Ethernet Networks Redundancy With Focus On IEC 61850 Applications

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Agenda

• IEC61850 Process Overview
• Basic Communications Network Topologies
• Redundancy and OSI Model
• Physical Redundancy
• Layer 2 Redundancy Protocols
  – Spanning Tree Protocol (STP; RSTP, MSTP)
  – Link Aggregation Control Protocol (LACP)
• Summary
IEC61850 Process - System Design

• Substation protection design → Two independent protection systems:
  – Protection A
  – Protection B

• Two protection relays from different manufacturers
• Individually connected to the process equipment
• Similar redundancy is required in the Ethernet network for IEC 61850 applications
• Duplication is required in:
  – IEDs
  – Communication system.
IEC61850 Process - System Design

• Substation automation consists commonly of three levels:
  – Station Level - Human Machine Interface (HMI) and Gateway (GW)
  – Bay Level - Protection and control IEDs
  – Process Level - Instrument transformers, breakers, etc.

• IEC61850 capable devices are connected to a communications network

• Sometimes one network per automation level

• Each network is based on Ethernet switches

• Station level requirements are needed for operations and supervision.

• Process level requirements are critical and real time
IEC61850 Substation Design
IEC61850 Substation Design

• In the Process Bus information exchange is real time
• Most critical information exchange is related to protection
• Protection is achieved as follows:
  – Sampled values from the instrument transformers to the protection relay
  – Application of P&C algorithms
  – Execution of commands
    • trip command → relay to breaker
    • interlocking commands → between relays (per-to-peer communications)
• Acceptable maximum communication delay is as low as 3 ms.
• Achieved independent from the load of the communication network.
IED Block Diagram

CTs

VTs

I/Os

Ethernet Packet Station Bus

Communication Ports and HMI

Microprocessor 2 (Algorithms & Communication)

Microprocessor 1 (Control)

S/H Circuit

A/D Converter

Trip and Alarm Circuits

Status Contacts

Relay Output

Contact Input
IED Block Diagram

Ethernet Packet Station Bus
Status, Trips, Close, GOOSE / GSSE
A, V, Hz, W, Wh, Var, Varh, SOE

Communication Ports and HMI

Microprocessor 2 (Algorithms & Communication)

Microprocessor 1 (Control)

CTs
VTs
I/Os

Filter
Buffer

Multiplexer

Trip and Alarm Circuits

Status Contacts

Relay Output
Contact Input
Process Bus data is used by other IEDs in the network to perform real time protection & control mission critical actions.
Basic Communication Architectures

- Star Connection
- Ring
- Star or Ring Redundant
- Multiple Redundancy
Non-redundant Star Communication System
Doubled Parallel Redundant Network

![Diagram of a doubled parallel redundant network with HMI, GW, IED1, IED2, IED3, and IED4 connected in a redundant fashion.]
Communications System with Ring Redundancy

Diagram showing a communications system with ring redundancy. The diagram includes an HMI (Human Machine Interface), a GW (Gateway), and multiple IEDs (Intelligent Electronic Devices). The IEDs are interconnected in a ring configuration, ensuring redundancy and fault tolerance.
Station and Process Bus Networks - Redundant Protection

Diagram showing the interconnected networks of IEDs, MUs, and CT/VT sensors, illustrating the redundancy in protection systems.
Redundancy of Process and Station Bus

Station / Process Bus Network

IED1

MU1

CT/VT Sensor Set 1

IED2

IED4

IED5

MU2

CT/VT Sensor Set 2

Circuit Breaker
Redundancy and the OSI Model

- Areas for Ethernet-based controls redundancy:
  - Physical
  - Data link
  - Network

- The lower in the OSI model, the greater the impact of failures that occur
Physical Security

• Physical security covers:
  – Physical Ethernet network connections
  – Physical hardware

• Network redundancy implies multiple routes between devices

• Physical redundancy scenarios:
  – Diverse routing of cables
  – Redundant hardware including:
    • Redundant power supplies
    • Multiple CPU cards

• Considerations for redundancy
  – What is the application?
  – Area of coverage including number of devices
Physical Redundancy Check List

To make decisions on physical redundancy, one must ask:

• Are devices grouped according to location and function?
• What will be the application performed?
• Device type?
• Will there be a requirement to connect to the existing Substation Backbone network?

Answer to above questions will assist to decide:

• How the Ethernet network will look like
• Number of ports required on the Ethernet switches
• Number of cables
• Physical routing of the cables
• Location of network nodes
Lack of redundancy implies that sections can be isolated with the loss of just 1 or 2 cables.
It is important to plan out redundant connections to devices that can support multiple connections.
Ethernet switches have multiple ports to support connections to other switches.
Multiple connections to other switches imply redundant paths.
Multiple paths allow to work around port and cabling failures.
Physical Redundancy Check List

To decide level of redundancy for maximum uptime, one must ask:

- Do we need redundant cabling between devices?
- Is it going to be redundant cable installation?
- Does it require physical segregation of the cabling?
- Is there more than one Ethernet interface on edge devices?
Layer 2 Redundancy Protocols

- Identify all the possible paths amongst the networking devices
- Place the redundant extra paths in a blocking state to remove network loops
- In the event network segment failure, unblocks segments to reestablish connectivity
- Fixes the issue before the process even knows there is a problem
Spanning Tree Protocols

• STP (Spanning Tree Protocol)
  – Standardized in 1996 as IEEE 802.1D
  – First and slowest of the Spanning Tree protocols
  – Average failover time starts at 30 seconds
  – Too slow for any industrial Process

• RSTP (Rapid Spanning Tree Protocol)
  – Currently standardized as IEEE802.1D 2004
  – Faster than STP
  – Failover times from about 250msec to up to 12 seconds

• MSTP (Multiple Spanning Tree Protocol)
  – Incorporated into IEEE 802.1Q 2003
  – Allows multiple instances of Spanning Tree Protocol per Virtual LAN

• Proprietary implementations of Spanning Tree that are optimized for use in Industrial Networks
N+1 Redundancy via RSTP

- Root bridge
- RSTP automatically determines that link B-C should be a backup – no traffic flows
- Protection X
- Protection Y
- 100FX
- 52
RSTP After Failure

RSTP quickly restores link B-C to repair connectivity.

Any link, switch, or IED can fail yet either X or Y protection is always online.
RSTP + Dual Homed IED

Any link or switch can fail yet protection is always online

MAC or IP Redundancy?
Link Aggregation Control Protocol

- Allows the configuration of multiple Ethernet ports between Ethernet switches into a Single virtual “Link”
- Allows load sharing of information between the links
- Extremely fast in moving data between ports in the event of port failure
- Bundle groups of ports to form one virtual link
- Bandwidth is of the member links
- Provides redundancy without the use of Spanning Tree
Link Aggregation Control Protocol

LACP provides several functions:

- Higher bandwidth
- Enhanced Bandwidth Granularity
- Load sharing across the member links
- Balance bandwidth across the member links
- Fault tolerance provided by offloading data to working member links when a member link fails
Example of a Spanning Tree Ethernet Network
Summary

- It is important to understand the relationships between:
  - The physical structure of a network
  - The protocols that run on the network
- Key to creating a truly maintainable and adaptable network that deals with issues effectively.
- Reconfiguration time is a critical issue for safety
- Use Ethernet switches with fastest rapid spanning tree
- Use fastest RST for mission critical applications such as GOOSE messages between IEDs
- For higher availability use doubled communication networks
- In HV substations, all bays are protected by redundant protection (Protection A, Protection B)
- The related process bus has to be doubled by definition to avoid a single point of failure
Thank You!

Questions?

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