First Practical Experience with IEEE 1588 High Precision Time Synchronization in High Voltage Substation with IEC 61850 Process Bus

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Introduction

This paper describes the experience from the world first installation of high voltage substation with IEC 61850 process bus where IEEE 1588 time synchronization and dynamic multicast filtering have been used.
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2. Process Bus Overview
3. Process Bus Performance and Requirements
4. IEEE 1588 Time Synchronization
5. Impact of IEEE 1588 on the Design / Cost of Equipment
6. The need for Optimization of Multicast Layer 2 Traffic
7. Application Details and Network Topology
8. Key Challenges Faced During the Project
9. Conclusions
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IEC 61850 Communications

• IEC 61850 standard encompasses two busses based on the Ethernet technology:
  – IEC 61850 **Station Bus** interconnects all bays with the station supervisory level and carries control information such as measurement, interlocking and operations
  – IEC 61850 **Process Bus** interconnects the IEDs within a bay that carries real-time measurements for protection called Sampled Values or Sampled Measured Values
Architecture of IEC 61850

Level 3 – Dispatch Center
- Control Center
- Corporate WAN
- Router

Level 2 – Substation SAS
- 61850 Station Bus
  Client-Server, GOOSE
- HMI
- SCADA
- Gateway

Level 1 – Bays
- IEDs
- 61850 Process Bus
  Sampled Values, GOOSE
- Switch

Level 0 – Process
- Intelligent Switchyard, Sensors, I/Os
- MU
- Brkr IED
- Switch
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The Process Bus enables sending of digitized sampled measured values from electronic instrument transformers to protection and control relays.

It also permits connection of intelligent switchgear devices such as circuit breakers, disconnectors or earthing switches.
Process Bus Overview

• IEC 61850-9-2LE data set “PhsMeas1”:
  – 8 elements being 4 currents and 4 voltages

• Two available sampling rates:
  – 80 samples per cycle - protection
  – 256 samples per cycle - power quality monitoring and waveform recording applications
Agenda

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• Sampled Values frame as specified in IEC 61850-9-2LE with sampling rate of 80 samples per cycle have total size of approximately 180 bytes.

• At 50Hz with the sampling rate of 80 samples/cycle a single Merging Unit sending frames with format according to IEC 61850-9-2LE will be consuming a bandwidth of approximately 6Mbit/s.
  – At 60Hz with sampling rate of 80 samples/cycle bandwidth of approximately 7.2Mbit/s.
• Having 14 merging units like in the project described in this paper only the 9-2LE traffic would consume 84Mbit of bandwidth
  – At 60Hz consume 101Mbit of bandwidth

Have to be Gigabit Ethernet
• Data shifted at the receiving IEDs by just 30 microseconds will result in a half degree phase angle error.

• According to IEC 61850-5 the merging unit shall have an accuracy of ±4us and according to IEC 61850-9-2LE the communication network shall not introduce more than 2us delay.

• IEEE 1588 v2 protocol Ethernet switches shall have the accuracy of less than 1us in order to meet the above requirements.
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IEEE 1588 Time Synch

• IEEE 1588 version II Time Synchronization that has been officially released as standard in mid 2009
• It eliminates the extra cabling requirements of 1PPS or IRIG-B to propagate highly accurate timing signals
• However IEEE 1588 differs from SNTP in one important aspect that allows for hardware assisted time stamping
IEEE 1588 defines four types of clocks in a PTP (Precision Time Protocol) system: ordinary, grandmaster, boundary, and transparent.

A PTP domain contains only one grandmaster at any given time; redundancy of the grandmaster can be accomplished via the best master clock (BMC) algorithm.
IEEE 1588 hardware assistance is placed between the PHY and MAC layer of an Ethernet device.
Problems Addressed

- Path delay - how long it takes a message to propagate from the grandmaster to the slave
- Many delays are introduced on the path including:
  - Cable delay
  - Encoding and decoding of symbols on the wire
  - Switch fabric latency
  - Store and forward of switches
  - Queuing from switches
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Impact on the Design

• Consider:
  – IEDs – Ordinary Clocks (OC)
  – Master clocks – Master Clocks (MC)
  – Ethernet switches – Transparent Clocks (TC)
Impact on IEDs

• Easiest in the IEDs – Implementation of OC
• The cost of goods sold:
  – Replacement of the Ethernet PHY chip
  – Just few dollars more expensive
• NRE for new circuit boards expected < $50k
• Biggest NRE impact is likely firmware
  – IEDs are often CPU constrained (running multiple applications running simultaneously like protection algorithms, control functions, internal logic functions, communication protocol drivers, etc.)
The implementation of IEEE 1588 master clock functionality requires high grade oscillators which are much more expensive than cheap oscillators or crystals.
The Transparent Clock is unquestionably the most difficult to implement.

- Switches have many Ethernet ports so requires replacing many PHY chips.
- Currently the additional Cost of Goods can easily exceed $100 depending on the port count.
- In the future this may be more cost effective as large Ethernet chip providers will start introducing high quality chips supporting IEEE 1588 v2.
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• GOOSE and Sampled Values are directly encapsulated in Ethernet layer and transmitted with Multicast destination MAC address.

Could flood the whole network leading to overloading of specific devices that cannot handle this traffic.
Multicast management can be done in a static or dynamic way:

- Static management is done by creating in all networking devices tables with multicast group addresses and to which ports a specific group address shall be forwarded.

- Multicast filters are created dynamically in Ethernet switches based on the GMRP requests from IEDs that want to subscribe to particular Sampled Values or GOOSE application.
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Application Details

• Installation in 110/10kV Air Insulated substation in China
  – Three 110kV lines
  – Three power transformers
  – Thirty six 10kV lines

• First stage of the project included two 110kV lines, two transformers and twenty eight 10kV lines

• The third 110kV line is planed for the future
• Breaker-and-a-half arrangement in HV side and the 10kV busbar is divided in 3 sections
• Each 110kV line had one distance relay
• Each transformer had redundant transformer differential relays
• Two busbar protection relays at 110kV
• Three bus coupler IEDs with breaker failure protection
Application Details

- Four electronic CTs and PTs
- Total of 14 Merging Units had been installed
- Time synchronization:
  - IEEE 1588 version 2 in the process bus
  - SNTP protocol in the station bus
- The devices connected to process bus were:
  - Electronic CTs and PTs
  - IEEE 1588 master clocks with GPS
  - Merging Units
  - HV protection and control IEDs
• The devices connected to station bus were:
  – HV and MV protection and control IEDs
  – IEEE 1588 master clocks with GPS
  – RTU with multiprotocol support that served also as a gateway for remote connection from control center
  – Operator workstation with local substation SCADA
  – Engineering workstation
Substation Architecture

Grid-Interop 2010
Network Topology

- Commissioned in January 2010
RuggedCom Switches
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Key Challenges

• Ethernet switch and IEEE 1588 v2
  – Development of a new generation hardware supporting all previously available features such as RSTP, Multicast filtering, GMRP etc.
  – Adding the high resolution accuracy of IEEE 1588 time synchronization

• Relay and merging unit
  – Implementation of GMRP and IEEE 1588 v2 protocols
Key Challenges

• The system integrator and solution provider
  – Major challenge was the lack of testing equipment supporting IEEE 1588 v2 protocol

• Utility
  – Change in philosophy for testing the secondary system was needed
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The IEC 61850 Process Bus provides benefits for distributed applications within electrical substations as it permits reducing conventional copper wiring and optimizing the total installed cost by minimizing the efforts related to engineering, installation, commissioning and maintenance.
References

• Standards:
• Periodicals:

• Papers from Conference Proceedings (Published):
Thank You!