

A plane can be uniquely determined by three non-collinear points -
how many do we really need?

Standard

IEC 61850





and Network Redundancy

IEC 61850

Redundancy

using IEC 62439

● The IEC 61850 standard has become the backbone of substation automation, allowing for the first time to engineer protection, measurement and control devices of different manufacturers and let them interoperate on the same Ethernet network, station bus or process bus. However, when high network availability is required, IEC 61850 left open how to provide network redundancy.

As a result, proprietary redundancy schemes emerged, but they were not interoperable and threatened the basic goal.

THE IEC 61850 STANDARD is a milestone in substation automation, replacing a plethora of busses and links by a hierarchy of well-specified switched Ethernet networks, namely the station bus between the bays and the process bus within a bay. A great achievement of IEC 61850 is the description of all communication in the substation in the Substation Configuration Language (SCL), which allowed for the first time engineering of a substation consisting of protection, measurement and control devices (called IEDs, for "Intelligent Electronic Devices") of different manufacturers. However, the IEC committee TC57 Working



Group 10 that created IEC 61850 did not specify in detail the underlying hardware of these busses, believing that solutions standardized for industrial Ethernet would find their way into substation automation. This applied especially to two indispensable network features: time synchronization and network redundancy. Time synchronization was solved by the SNTP (Simple Network Time Protocol) and for stricter requirements by the IEEE standard 1588 [8] (which is not subject here), but redundancy was a major hurdle. Indeed, the lack of a commonly accepted redundancy solution was threatening the whole interoperability concept, since manufacturers started putting on the market proprietary redundancy solutions, preventing effectively to build a substation when the interfaces did not fit. Fortunately, the IEC committee SC65 WG15 “Highly Available Automation Networks” published just in time the IEC standard 62439 which specifies several redundancy methods, one of them applicable to substations of any size and topology, for the station bus as well as for the process bus.

The Parallel Redundancy Protocol (PRP) IEC62439-3 Clause 4, relies on the parallel operation of two local area networks, and provides completely seamless switchover in case of failure of links or switches, thus fulfilling all the hard real-time requirements of substation automation. PRP can also be applied to build a simple, seamless ring by treating each direction as a separate network, a method called HSR (High Availability Seamless Ring), currently circulated as IEC CDV 62439-3 Clause 5. This method has been now proposed as an integral part of IEC 61850.

IEC 61850 network topology

IEC 61850 encompasses two busses based on the switched Ethernet technology:

- the station bus that interconnects all bays with the

station supervisory level and carries principally control information such as measurement, interlocking and select-before-operate (typically MMS for station level to bay level IEDs and GOOSE for bay IED to bay IED).

- the process bus interconnecting the IEDs within a bay that carries real-time measurements for protection called sampled values (SV), nominally at a 4 kHz sample rate.

However, IEC 61850 does not prescribe a topology, tree, star or ring, so any topology is conformant. It is even conformant to have the same physical Ethernet carrying both the station and the process bus traffic.

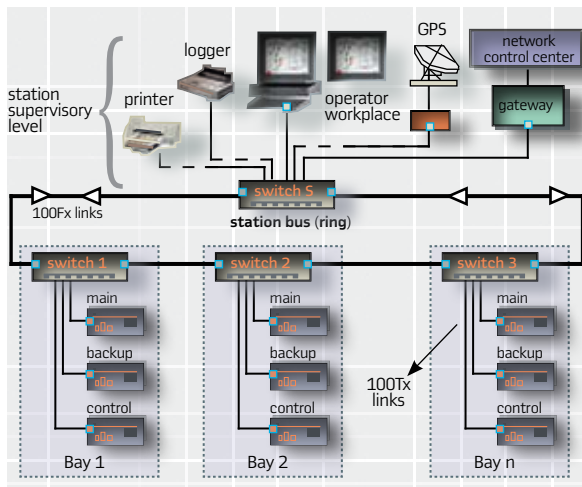
For the station bus, the network topology that imposed itself in large substations is that each voltage level uses a ring of switches, which connect the IEDs, typically main protection, backup protection and control IEDs (Figure 1).

In large substations, the rings of the different voltage levels are connected in a tree form to the station level. The station bus therefore exhibits a mixed ring and tree topology. In small substations, for instance in medium voltage, there is typically only one IED per bay and each IED incorporates a switch element, so the IEDs can be chained into a ring (Figure 2). At the process bus level, IEDs are typically simple measurement and control devices connected in a tree form to a merging unit, which performs the protection functions and acts as interface to the station bus (Figure 3).

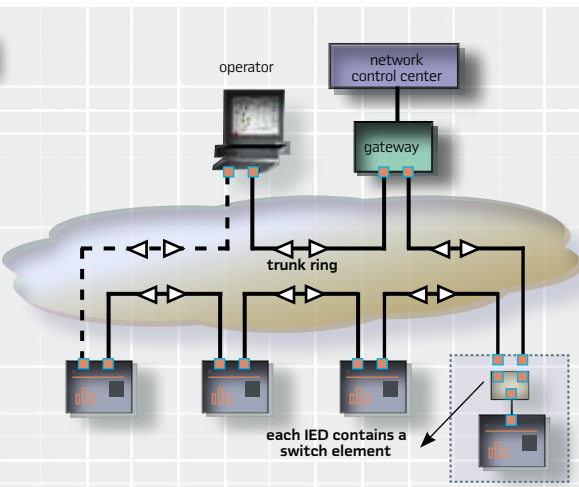
The timing requirements for the station and for the process bus are distinct, they dictate the redundancy method to be used.

When the station bus carries only command information, delays of some 100 ms are tolerable, but when carrying interlocking, trip signals and reverse blocking, only a 2 milliseconds delay is tolerable in the

1 Station bus topology for one voltage level



2 Ring with switching end nodes



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normal case. Although it is unlikely that a failure will take place exactly when an (infrequent) control sequence is issued, no more than 4 milliseconds are tolerable in the worst case.

The process bus carries real-time data from the measuring units, which requires a deterministic mode of operation, with maximum delays of 0 ms. Here there is no difference between normal operation and worst case.

Availability requirements in substations

Source: These requirements have been compiled by the TCS7 Working Group 10.

General requirements: Substations operate around the clock all year round, and are seldom shut down for maintenance. Live removal and reinsertion of components is therefore required. This means that the recovery time applies not only to the insertion of redundant components in case of failure, but also to the reinsertion of repaired components.

In protected systems, a failure of a protection component can have two outcomes:

Overfunction: the system shuts down unnecessarily;

Underfunction: the system is no longer protected and becomes unsafe, a subsequent internal fault or external threat occurring in this state could cause severe damages.

table 1 Recovery time requirement

Communicating partners	Bus	Recovery Time
SCADA to IED, client-server	station bus	400 ms
IED to IED interlocking	station bus	4 ms
IED to IED, reverse blocking	station bus	4 ms
buss bar protection	station bus	0 ms
sampled values	process bus	0 ms

PRP-IEC 62439 provides an ideal redundancy scheme based on IEC 61850:

- Can be used with any Ethernet and topology
- Is compatible with RSTP or MRP (IEC 62439)
- Is transparent & Achieves zero recovery time
- Tolerates any single network component failure
- Does not rely on higher layer protocols
- Allows nodes not equipped for redundancy to operate
- Uses off-the shelf network components
- Fulfills all requirements of substation automation
- Supports time synchronization

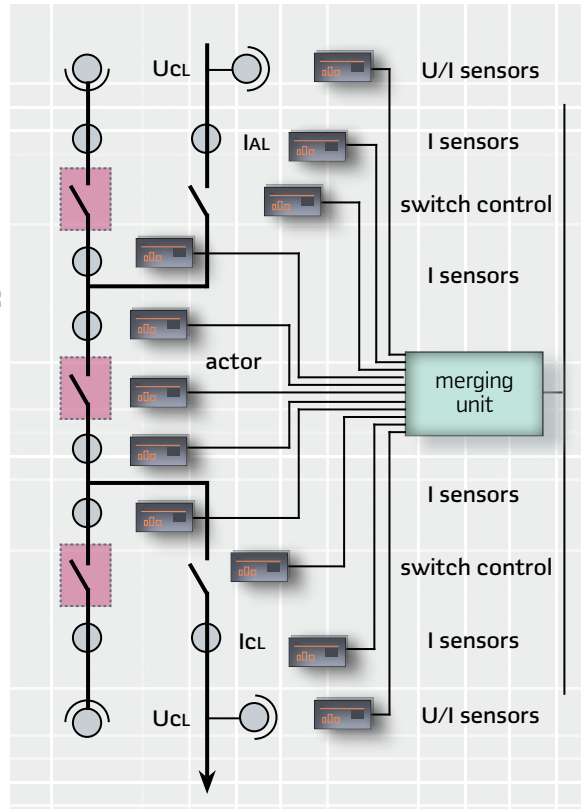
Live removal and reinsertion of components may be required in substations.

The substation automation system is designed so that a network failure cannot cause an underfunction, but it could cause an overfunction, since missing data are tagged as unsafe and would cause a shutdown of the substation. The time during which the substation tolerates an outage of the automation system is called the grace time. The network recovery time must therefore be lower than the grace time. The requirements on recovery time of TC57 WG10 are summarized in Table 1.

Requirements on protocol dependency: The redundancy scheme shall not depend on the IEC 61850 protocol for its function. Devices not obeying the IEC 61850 protocol shall be connectable and benefit from the same redundancy as IEC 61850 IEDs.

Mixed installations such as small power plants require that the communication network supports other protocols

3 Process bus topology



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in addition to IEC 61850. The same redundancy scheme shall be applicable to the station bus and to the process bus. Either bus can run the IEC 61850-8 or the IEC 61850-9-2 protocol. For ease of configuration and warehousing, only one solution for all devices is desirable. The redundancy scheme shall support GOOSE and SV traffic. Therefore, a method exploiting network router redundancy is unsuited, since it would not forward GOOSE or SV traffic which use layer 2 protocols. Devices not equipped for redundancy shall be connectable to the redundant network; full connectivity with non-redundant devices in case of failure is not required.

Requirements on the products: Network devices (switches, routers) shall be standard devices, such as ones used when the network exhibits no redundancy.

Standard PCs shall be connectable without modification as singly attached nodes. The redundancy solution shall be realizable with open standard solutions.

Requirements on configuration: The redundancy scheme shall not require incompatible modification to the present IEC 61850 SCL, but extensions are allowed.

Redundant IEDs shall not require a distinct configuration from non-redundant ones.

Supervision requirements: Redundancy shall be regularly checked, at intervals lower than 1 minute for the complete network. Only one device, station operator or gateway to NCC, shall be needed to monitor the network.

Due to the presence of non-IEC 61850 devices (e.g. Ethernet switches), network management shall not rely on IEC 61850 protocols, but preferably on SNMP. It is strongly recommended to include the state of redundancy in IEC 61850 objects.

Configuration errors shall be reported to station operator or NCC gateway.

Highly Available Network Topology

IEC 62439 is a general standard developed by IEC SC65C Working Group 15 “Highly Available Automation

Networks”, applicable to all Industrial Ethernet [5], since it considers only protocol-independent redundancy methods. It contemplates two basic methods to increase availability of automation networks through redundancy: “*redundancy in the network*” and “*redundancy in the nodes*”.

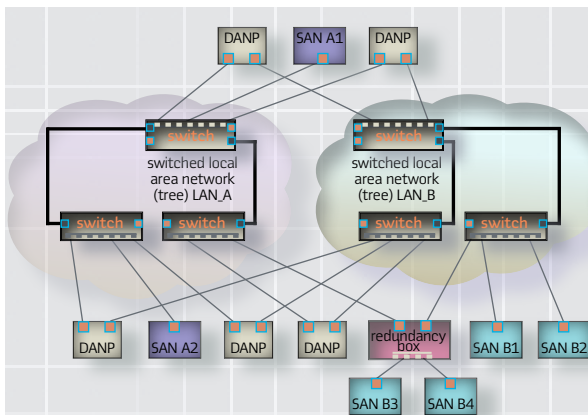
■ **Redundancy in the nodes:** a node is attached to two different, redundant networks of arbitrary topology by two ports (Figure 4). Each node chooses independently the network to use. This scheme supports any network topology; the redundant networks can even exhibit a different structure. The costs of such a redundancy is the doubling of the network infrastructure, but the availability gain is large – the only non-redundant parts are the nodes themselves. IEC 62439 specifies the PRP (Parallel Redundancy Protocol), a “redundancy in the nodes” solution in which nodes use both networks simultaneously. This offers zero recovery time, making PRP suited for all hard real time applications.

■ **Redundancy in the network:** the network offers redundant links and switches, but nodes are singly attached to the switches through non-redundant links. Availability gain is small, since only part of the network is redundant, but so are costs. Redundancy is inactive and requires some insertion delay. A typical example of such a method in office automation is RSTP (IEEE 802.1D [7]). While some manufacturers of RSTP switches promise recovery times below a few seconds for certain topologies, the RSTP standard provides at best a 2 s recovery time. The current IEC 62439 CDV specifies the High Availability Seamless Ring (HSR) that applies the PRP principles to a simple ring, such as the one shown in Figure 2, by treating each direction as a separate network, and offers zero recovery time.

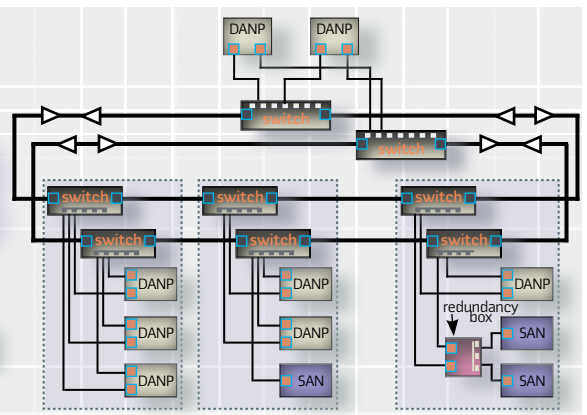
Application to substations: For the station bus of small substations that operate with a single ring and a limited number of IEDs, a “redundancy in the network”

Increase in the availability of automation networks can be achieved through redundancy in the network and redundancy in the nodes.

4 Duplicated network



5 Duplicated station bus with PRP





solution such as RSTP is applicable, as long as the station bus does not carry interlocking information (see Table1). Therefore, this solution has only limited applicability and it is not further detailed here. By contrast, for the process bus and for large substations, only a “redundancy in the nodes” solution provides high enough availability and small enough recovery time. Applied to a voltage level in a substation, the redundant topology appears in Figure 5.

Each IED is attached to the two networks, which are operated simultaneously. The same method can be applied to single ring substations, as shown in Figure 6.

Obviously, the same scheme applies to complex substation automation systems of any topology.

PRP operating principle

Network topology: Each PRP node (called a DANP, or Doubly Attached Node with PRP) is attached to two independent LANs which may exhibit different topologies. The networks are completely separated and are assumed to be fail-independent. The networks operate in parallel, thus providing a zero-time recovery and allowing checking redundancy continuously to avoid lurking failures (Fig. 4).

Non-PRP Nodes, (called SAN or Singly Attached Nodes) are either attached to one network only (and therefore can communicate only with other SANs attached to the same network), or are attached through a “Red Box”, a device that behaves like a DANP (Figure 5).

Node failures are not covered by PRP, but duplicated nodes may be connected via a PRP network.

Node structure: Each node in PRP has two Ethernet bus controllers (Figure 7), which have the same MAC address and present the same IP address(es); Therefore, PRP is a layer 2 redundancy, which allows network management protocols to operate without modification and simplifies engineering.

For substation automation, a layer 2 redundancy means that PRP fully supports the GOOSE and SV traffic. The Substation Configuration Description (SCD)

PRP is an important contribution to achieve interoperability with respect to redundant communication for protection, measurement and control devices of different manufacturers.

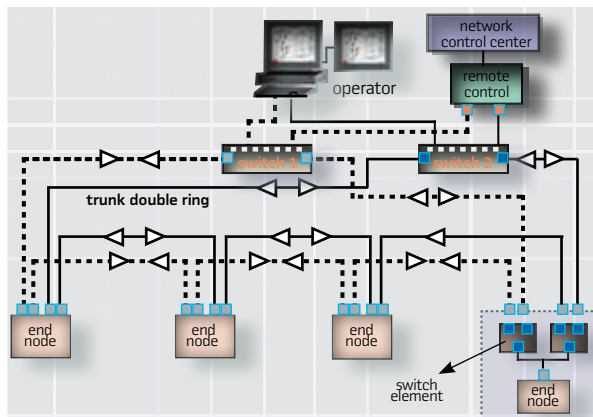
file does not need to be changed, the only additional components introduced when going redundant are the additional switches. An additional layer is introduced in the (otherwise unmodified) communication stack, the LRE (Link Redundancy Entity), a software that handles both Ethernet controllers and presents the same interface towards the upper layers as a single Ethernet interface.

In a sending node (e.g. node X in Figure 7), the LRE duplicates the frame it received from its upper layer and sends the frames over both bus controllers at the same time. The two frames propagate through both networks (if both are operational), and arrive with a certain time skew at the receiving node. In a receiving node (e.g. node Y in Figure 7), the LRE receives the same frame from both bus controllers. If a network or a bus controller is damaged, the LRE will still receive frames over the other network. So in case of failure of one network path, data keep flowing over the other network.

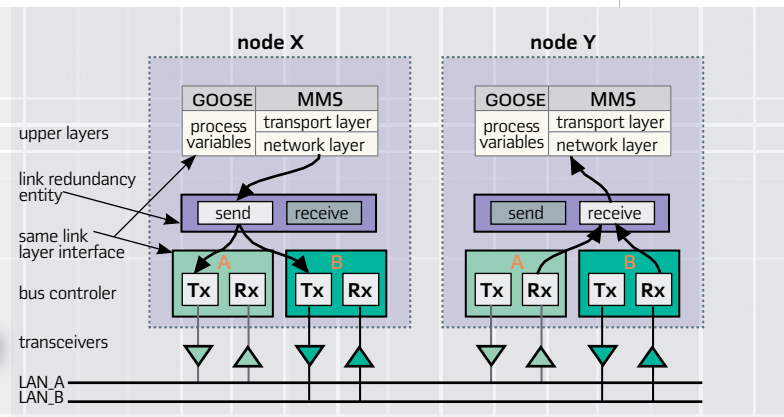
In principle, a receiving LRE could forward both frames it receives to its upper layers, since a well-designed application can handle duplicates. Indeed, switched Ethernet networks cannot guarantee freedom of duplicates.

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6 Duplicated ring with PRP



7 Node structure in PRP



TCP has for instance been developed to discard duplicates. Applications using UDP must be able to treat duplicates since UDP is a connection-less protocol.

However, discarding duplicates at the link layer level allows to offload the application processor and to provide network supervision. Since it is not necessary to discard all duplicates, the LRE can discard duplicates on a best-effort basis, which considerably simplifies the protocol.

To this effect, the LRE of a sending node appends a sequence counter, a size field and a LAN identifier to each sent frame. This keeps the frame structure unchanged and allows mixing PRP and non-PRP devices.

Seamless Single Ring: The PRP algorithm can be applied to a single ring, treating it as two virtual LANs. This allows a significant reduction in hardware costs since no switches are used and only one link is added, but all nodes of the ring must be “switching end nodes”, i.e. they have two ports and integrate a switch element, preferably implemented in hardware, as Figure 8 shows.

For each frame, a node sends two frames - one over each port. Both frames circulate in opposite directions over the ring. Every node forwards the frames it receives from one port to the other. When the originating node receives a frame it sent itself, it discards it to avoid loops; therefore, no special ring protocol is needed. With respect to a single ring, the bus traffic is roughly doubled, but average propagation time is reduced, so the ring can support a similar number of devices. Singly attached nodes such as laptops and printers are attached through a “redundancy box” that acts as a ring element.

A pair of such redundancy boxes can be used to attach a seamless ring with a duplicated PRP network. In this case, each “red box” sends the frames in one direction only. This allows overcoming the basic limitation of a ring, and constructing a hierarchical or peering network.

Components availability: PRP has been developed at ABB Switzerland in collaboration with the Zurich Technical University Winterthur for use in hard real-time

automation systems. Components for VxWorks and Windows have been developed and used in revenue projects. Winterthur [7] developed a Unix version of PRP and a “Red Box”, the device used to connect standard devices to two redundant lines.

Compatibility with IEEE 1588: The PRP scheme presents a challenge for time synchronization according to IEEE 1588, since the delay over the two redundant networks is different. However, IEEE 1588 can be configured to treat those networks as distinct clock systems and therefore increases the robustness of the clock system.

Field experience

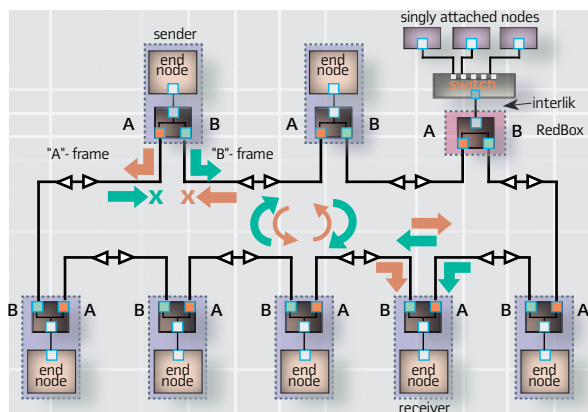
The first substation automation system for a high-voltage substation with control devices operating under PRP successfully passed the factory test last year, after extensive tests. The tests have proven that the technology is ready to be applied to substation automation devices and that it performs as expected with zero switch over time.

One of the major requirements for this project was to have fully redundant communication down to the bay level IED to ensure no single point of failure in respect of controlling the substation. Therefore a fully redundant solution with redundant station computers (MicroSCADA 1 and MicroSCADA 2) in hot stand-by configuration for the control and monitoring at the substation level as well as redundant gateway functionality for the telecontrol function has been supplied. For control at the bay level ABB's latest control devices for high voltage applications REC670 were used.

The connection of the bay control units (REC670) is done using two completely separated networks which are configured as a ring. The entire system is synchronized using SNTP sent in parallel to both networks using two independent GPS receivers with integrated SNTP time servers. The communication system is supervised using SNMP, thus any failure of the redundant connection of any device is immediately reported to the system.

The PRP algorithm can be applied to a High Availability Seamless Ring, treating it as two virtual LANs.

8 High Availability Seamless Ring



9 System Overview using PRP

