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WP 1004HE – Part 2

White Paper – Data Communication in a Substation Automation System (SAS)

Communication network requirements

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1. Communication Network Requirements

A substation network is a mission-critical network and must have the capacity and flexibility to support many different applications at the same time. Besides peer-to-peer access within the network, successful implementation of a substation network demands comprehensive network performance and a wider diversity of requirements.

1.1 What are the Requirements for Communication Network Design?

Substation communication networks are normally designed according to their voltage levels, location and technology of equipment, protection and control application, data flow, etc. The following performance requirements need to be considered to implement the various functions on a substation Ethernet communication network.

Ruggedized Communication Devices and Physical Media

Under the specially harsh environmental conditions in a substation, all communication devices, including Ethernet communication switches, must be ruggedized and comply with IEC61850 and IEEE1613. Furthermore, the physical medium should also be chosen based on the EMI conditions, traffic volume and speed, transfer distances and cost. As a result, optical fiber instead of copper wiring is increasingly required.

Network Topology

Each communication network is built with a different topology. Basic topologies are bus, star and ring topology. Many other redundant topologies with parallel ring, start-ring or double star are derived for modern substation communication networks. In general, network topology in a process bus and a station bus are separate for security and availability reasons. An Ethernet switch is essential in order to build the network topology.

Resiliency and Redundancy

The complete functionality of a substation communication network must be sustained when any single point in the network fails. The network must be able to recover from a failure in the network and at least one alternative path should be designed. As a result, redundant links, protocols and topologies with redundant switches or even redundant devices are always required in a substation communication network.

Network Management

As a mission-critical substation network, all information and devices must be easily managed, monitored and controlled using network management software. Common network management software is based on SNMP and a managed Ethernet switch is required for the network. If an unmanaged switch is implemented in a substation application for data and message transfer on the network, the information can only be acquired from the system browser, the devices cannot be configured, and worse, the end user cannot locate any problems in the network.

Transportability

The system software must be applicable to multiple hardware, software, and network operating environments and support the object management structure as well as its expansion.

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Availability and Reliability

Once a substation is in operation, it must run all year round without disruption. If any failures occur in the system (e.g. network, primary or secondary equipment) the communication system must return to normal operation in a very short time. Even with system maintenance, some defective components must be hot-swappable and repaired components must be reinserted. This requires high availability and reliability which network redundancy can enhance. MTTF (Mean Time to Fail), MTBR (Mean Time between Removals) and MTTR (Mean Time to Recovery) of the communication network must be also considered.

Time Synchronization and Accuracy

A communication network is required to support time-critical real-time monitoring, protection, and control functions of the substation automation systems (SAS). Time synchronization is required in the network to allow precise data control; avoid information traffic collision and enable precise logging if failure occurs. Many time synchronization protocols can be applied to a substation communication network. SNTP protocol is specified for a station bus and a time accuracy of 1ms is required. IRIG-B and 1PPS for time synchronization in a process bus is also required. Nowadays, IEEE 1588-2008 (PTPv2) is the new standard for synchronization of IEDs and switches are also specified in IEC61850-9-2.

Cyber Security

In modern substation automation systems, the network is always connected to the corporate WAN or remote access is allowed. Even a completely isolated substation network is under threat of attack. Network security mechanisms like syslogs, security audit trials, user authorization passwords, access control, port security and encryption should be implemented.

Maintenance

A communication network should be designed and configured so that it can be easily maintained or restored to a specified condition within a given period of time.

For regulatory compliance, country-specific regulations must be considered in network design, e.g. Nerc CIP in North America.

In terms of scalability, upgradeability and future-proofing, the devices and protocol profile chosen should be robust enough for operation today and should have a clear migration path to increased performance in the future. The network must allow detection and addition of new bays, devices and applications without significant modifications to the backbone of the core network. It should support online network and IED system upgrades. In order to achieve future-proofing of the network, equipment with protocols that allow for future trends should be selected.

2. Physical Layer of the Network

2.1 What is the Physical Layer of a Substation Network?

A communication network follows the OSI model with seven layers. The physical layer is the lowest layer in this model. In the physical layer, bits are converted into signals for outgoing messages and signals are converted back into bits for incoming messages.

The physical layer describes the signal transmission media connection (line coding, line driver), connectors and cabling (copper, wireless, or fiber) which are independent of the communications protocols.

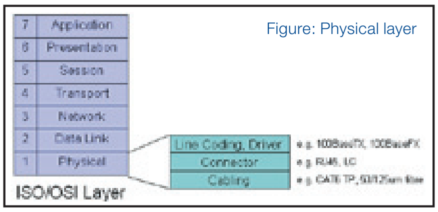


Figure: Physical layer

Ethernet defines several physical layer specifications that differ in line speed (10 mbps, 100 mbps, 1 gbps, 10 gbps) and physical media (twisted pair copper, multimode optical fiber, single-mode optical fiber).

IEC 61850 typically uses Fast Ethernet with 100 mbps, either on copper (100BaseTX) or on fiber optics (100BaseFX). Gigabit Ethernet with 1000 mbps data rate could be considered as well for future use.

2.2 How to Select Physical Layers for Substation Communication

The physical layer deals with the transmission of bits between two devices. Normally physical layers should be selected with the following criteria.

Line Rate

Today Fast Ethernet is the line rate of choice for almost all substation networks. For standard substation automation applications, 100 mbps is absolutely sufficient even for larger installations. Nevertheless one should consider the use of Gigabit Ethernet, at least in the backbone.

Bandwidth

Sufficient bandwidth is key to ensuring that substation network performance requirements are met. Additional high bandwidth applications, like video streams, will use the same network infrastructure. In general the network should be designed in such a way, that network load never reaches the capacity limit even in critical situations.

If in the future the use of sampled values in process bus applications is planned, it should be taken into account that sampled values need significant bandwidth and may require the use of Gigabit Ethernet networks.

Latency

For application reasons, latency has to be as short as possible. Especially if many cascaded switches are used, latency increases with each switch hop. By using Gigabit Ethernet latency can be significantly reduced.

2.3 How to Select Cable (Fiber or Copper)

While copper cabling is quite cheap and easy to use, copper covers only a limited distance of a maximum 100 meters. Copper is also much more sensitive to EMI (electro-magnetic interference) than fiber. Because of EMI, all Ethernet connections outside a cabinet and in EMC sensitive environments should be made using fiber optics. Copper links should be used only inside a cabinet or inside a building, while the cable length should be limited to 25 meters so it has an additional noise margin.

Copper connections for Gigabit Ethernet are not recommended because of long link set-up times and lower noise margins.

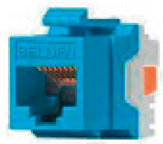
For copper connections, CAT5e cables should be used at the least, CAT6 cable is even better. Twisted pair cables should always be shielded. While Fast Ethernet needs only 2 pairs of wires, Gigabit Ethernet requires 4 pairs. If for any reason the use of Gigabit Ethernet over copper is a future possibility, 4 pairs of cables can be installed. Only direct cable should be used, the auto-polarity function of the devices will automatically connect sender to receiver pairs.

For fiber optic links, multimode fiber with a 50 µm core diameter is recommended. This can be used up to 2,000 meters for Fast Ethernet and up to 550 meters with Gigabit Ethernet. If longer distances have to be covered, the use of single-mode fiber with a 9µm core diameter is possible. In this case the link distance can be up to 10 kilometers.

All fiber connections should be operated at an optical wavelength of 1.300 nm, which means 100BaseFX standard for Fast Ethernet and 1000BaseLX standard for Gigabit Ethernet.

2.4 How to Select Connectors

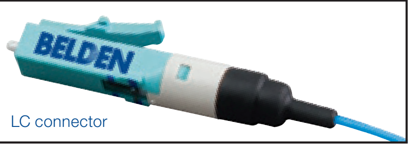
For copper RJ45 is the commonly used connector. For standard applications in protected environments this works without any problems. However, in harsh environments with vibration, shock or strong humidity more robust connectors like M12 can be applied.



RJ45 connector

M12 connector

The different types of fiber connector are ST, SC, and LC. While in today's applications a lot of traditional ST and SC connectors are still used, small form factor (SFF) connector LC is recommended for substation communication. With its paired fibers it will become a very common solution because of its small size and robustness.



LC connector

3. Network Management

There are normally two kinds of substation applications: specific applications and generic applications. Network management software must be selected according to different substation network situations. Because of the complexity of cabling and configuration of devices in the substation, network management software solutions are supplied by many application vendors.

3.1 What is Network Management in Substation Communication?

In a substation, devices are connected with Ethernet communication switches to build different LANs at the process level, bay level and station level. In order to know what is happening in the substation communication system, all data traffic should be monitored and managed by network management.

Network management of a substation includes operation, administration, maintenance, and provisioning of substation network systems to ensure everything in the communication network is working properly, safely and under control.

A substation network management system consists of 3 main communication components: agent, NMS manager and SNMP protocol. The task of the agent in a network device (IEDs) is to configure the device, collect status and performance data and send it to the NMS (Network Management Station) manager.

The task of the NMS is to collect data from all agents and carry out central control and configuration. Communication between agents and the NMS is carried out through SNMP (Simple Network Management Protocol).

3.2 What can be Managed by the Network?

Everything imaginable in the substation should be managed. The requirements of network management in a substation can be divided into following functional areas.

Configuration Management

Substation communication devices must be configured and one or more databases inside the devices should be used to store the configuration data of IEDs, switches, ports, VLAN or redundancy, etc.
The task of configuration management is to download, activate and retrieve configuration data from the communication devices to set up or maintain the communication system by answering the following questions:

1) How are the hardware and network configured, e.g. cabling infrastructure?
2) Where is the configuration data stored?
3) How can configurations files be made available to service people, e.g. substation modification?
4) Have any hardware configurations changed, e.g. substation extension?
5) Has any software configuration changed without a hardware change, e.g. bugs or addition of a new function?

Configuration management is normally performed in the set-up, maintenance, upgrade or extension phase of a substation communication system.

Fault Management

Faults in substation communication may be persistent or transient as particular events or errors may cause substation systems to fail. Fault management encompasses fault detection, isolation and the correction of abnormal operation by using the following functions:

a) Maintaining and examining error logs

b) Accepting and acting upon error detection notifications

c) Tracing and identifying faults

d) Carrying out sequences of diagnostic tests

e) Correcting faults

Supervisory Management (Troubleshooting)

If a substation network gets out of control because of a failure or error in the network, it will have serious consequences. Supervisory management can proactively monitor the communication network and identify issues as soon as they occur. Since a substation is a critical infrastructure, the failures in a substation should be predicted in advance. Hirschmann™ HiVision network management software can predict possible problems before they happen by observing trends and investigating the signal threshold, number of errors, bandwidth utilization and percentage of link capacity.

Asset Management

Asset management monitors and diagnoses the asset to ensure it is operating in the most efficient way and to identify who is responsible for events occurring in the substation.

Many utilities have more than one database that refers to critical assets. This helps ensure a high degree of system reliability and reduces asset downtime and the risk of catastrophic failure of the substation system.

By using asset management, network operators can manage limited resources in the substation in a way that meets targets like system expansion with constant or even increasing power quality requirements.

Accountability Management

With a large quantity of signal traffic and events in the substation, network management cannot monitor all devices constantly. It is not easy to discover the real status of substation communication through the ask (server)-answer (client) mechanism.

Accountability management is a standard security policy from Nerc CIP. It can help end users to understand their substation communication network in more detail. With accountability management, end devices are configured to inform the server if anything is happening.

There are two ways for end devices to inform the server:

1) By using syslog, alarms from devices are sent to the server.

2) By using SNMP traps, devices send information to the server. The network system is able to find out who did what, when and from where by using SNMP traps in the network management station server.

Performance Management

Performance management in a substation involves monitoring the performance of devices and evaluating the effectiveness of communication activities. It will ensure that everything in the substation is working properly. There are many way to monitor the performance of devices.

Performance management generally includes the following functions:

1) Gathering statistical information

2) Maintaining and examining logs of system state histories

3) Determining system performance under natural and artificial conditions

4) Altering system modes of operation in order to conduct performance management activities

For instance, a pinging device can be used to check whether the response time (time interval) has changed. If the response time or bandwidth utilization has increased, network performance has decreased. Special tools are normally required for performance management.

Security Management

A substation is subject to security issues both within (human error or attack) or outside (environmental or attack) the network. The purpose of security management is to support the application of security policies using the following functions:

1) Creation, deletion and control of security services and mechanisms

2) Distribution of security-relevant information

3) Reporting of security-relevant events

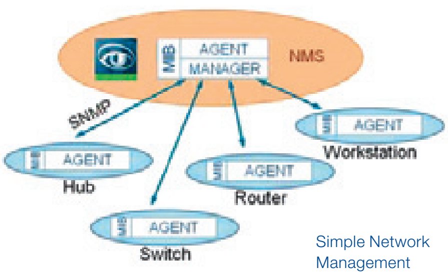
3.3 Which Protocols are Applied?

There are two standard protocols for substation network management: SNMP and OPC. As part of SNMP, the Remote Monitoring protocol (RMON) allows remote collection of network information.

SNMP

The Simple Network Management Protocol (SNMP) is a popular protocol for network management. It is used to collect information and configure the communication network.

SNMP involves two players: the manager and the agent. The manager is generally the Network Management Station or NMS. It usually requests data flow. The agent is the SNMP software running on a client system which is monitored.



Simple Network Management Protocol (SNMP)

SNMP exchanges are always initiated by the manager; the agent can also send traps to inform the manager about an important event.

There are three version of SNMP: SNMP V1, SNMP V2 and SNMP V3. The most common versions are V1 and V3. SNMP V3 includes a security function.

Network data is exchanged between agent and manager by using a virtual information database called the Management Information Base (MIB). Information about communication switches or other devices can be read from or written to this database. Two types of MIB are available:

1) Public MIB. This is also called standard MIB II and contains standard information about standard Ethernet function and network information. For instance, port states (on or off) of switch or link operational states (up or down) of bridge.
2) Private MIB. This is a manufacturer-defined database and contains specific information. For instance, status of power supply is a private MIB.

OPC

OPC stands for OLE for Process Control. It is a protocol used in process control for exchanging data between devices. There are different types of OPC, one is widely used OPC DA (Data Access) and the other is OPC UA (Unified Architecture), which provides a cohesive, secure and reliable cross-platform framework and is becoming more popular. An OPC client application can provide a generic interface to outside data which is independent of any specific protocol. OPC Servers can support a wide variety of protocols like IEC61850, Modbus, DNP3, etc. It enhances the user selectivity and flexibility. Communication devices in a substation should support both and the Application Program Interface (API) of an OPC foundation. With built-in support for object discovery in an OPC browsing interface, the substation network configuration and installation can be done easily. By using an OPC client application on top of an IEC61850 server, any legacy devices with other protocols can be integrated into the current substation system.

3.4 Summary

Hirschmann™ HiVision network management software is an essential management tool for all stages of a substation network lifecycle. Designed for effective industrial supervision, Hirschmann™ Industrial HiVision can be easily integrated into substation SCADA applications. It offers a built-in SNMP for an OPC server.

Hirschmann™ HiVision network management software integrates end products (e.g. PLCs, DCS, and IEDs) and information from different utility suppliers like ABB, Siemens, Schneider, etc. Utility customers can easily integrate new products from different vendors into their substation network with Hirschmann™ HiVision.

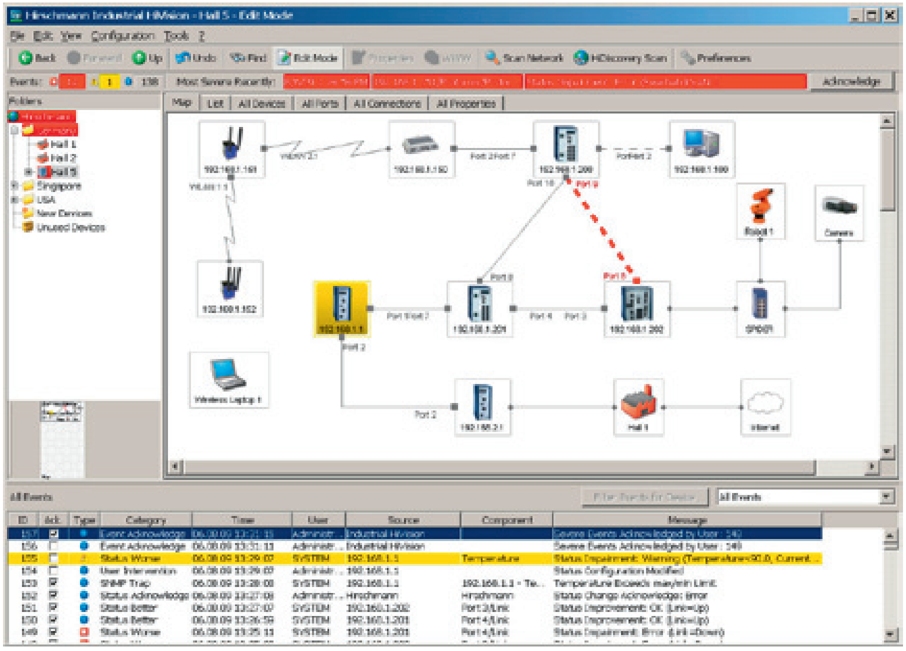


Figure: Hirschmann™ Hivision Management Software

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Appendix: Further Support

Technical Questions and Training Courses

In the event of technical queries, please contact your local Hirschmann™ distributor or Hirschmann™ office. You can find the addresses of our distributors on the Internet: www.hirschmann.com

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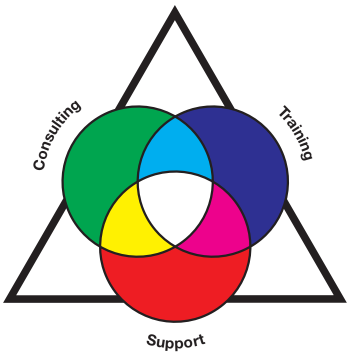
Current training courses for technology and products can be found under http://www.hicomcenter.com.



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