integrated networks is meeting the differing performance requirements of various applications. Protection signalling is perhaps the most severe of these requirements, discussed further below, but SCADA and other control processes also require high performance guarantees. File transfers such as oscillography capture files and metering applications have exacting performance parameters, perhaps less time sensitive but still requiring accuracy.

One very basic key to performance is having sufficient bandwidth in the network. Gigabit Ethernet trunks interconnecting with core switches and switches with non-blocking switch architectures is a first line of defence in assuring sufficient capacity for multiple concurrent applications.

But even with sufficient capacity there is a statistical probability that congestion will occur from time to time. It is thus important that the Ethernet infrastructure implement traffic prioritisation as defined in standard 802.1p. The three key elements of traffic prioritisation are: (1) policies for deciding priorities as traffic enters the Ethernet network, (2) effective marking of traffic for the appropriate priority (802.1p priority tagging) so that the policy can be communicated to each of the switches in the network, and (3) effective traffic queuing and prioritised forwarding, following specific pre-emption and weighting factors.

Virtual Local Area Networks (VLANs per 802.1Q) that are sometimes implemented for security purposes can also be useful in implementing prioritisation policies. Devices of similar priority and traffic profile may be assigned to a common VLAN with the priority treatment associated with that VLAN, rather than assigned individually to each device.

C. *Reliability*

Reliability of the substation network is critical, both because certain specific applications such as control and protection are critical, but also because so many different applications may be affected by a single network failure. Fortunately, an Ethernet-based substation network provides many tools to ensure reliable behaviour.

Reliability is influenced by several factors acting together: product reliability of network switches, reliability of the connection media, the physical topology of the network connections, and the intelligence of the network software in recovering from various physical failures.

For the sometimes electromagnetically harsh environment of substations, IEC 61850-3 standards specify a number of “hardened” characteristics that network products should meet for substation use. These deal with immunity to electrical surge, electrostatic discharges and other phenomena that would cause non-hardened devices to fail.

For the most critical connections, and ideally for all those traversing any distance within the substation, fibre media should be used to protect both signal integrity and the attached devices from surges. Ethernet switches with all fibre connections should be capable of withstanding immunity challenges with no loss of data.

Ethernet supports various topologies in a way that ensures that there is always at least one alternative path if a particular facility or intervening device fails. A common architecture is to have a small core of mesh-connected switches with rings of edge switches centred on this core. In some cases, smaller edge switches may be dual-homed, connecting to the resilient rings with two fibres, but not participating in protecting the ring itself.

Rapid Spanning Tree Protocol (RSTP per 802.1w) is the primary standard protocol for ensuring network recovery from facility or switch failures, while also ensuring a valid network topology. Many vendors have made their own variations to improve performance over basic RSTP. Implementers should be careful to maintain support for standard RSTP to maintain design flexibility. With attention to ring size and topology planning, networks should recover in tens of milliseconds from single faults in rings.

IV. PROTECTION SIGNALING

The critical nature of protection switching within substations was one of the principal challenges addressed in the development of IEC 61850 network protocols and related network design guidelines. A major development was the definition of GOOSE messages (Generic Object Oriented System-wide Event messages). GOOSE messages, as shown in Fig. 2, have a direct mapping into Ethernet, bypassing the protocol overhead of TCP/IP protocols. GOOSE messages are recognized by compliant Ethernet switches to have pre-emptive priority over other network traffic. Within milliseconds of a critical system event, GOOSE messages are multicast to other registered IEDs attached to the Ethernet network, replacing earlier generation station bus communications.

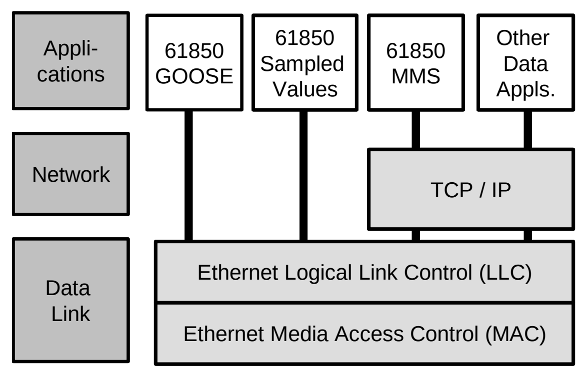

Fig. 2. Illustration of protocol stack of general data (TCP/IP) vs. GOOSE messages.

Ethernet switches involved with protection signalling must be capable of recognizing GOOSE messages, and forwarding them on a pre-emptive priority basis. All involved switch connections must be fibre and must be at least 100 Mbps at the edge with non-blocking Gigabit Ethernet in the core. With careful engineering and multiple priority classes, station bus signalling and data processing traffic can share a single Ethernet infrastructure.

V. SERIAL AND LECAGY INTEGRATION

Another special challenge in network integration is the inclusion of non-Ethernet, serial protocol devices. One common class of serial devices are IEDs with legacy control protocols. In addition, there are many devices with serial console type interfaces for administrative functions.

There are three generic approaches to legacy serial protocols, illustrated in Fig. 3, a., b. and c., below: (1) leave them on separate local connections from control stations to the

IEDs/RTUs, usually using serial-over-fibre Link/repeaters for signal protection on long wiring connections across the substation; (2) deploy distributed protocol gateways, consistent with the IEC 61850 architecture, to convert the legacy protocol to the standard 61850 information structure at the edge of the network, and then integrate the standard IP-based communications onto the Ethernet LAN; and (3) use distributed serial-IP terminal servers/device servers around the edge of the LAN to encapsulate the serial messages onto the Ethernet to reach centralised protocol gateway processors that then translate the legacy protocol to modern IEC standards. Alternatively, serial-IP encapsulation can be reversed centrally to interface to legacy serial servers.

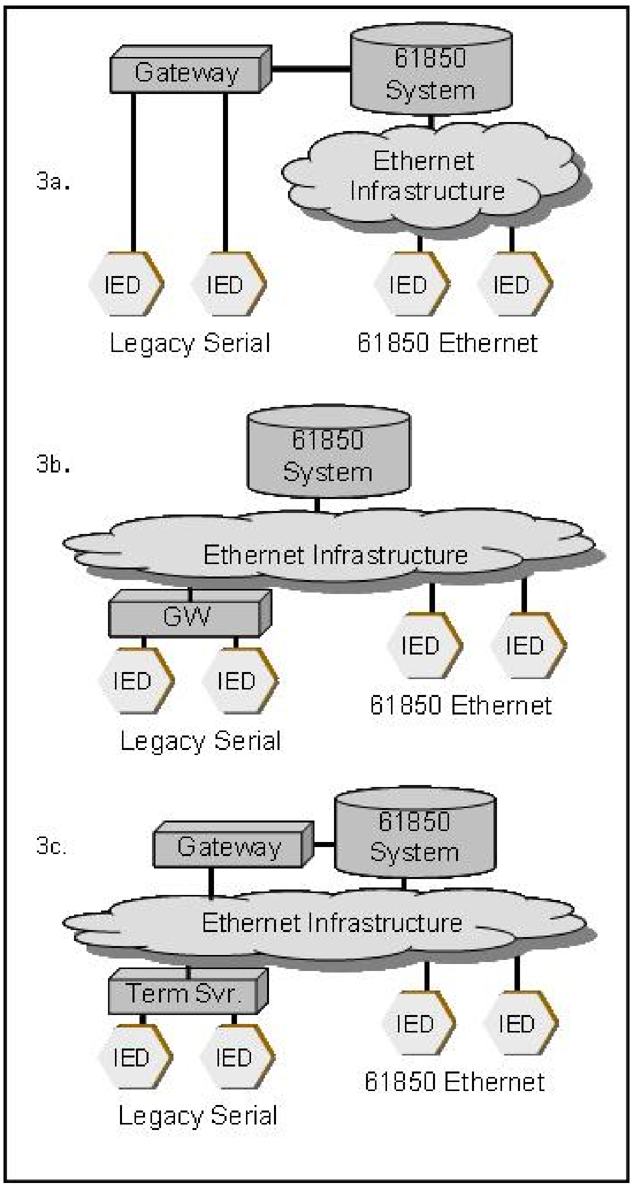

Fig. 3. Three architectures for legacy and 61950 Ethernet IEDs with 61850 applications.

It is also desirable to network-enable serial consoles. By attaching serial consoles via serial-IP terminal servers onto the IP-Ethernet infrastructure, the console ports can be centrally administered and remotely accessed by any authorised user of the network from a remote work position.

The serial edge networking approach of distributed serial-IP terminal servers creates a common solution to these two requirements. Newer-generation serial-IP device servers have direct fibre Ethernet interfaces and more than one Ethernet connection into the core network, providing a highly reliable, dynamic serial edge.

VI. VIDEO SURVEILLANCE

The risks of sabotage and theft have increased concern for the physical security of substations. Many utilities are employing video surveillance as a key element in providing access control and intrusion detection. Video surveillance acts as a complement to other sophisticated access control systems. With the addition of motion-sensing software intelligence it becomes an important part of intrusion detection; and it also provides another operational view of the status of equipment and of weather conditions.

Digital video cameras have recently overtaken analogue video cameras in terms of price and performance for many applications, especially where high-resolution, full-motion video is not required. IP-enabled video cameras can now share the Ethernet infrastructure with other applications so long as bandwidth is sufficient and Quality of Service is effectively implemented. Some Ethernet vendors implement enhancements to IGMP multicast protocol handling by the Ethernet infrastructure in order to better optimize network performance when integrating video applications.

One enabling technology for video camera is PoE. IETF RFC 802.1af provides a standard for implementing the distribution of electrical power directly over a 10/100TX electrical Ethernet connection from an Ethernet switch to an end device. As shown in Fig. 4, PoE can be used to simplify the deployment of video cameras by eliminating the need for separate electrical power feed to the camera. PoE may also be used for applications such as powering VOIP telephone handsets or access control readers.

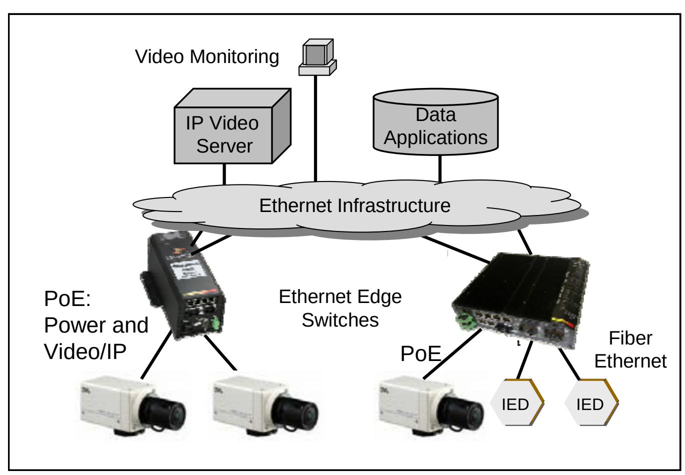

Fig. 4. PoE use in deployment of remote video applications.

VII. Wide Area Network Connections

Some distribution substations are operated locally with personnel on site on a regular basis and with limited remote monitoring. Increasingly, larger substations also have full-time communications to central operations centres so that the utility operations staff can monitor the overall status of the power grid and respond more quickly to service-affecting issues.

Prior to the integrated substation network, it was typical for any remote system to require its own communication connection to the substation. This drove up costs and limited the attractiveness of remote communications.

With an integrated substation network, a single wide area communications link can provide remote access to a number of different systems within the substation. SCADA and Energy Management Systems (EMSs) can be connected from central systems to remote IEDs in real time. Engineers working from their main office can access administrative ports on remote devices, gather register settings or reprogram IED parameters without travelling to the substation.

One key is to implement Internet Protocol (IP) as the common protocol across systems. As described above, legacy serial ports, including administrative IED ports, can be accessed from a central PC using common terminal emulation software such as Windows HyperTerminal or by PC client programs provided by many IED manufacturers.

The WAN gateway device is basically an IP router. Like the other devices in the substation, it should be hardened to substation equipment standards. It should provide more than one connection into the Ethernet core network over Ethernet and participate in RSTP for greater reliability. There are several different WAN media available, including wireless, fibre and various telecommunication carrier services. The WAN gateway should support direct interfaces to the appropriate service, such as an E1 carrier line.

The WAN gateway also plays an important role in cyber security for the substation. The WAN gateway should provide the primary electronic security perimeter protection. The gateway should include IP Firewall features to block unauthorized access to the substation network. Virtual Private Network (VPN) technologies such as IPsec and Secure Socket Layer (SSL) should at least be available to provide increased security in the future. Secure management of all network devices is also important, using SSL/SSH (Secure Shell) and Simple Network Management Protocol (SNMP) v3.

VIII. Summary

The technology is now available to integrate the various communications requirements within a substation onto a single infrastructure. Such an integrated approach has many economic benefits and the practical advantage of making it easier to add automation projects over time.

Ethernet switching is at the core of this strategic architecture. Various technologies will create a dynamic edge of services around this core, accommodating a multitude devices and applications with specialized needs.

Advanced planning and a clear vision of target architecture are required to ensure the successful integration of substation communications. With this vision, the network can grow one project or one new device at a time. The key success criteria remain constant from the initial vision to each incremental project: flexibility, performance and reliability. Ethernet technology is now ready to deliver on all three.

IX. Biography

J. M. Shaw is Executive Vice President of GarrettCom and head of GarrettCom Utility Networks, an organisation focused on sales, technical services and product development for power utility customers worldwide. John was president and CEO of DYMEC, Inc, the leading provider of substation-hardened networking products recently acquired by GarrettCom. John has more than 25 years of experience in telecommunications, with technical marketing and planning background in enterprise, industrial and carrier sectors. Previous executive roles include Co-Founder and VP at successful technology start-ups Hillcrest Communications and NetCore Systems, and senior positions at Tellabs and Newbridge Networks (now part of Alcatel), all of these significant equipment and software suppliers to major carriers. As Director of Data Services for NYNEX (now Verizon), he pioneered frame-relay and fibre-based enterprise data services in New York City and elsewhere. He has an MBA from Boston University and extensive early career experience in computer network planning and implementation