Network redundancy in substation applications

The standard IEC 61850 Edition 1 of 2004-4 does not describe communication network redundancy topics or even Ethernet network layouts. During the last years, the Ethernet based IEC 61850 standard series became a big success and thousands of applications are now in place. In parallel, Ethernet technologies have been refined. Consequently the IEC 61850 users need some guideline how to use these new technologies and how to layout the Ethernet system, especially regarding communication network redundancy. IEC 61850 ED 2 will offer references to other standards dealing with Ethernet media redundancy and will also offer a technical report covering Ethernet networks topics. All of these documents will mainly reference to IEC 62439, “High availability automation networks”. The following paper will overview this topic.

1. Substation environment

In substations, IEC 61850 communications based on Ethernet networking is state of the art today. Four types of communication take place on such networks:

- Client – Server based on TCP/IP MMS (connection oriented)
- Basic services like NTP, SNMP, HTML (non time critical)
- GOOSE directly on Layer 2   (multicast, repetition mechanism)
- Sampled Values directly on Layer 2 (multicast, data stream)
**Figure 1: IEC 61850 Substation Communication - Overview**

These services have different delivery times and network’s recovery time requirements

<table>
<thead>
<tr>
<th>Protocol type</th>
<th>Max. Delivery time</th>
<th>Max. Recovery time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client Server</td>
<td>800 ms</td>
<td>400 ms</td>
</tr>
<tr>
<td>NTP, SNMP etc</td>
<td>500 ms</td>
<td>300 ms</td>
</tr>
<tr>
<td>GOOSE (multiple purpose)</td>
<td>12-100 ms</td>
<td>4-50ms</td>
</tr>
<tr>
<td>GOOSE</td>
<td>8 ms</td>
<td>4 ms</td>
</tr>
<tr>
<td>Sampled Values</td>
<td>2 ms</td>
<td>0</td>
</tr>
</tbody>
</table>

In today’s substations, the Process Bus Application has not yet big evidence in projects. But it is expected to be in hot projects in beginning/mid of the 2010 decade.

Nevertheless, redundancy is a big topic for the IEC 61850 station bus as well. One critical parameter is the recovery time of a redundant system. This means the time between the occurrence of the n-1 failure and the moment when the network has fully recovered.

Applications from a Substation Controller to an IED (Intelligent Electronic Device e.g. protection relay) using the Client/Server services are not time critical. The acceptable latency of Client/Server communication is in the area of human response time, which is 100-200ms. TCP/IP mechanisms also care for repeating lost frames and the right ordering in the receive buffers.

Applications between IEDs (e.g. Interlocking Signals and Trip messages) use the GOOSE service based on a connectionless one to many – the multicast service. Through a repetition mode defined in IEC 61850, it is ensured that these messages or signals also do not get lost. Therefore, the communication blackout during the recovery time does not mean that the messages send out during this period are lost. Even when
the double signal change is short enough that it is missed because at the end of the recovery period the signal has the same state as at the beginning, the application is able to recognize the uncertain state by checking the GOOSE message counter which is incremented each GOOSE repetition.

In contrary to this, the use of sampled values in a process bus application for transmitting digitized sensor signals is a different issue. Even if one sample is missing, the protection relay has a measuring blackout of a measuring window.

2. Possibilities for Ethernet media redundancy in real Substation layouts.

2.1 The Issue of rings in media redundancy:
In principle, an Ethernet System MUST NOT be configured a real ring. Due to its network access mechanisms, no data frame is allowed to circle around the network.

In case of a closed loop / closed ring all connected devices will pump frames into the system but these frames will never disappear in closed rings. Depending on the number of frames per second of the connected devices, even GBit/s systems will crash in seconds.

Therefore, measures have to be taken to prevent circulating frames in these systems (loop-prevention). There are different, standardized systems available which prevent circulating frames even in a physical ring topology. The most common system is the Rapid Spanning Tree Protocol, covering topologies of rings and meshed systems.

2.2 RSTP (IEEE 802.1d-2004, IEC 62439-2)
RSTP can provide pure ring configurations but meshed configurations as well. Consequently, the loop prevention principle must be more sophisticated compared to pure ring systems.

One of the Ethernet switches is the so called root bridge (Simplified: bridge = switch). This is the bridge with the highest so called “root priority”. All ports at this switch are designated ports. Ports closest to the root bridge are “root forwarding”. The path with the closest connection to the root is active. Non necessary ports are blocked for the loop prevention reason.
Figure 2: RSTP principle – normal operation

But if the network configuration is able to - every path has an alternative path preconfigured; blocked ports can become active when the primary path is defective. In the case of root bridge failure, the bridge with the next higher root priority takes over the root bridge function.

Figure 3: RSTP principle – redundancy case operation

RSTP can be used in ring configurations as well. In pure rings it shows good performance of recovery speed 4-5 ms per hop, multiple meshed systems can lead to larger recovery times. This mechanism utilizes implementation of small switches in IEDs like Protection relays directly. One of the most common configurations is shown below.
The IEDs have integrated switches which are RSTP-aware. Up to 30 are connected in a ring configuration with the multiport switches. Multiple rings are possible. One of the multiport switches is the root switch and organizes the optimal communication paths by establishing Root ports and designated ports. At the same time alternative redundant paths are foreseen, but blocked in normal operation.

Only in the case of n-1 failure the alternate path will be activated.

RSTP has a bunch of parameters settable such as aging time, root priority and others. Using the recommended, preconfigured parameters can end up in recovery times of 1 second but optimized parameters allow much smaller reconfiguration times.

2.3 Dual homing (dual link) redundancy

In a dual homing configuration, the two interfaces in an IED and in a substation controller have two interfaces. One is active; the other is actively monitoring the backup link if it is still usable.

In the case of an n-1 failure the IED checks the missing link and switches over to the reserve link. It sends out a special message in order to establish the alternative path. This establishment is reduced to the missing link only; therefore the recovery time is very fast.
This type of redundancy is described in principle in IEEE 802.1d but often completed with some proprietary functionality.

2.4 Mixed Configurations
Dual homing and ring configurations can easily be mixed. The most typical configuration is as follows.
Figure 6: Mixed RSTP-Link redundancy configuration

The main ring and the sub rings are using RSTP, the IEDs are dual connected by use of link redundancy. This kind of mixed technologies provides true n-1 redundancy with very low deterministic recovery times based on today available and proved technologies. Due to the fact that both technologies work independently, the recovery times do not add.

2.5 New Seamless Redundancy Mechanisms

2.5.1 General
Seamless means, that the redundancy system has almost no recovery time. This can be accomplished in only one way. The message is packed into two frames and sent in two different ways to the receiver. The receiver takes the first frame, identifies it and discards the redundant second one with the same message. This works in a parallel configuration as well as in a ring configuration; the principle is the same. IEC 62439 specifies in part 3 two seamless systems: PRP and HSR. Both are new and not yet used in applications but currently in the state of evaluation.

2.5.2 PRP Parallel Redundancy Protocol (IEC 62439-3)
The PRP principle is shown below. The networks A and B can have any structure, star, line, ring, meshed. It is also not necessary to use the same configuration on Network A and Network B.
Each PRP device has a DANP (Dual Attached Node using PRP). The redundancy entity is below Ethernet layer 2, it works for all Ethernet protocols. This means A and B frames have the same MAC and IP – address. As a result network A and B must be isolated, a connection between A and B will lead to double addressing and consequently trouble the network.

![Network A and B](image)

**Figure 7: PRP-principle**

Below is a basic structure of PRP. Switches do not need PRP-extensions they can be off the shelf but must fulfill the substation’s environmental requirements. Most of the devices are DANPs. SANs (Single Attached Nodes) can be involved in the PRP mechanism by use of a redundancy box. The system allows also connecting SANs without the need for redundancy to one of the networks. This communication is subsequently limited to one network. A single attached node can be involved in the PRP Redundancy system by use of an external device called Redbox.

![PRP-Configuration](image)

**Figure 8: PRP-Configuration**
The duplicate Filtering takes place by use of a PRP control sequence at the end of the Ethernet frame. It consists of a sequence number related to a sender-receiver pair, a LAN A/B information and an additional indication about the length of the frame size. Special supervision messages are defined also in the standard in order to monitor a RPR system and to provide information about failures occurred in the network system.

2.5.3 HSR (IEC 62439-3) High availability seamless redundancy

With some minor but decisive changes (Now it is a common network!) in the Ethernet frame the mechanism of duplicating frames at the sender side and removing the second one received on the receiver side can be extended to ring configurations. HSR extends the zero-recovery-time-redundancy to any topology, e.g. rings, coupled rings and dual network (parallel) configuration.

This has the advantage that integrated switch interfaces like the integrated RSTP-Switches of IEDs are possible.
Figure 10: HSR-configuration parallel mode, ring mode, coupling of both

The Source sends out the frame in two directions, the receiver takes the first and discards the second frame. Nodes without a HSR-interface can be connected by use of a RedBox (Redundancy Box). In case of a multicast frame, the sender discards both frames.

The parallel structure can run with PRP or HSR end nodes. The Ring structure requires HSR in any case. Both can be interlinked with a Redbox.

Consequently, coupling HSR frames only from parallel to ring is very effective and can handle lots of nodes. This makes the Redbox function easier. A Redbox converting PRP into HSR frames and vice versa need lots of memory space and computing power.

Monitoring and supervision of the Redundancy system is provided by use of special monitoring frames.

3. Application layer redundancy

Redundancy based on doubled systems using hot standby functionality use coordinated dual computers with complete separated communication stacks. Usually they have two MAC and two IP addresses. They shall be mentioned but not handled here.
### 4. Status of Standardization

The solutions described have the following status:

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Status/Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSTP</td>
<td>IEEE 802.1D-2004, referenced in IEC 62439-1 ED 2 2010-1</td>
</tr>
<tr>
<td>Link Redundancy</td>
<td>In base in IEEE 802.1D mostly with proprietary extensions</td>
</tr>
<tr>
<td>PRP</td>
<td>IEC 62439-3 ED1 2008-5 – Edition 2 IS -2010-1</td>
</tr>
<tr>
<td>HSR</td>
<td>IEC 62439-3 IS ED 2 2010-1</td>
</tr>
</tbody>
</table>

**Relation to IEC 61850**

IEC 61850 does not define Ethernet protocols or redundancy systems in principal. It references to existing standards. In Edition 1 (2004-5) none of the protocols above is listed. The Topic of redundancy is not handled in this document. In Edition 2 (most parts will be issued beginning from end of 2010 on) the issue of redundancy is newly discussed. Parts of discussion of this topic are:

- **Mapping MMS/Ethernet**
  - Status CDV
  - RSTP, PRP, HSR are mentioned as optional protocol Reference to TR 90-4

- **Mapping of Sampled Values**
  - Status CDV
  - PRP and HSR is mentioned as optional protocol Reference to TR-90-4

- **Network Engineering Guidelines**
  - Technical Report, CD
  - All of the described protocols are mentioned and their use in substations are described.

### 5. Conclusion

Today, the use of RSTP is state of the art. GOOSE interlocking and even Trip messages are transferred over RSTP networks today. Sampled Values and the Process Bus have no importance so far but will come in the future.

More than 1000 applications with IEC 61850 RSTP in station bus applications show the maturity of this solution. Especially not meshed systems of RSTP combined with link redundancy provide short reconfiguration times. The protocols PRP and HSR are new and will offer additional redundancy levels. This is required especially in Processes Bus Applications with sampled values but can work at any level. In such a process bus with sampled values, seamless or zero-recovery-time- redundancy is a prerequisite. In the case of a combined station- and process bus application and if PRP and HSR come into operation, a seamless solution process bus – station bus concept will be very beneficial. Later on, HSR may become the default redundancy system.

HSR is expected to turn out as the universal, standardized, multi-vendor supported solution for seamless redundancy.

TC 57 WG 10 is currently working on a Technical Report IEC 61850-90-4 which describes Network Engineering Guidelines for Substation Applications, where RSTP, PRP and HSR are included.

### References

1. IEC 61850
2. IEC 62439 Ed 2/2010
3. IEEE 802.1D, 2004 Edition