IEEE 1588v2 Time Synchronization in Energy Automation Applications – Case Studies from China

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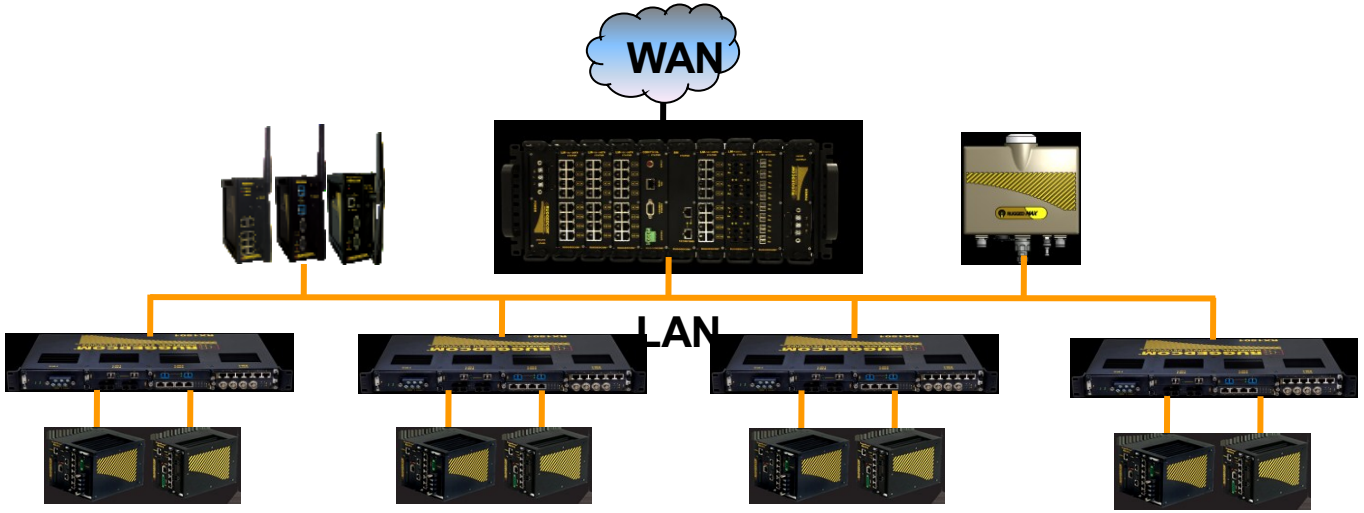
Who is RuggedCom?

"RuggedCom designs and manufactures rugged communications networks for mission critical applications in harsh environments."



- Founded in 2001, Maple Ont.
- Roots in Electric Power industry
- Pioneer in substation communications

- Publicly listed in 2007 (TSX:RCM)
- Over 2,200 customers worldwide
- Leader in Electric Power market (>50%)

A brief history….

- Founded in 2001 by people with Protection & Control backgrounds
- First to introduce "substation hardened" Ethernet switches – 2002
- First to introduce IEC 61850-3 compliant networking devices - 2002
- Pioneered Zero-Packet-Loss™ technology - 2002
- Pioneered IEEE 1613 standard for substation communications - 2003
- First IEEE 1613 Class 2 "error free" devices – 2003
- Pioneered Enhanced Rapid Spanning Tree (eRSTP™) - 2004
- Recipient of Frost & Sullivan Excellence in Technology Award – 2006
- Rated Best-in-Class by North American Utilities – 2007
- First to introduce 1588v2 Time Sync over gigabit Ethernet – 2009
- First to demonstrate GOOSE over WiMAX for DA – 2010
- Market leader in the substation with >50% market share - 2010

RUGGED RATED

ZPL
Zero-Packet-Loss™

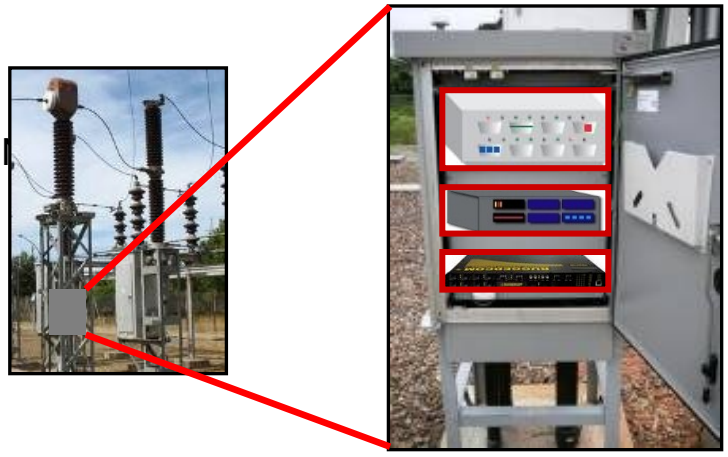
Time

eRSTP™

History of innovation in substation communications.

Time Accuracy Requirements in Energy Automation Applications

– SCADA	1sec
– Distribution Automation	100ms
– Substation Automation (Sequence of Events)	1ms
– Process Bus	10us
– Synchrophasors	1us



IEC 61850 Architecture

Level 3 – Dispatch Center

Corporate WAN

WAN

Router

Future use of IEC 61850:

- Substation-to-Substation
- Substation-to-Dispatch Center
- Synchrophasors over 61850-90-5

Level 2 – Substation SAS

HMI

SCADA

Gateway

61850 Station Bus
Client-Server, GOOSE

Level 1 – Bays IEDs

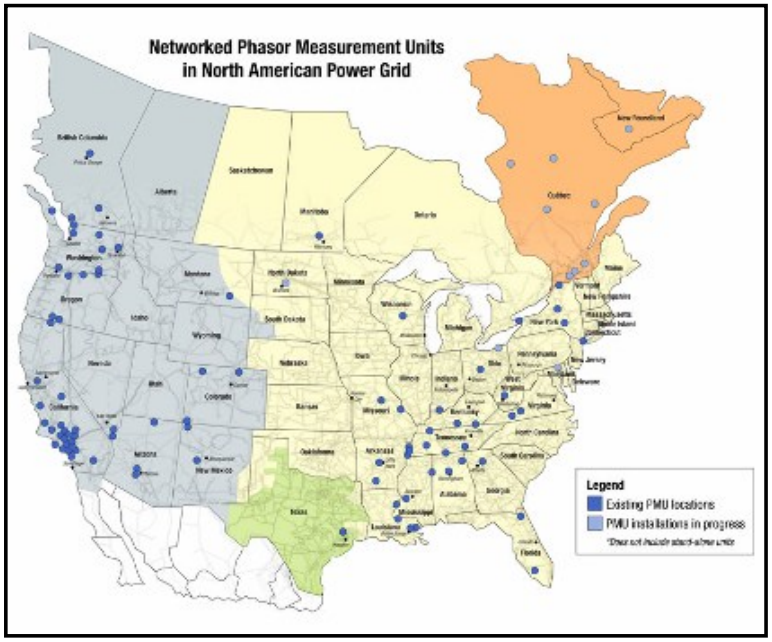
Level 0 – Switchyard Intelligent Sensors, I/Os

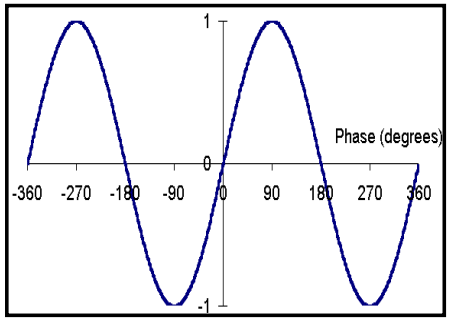
MUs, Brkr IEDs

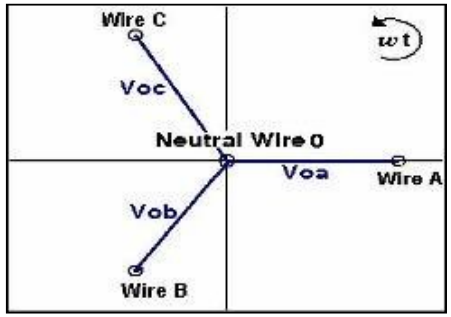
61850 Process Bus
Sampled Values, GOOSE

Synchrophasors

- **IEEE C37.118-2005, IEC 61850-90-5:**
  - Measurements from across power system
  - Synchronized to the same precise time base
  - Allow real-time power system stability analysis
  - Critical in helping avoid cascading blackouts







Process Bus Overview

The Process Bus enables sending of digitized sampled measured values from electronic instrument transformers (eg. Rogowski Coil) to protection and control relays

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

Relevant documents and standards

IEC 61850-9-2

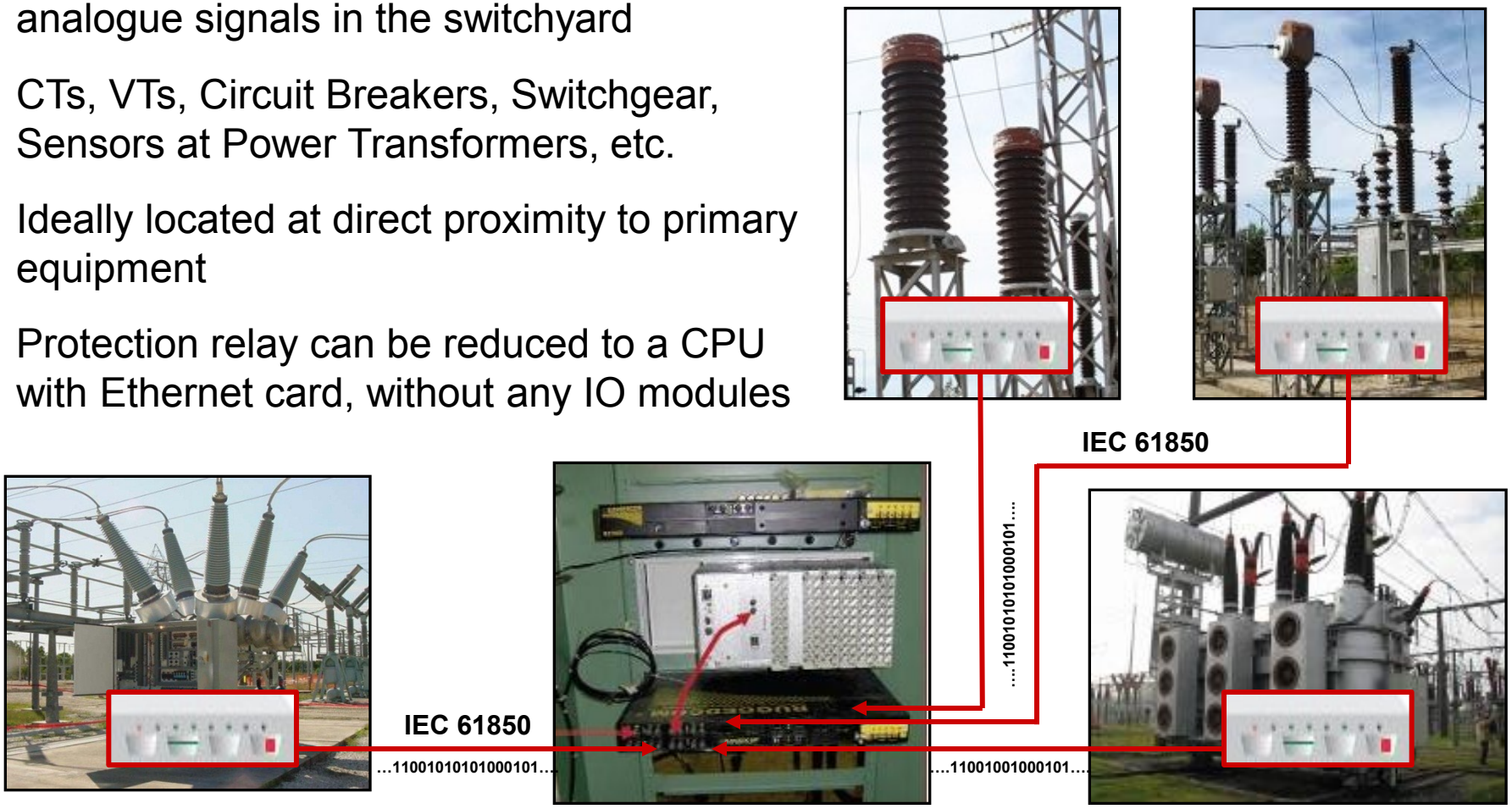
UCA 61850-9-2LE Implementation Agreement

IEC 61869 series

Key benefit - reduction of primary copper wiring, cost optimization, better measuring accuracy, increased safety

Process Bus is a Fiber Optic Digital Switchyard

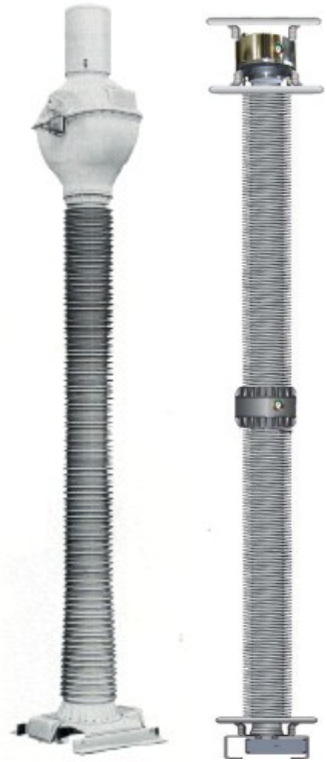
- Merging Units (MUs) are digital interfaces to analogue signals in the switchyard
- CTs, VTs, Circuit Breakers, Switchgear, Sensors at Power Transformers, etc.
- Ideally located at direct proximity to primary equipment
- Protection relay can be reduced to a CPU with Ethernet card, without any IO modules



Non-Conventional Instrument Transformers

Disadvantages of conventional CTs

- Very heavy for 1100kV weight up to 8.000kg
- Extreme size, seismic protection problematic
- Thermal stability difficult to achieve
- Distortion due to magnetic core saturation
- High cost

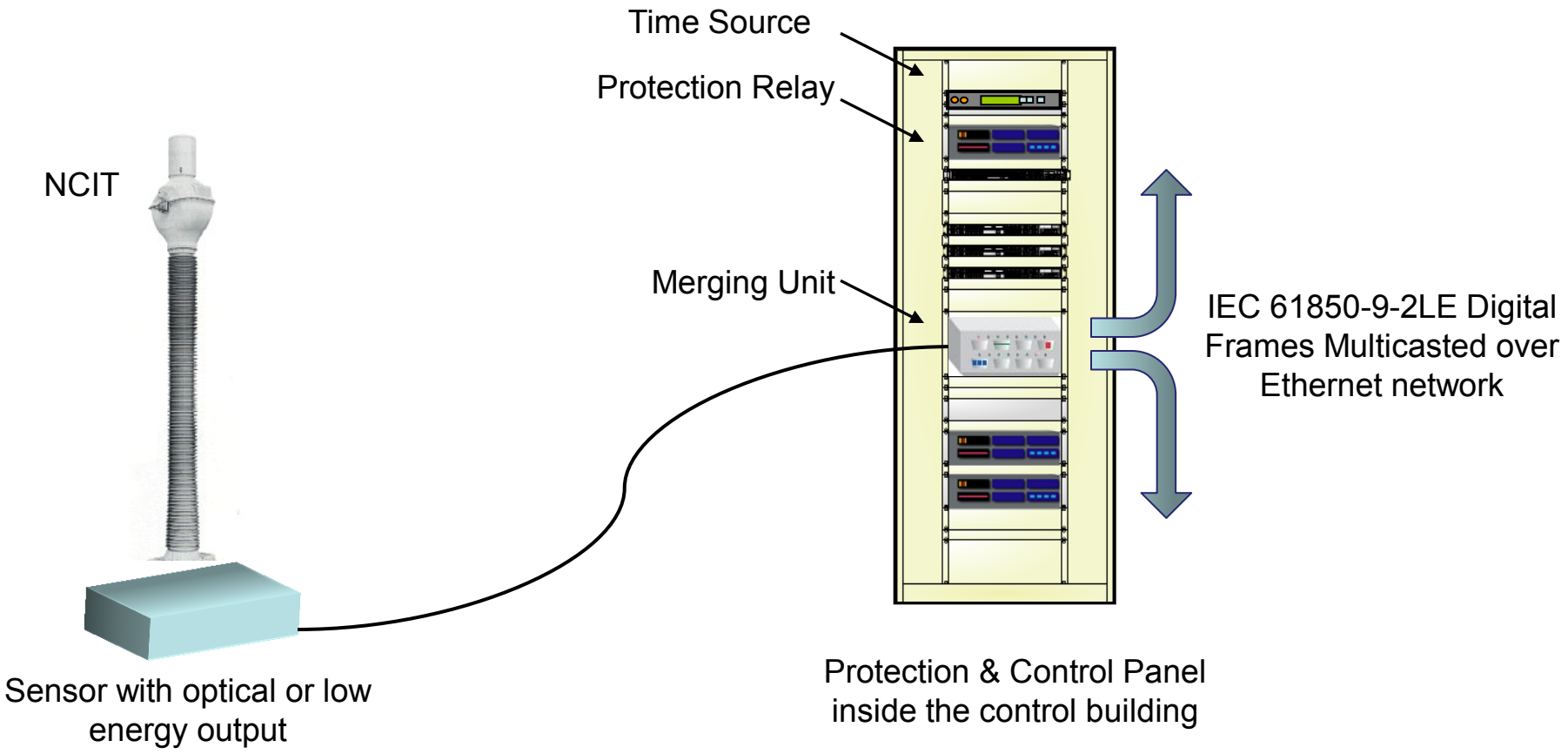


Benefits of Electronic CTs

- Major benefits for UHV, above 500kV
- Reduced size, weight (10-20 times less) and cost
- Highly accurate sensing for protection and metering
- Eliminates safety problems with open secondary
- Environmental friendly design, no oil, SF_6 or other gases

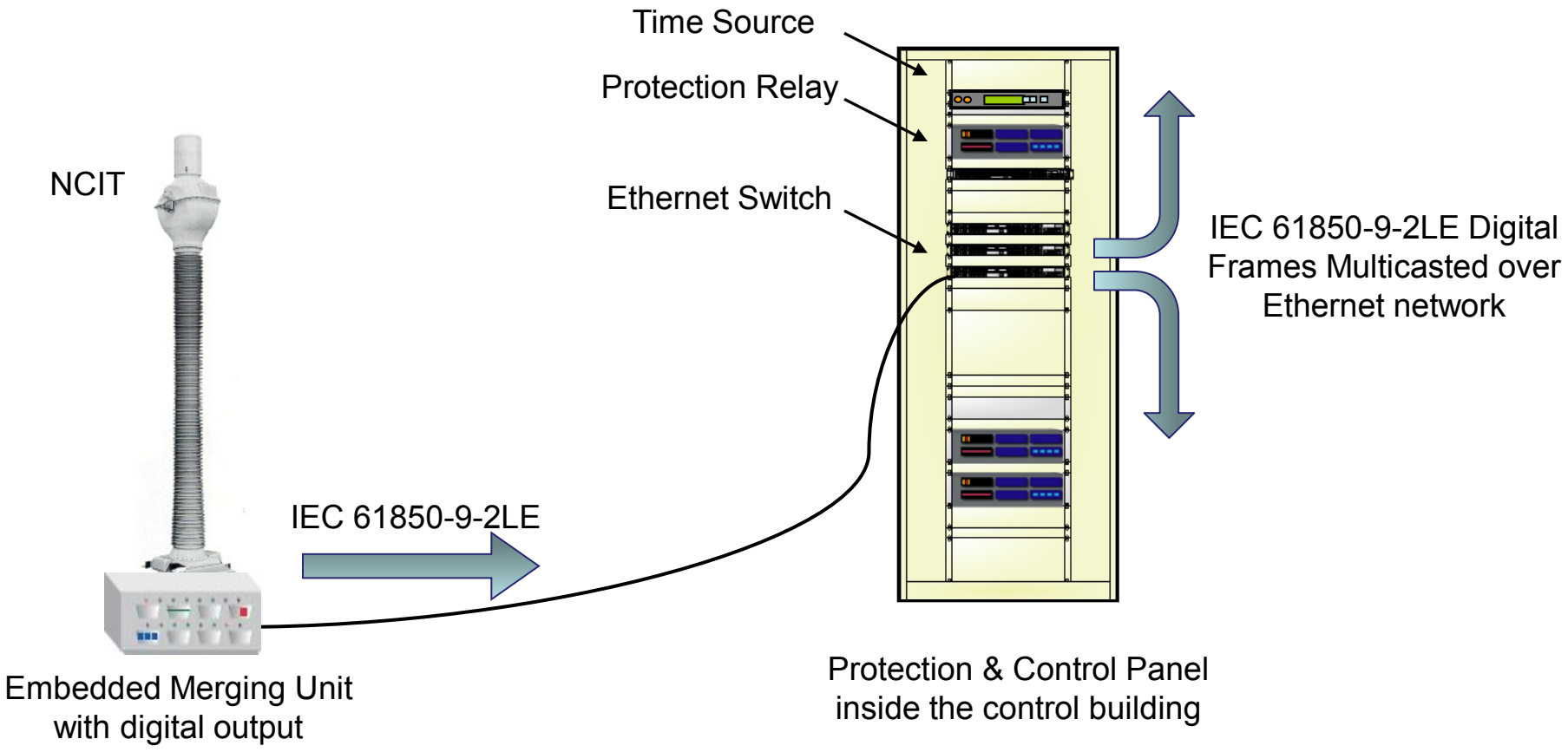
Substation Topology with Process Bus

- NCIT with optical or low energy sensor, MUs in the relay panel?



Substation Topology with Process Bus

- NCIT with integrated MU or mounted at the base of NCIT?



Process Bus Topologies

- Point-to-point, merging units with multiple direct connections to IEDs
  - No high accuracy global time reference required, IEDs as synch masters, scalability issues
- Process bus as Ethernet network isolated from station bus
  - Increased security and simplified engineering, required dual homed IEDs
- Process bus sharing a common Ethernet network with the station bus
  - Cost effective solution but requires careful network engineering for logical separation
- Process bus as redundant PRP stars
  - Zero-time recovery, duplication of network, higher cost of network infrastructure
- Process bus as multiple redundant HSR rings
  - Cost effective, large network traffic traversing all nodes, maintenance issues

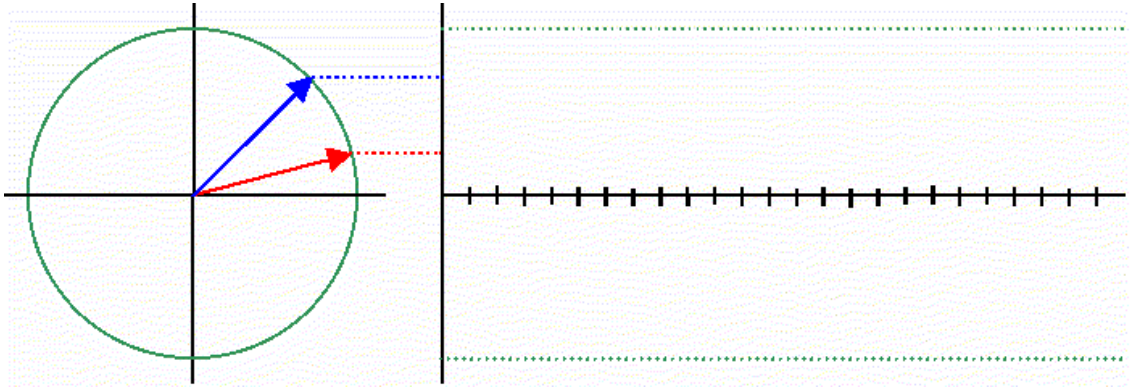
Process Bus Performance and Requirements

- Sampled Values frame as specified in 61850-9-2LE with sampling rate of 80 samples/cycle have total size of approximately 160 bytes.
- At 50Hz with the sampling rate of 80 samples/cycle a single 61850-9-2LE Merging Unit consumes a bandwidth of approximately 5Mbit/s.
  - At 60Hz with sampling rate of 80 samples/cycle bandwidth of approximately 6.2Mbit/s.
- Encapsulated directly in Ethernet layer
- Multicast traffic needs to be filtered either by physical network separation of logical separation (VLAN, Multicast MAC filters)

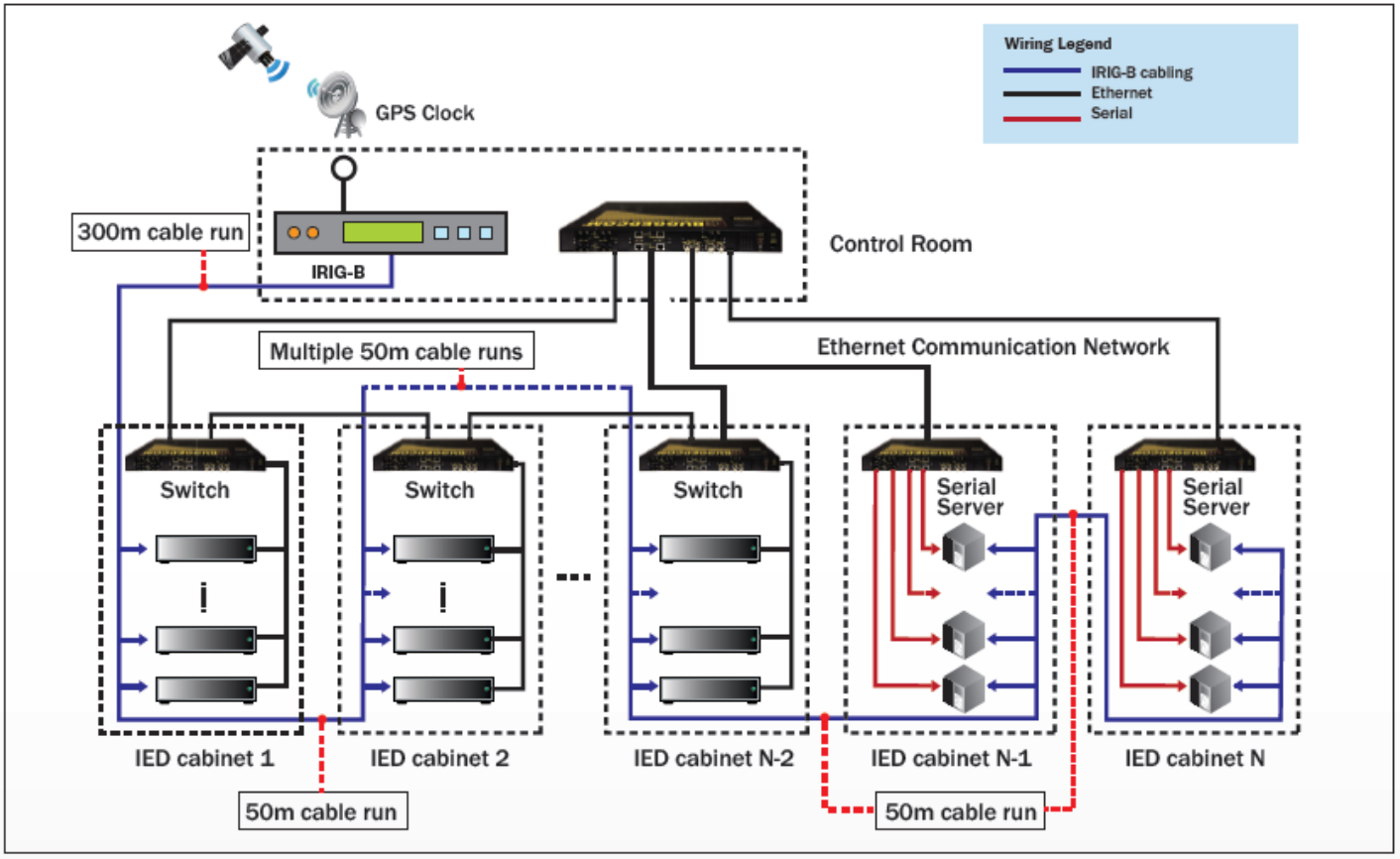
Gigabit Ethernet is strongly recommended for Process Bus

Process Bus Performance and Requirements

- Data shifted at the receiving IEDs by just 30 microseconds will result in half degree phase angle error
- According to 61850-9-2LE the merging unit shall have the timestamp accuracy of category T4 which is specified in IEC 61850-5 as ±4us
- Merging Unit delay bound (primary sensor to Ethernet) according to IEC 61869-9
  - 1.5ms for protection
  - 10ms for metering
- Currently PPS and IRIG-B specified in 61850-9-2LE
- IEC 61869-9 specifies IEEE 1588 (IEEE C37.238)

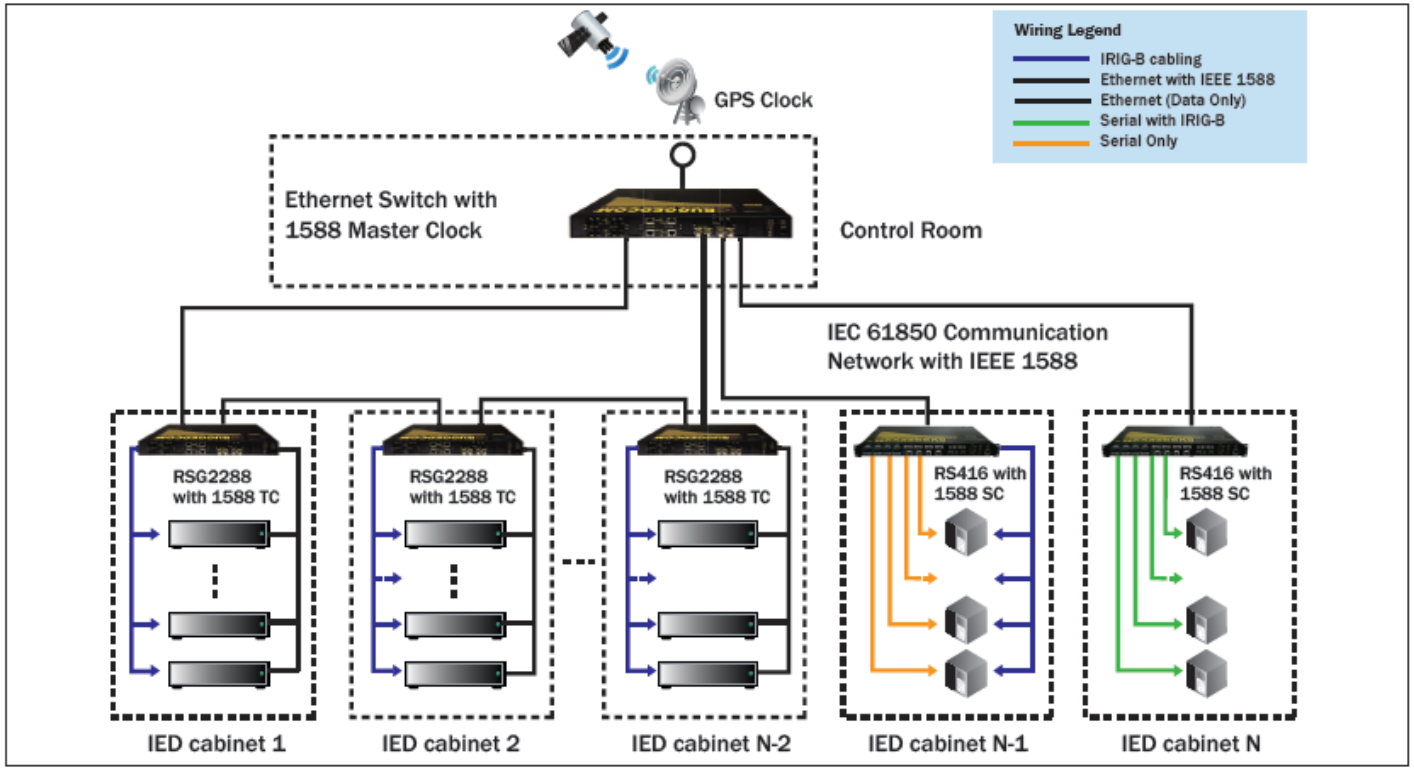


Conventional Approach for Time Synch in HV



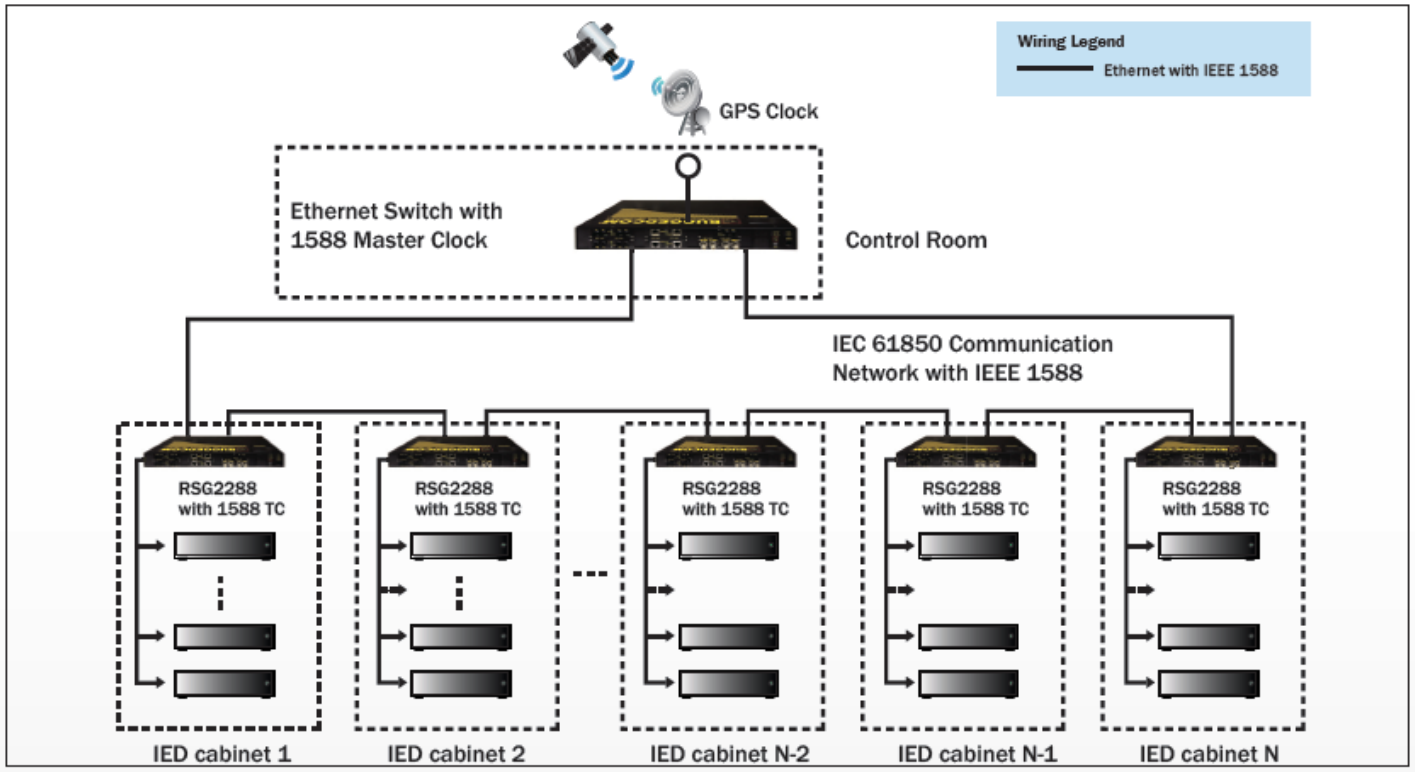
- Communications with IEDs based on Ethernet
- Beside Ethernet network there is a dedicated wiring for time synch signal

Migration Path for IEEE 1588 Time Synch in HV



- Time synch distributed over IEEE 1588 enabled Ethernet network
- IEEE 1588 converted to IRIG-B on “last meter” for non-IEEE 1588 capable IEDs

Full Implementation of IEEE 1588 Time Synch



- All devices in the substation with native IEEE 1588 interface
- New generation of IEDs with specialized communications card is needed

Benefits of IEEE 1588v2 for Substations

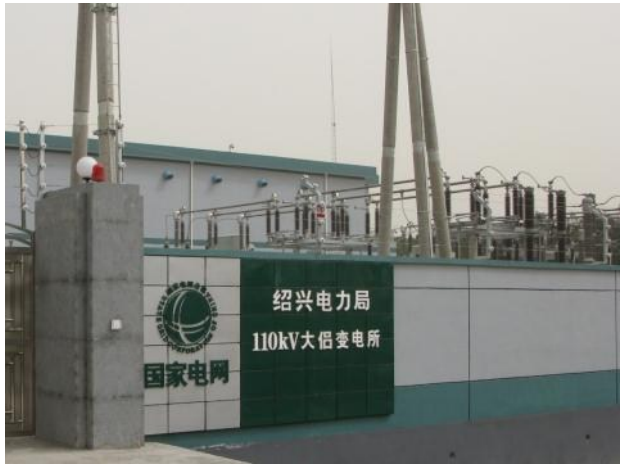
- Eliminates the extra cabling requirements of IRIG-B by using common Ethernet cabling
- Achieves guaranteed millisecond accuracy for substation Sequence of Event (SOE) timing
- Microsecond accuracy for critical applications like IEC 61850-9-2 Process Bus or Synchrophasors
- 'All-Ethernet' substations
- Facilitates migration path from legacy solutions and paves the way towards IEC 61850 Edition II

Energy Automation with IEEE1588 Case Studies




World First HV Substation with IEC 61850 Process Bus, IEEE 1588v2 Time Synch and GMRP Multicast Filtering

- Dalv 110kV Substation in China
- End User: Zhejiang Electric Power Company in Eastern China
- Protection relays, merging units and NCITs from Chinese manufacturers
- Ethernet communication network, IEC 61850, IEEE1588v2
- Commissioned in January 2010



Protocols and Applications at IEC 61850 Process Bus and Station Bus

IEC 61850 Station Bus

- IEC 61850-8-1 Client Server comms to SCADA
- GOOSE for interlocking
- SNTP Time Synch
- Ring network topology
- RSTP for redundancy

IEC 61850 Process Bus

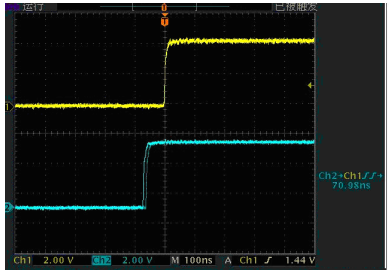
- IEC 61850-9-2LE Sampled Values
- GOOSE for interlocking
- IEEE 1588v2 Time Synch
- GMRP for dynamic multicast filtering
- Non-redundant linear network topology
- Dual homed IEDs for redundancy

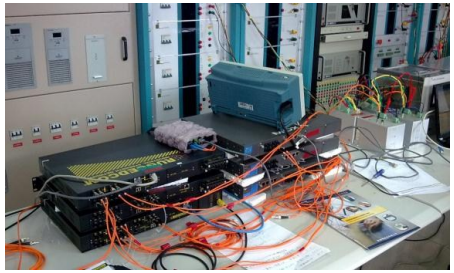
IEC 61850 Process Bus at Dalv Substation

- Process Bus logically separate from Station Bus
- IEEE 1588v2 Ethernet Switch with Transparent Clock feature
- Redundant 1588 Clocks running BMC algorithm, each clock with additional SNTP output for Station Bus
- IEEE 1588 Peer-to-Peer delay measurement, 2-step mechanism
- IEEE 1588 implementation in Dalv based on early draft C37.238
- PTP packets over Layer 2 Ethernet
- GMRP dynamic multicast filtering
- New Generation of IEDs supporting IEEE 1588 Ordinary Clock functionality and GMRP

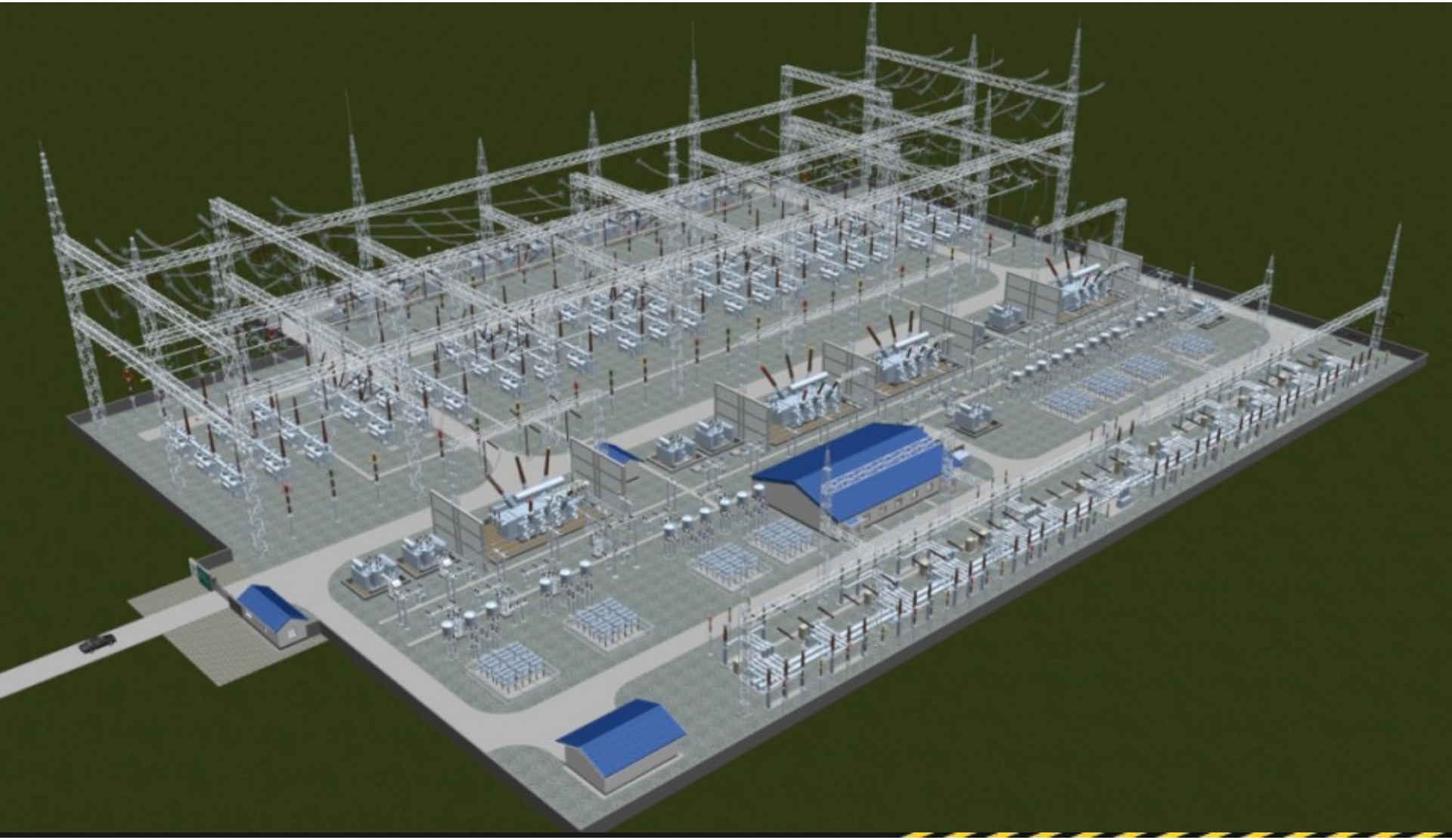
Key Challenges Faced During the Project

- Ethernet switch and IEEE 1588 v2
  - Hardware timestamping while optimized performance of switching fabric dealing with large amount of high priority critical traffic
  - Development of combined device featuring Grand Master and TC, optional card with GPS input, IRIG-B input/output
- Relay and merging unit
  - Implementation of GMRP and IEEE 1588 v2 protocols
- The system integrator and solution provider
  - Lack of testing equipment supporting IEEE 1588 v2 protocol
  - Lack of knowledge how to handle network redundancy and dynamic protocols like GMRP and at the same time ensure IEEE1588v2 accuracy
- Utility
  - Change in philosophy for testing the secondary system
  - Exhaustive testing to demonstrate long term stability and reliability upon network failure scenarios



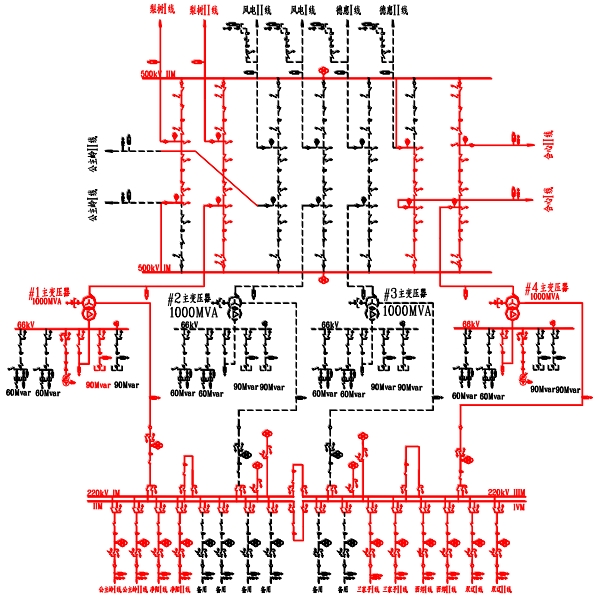


Changchun Nan 500kV Smart Substation in China

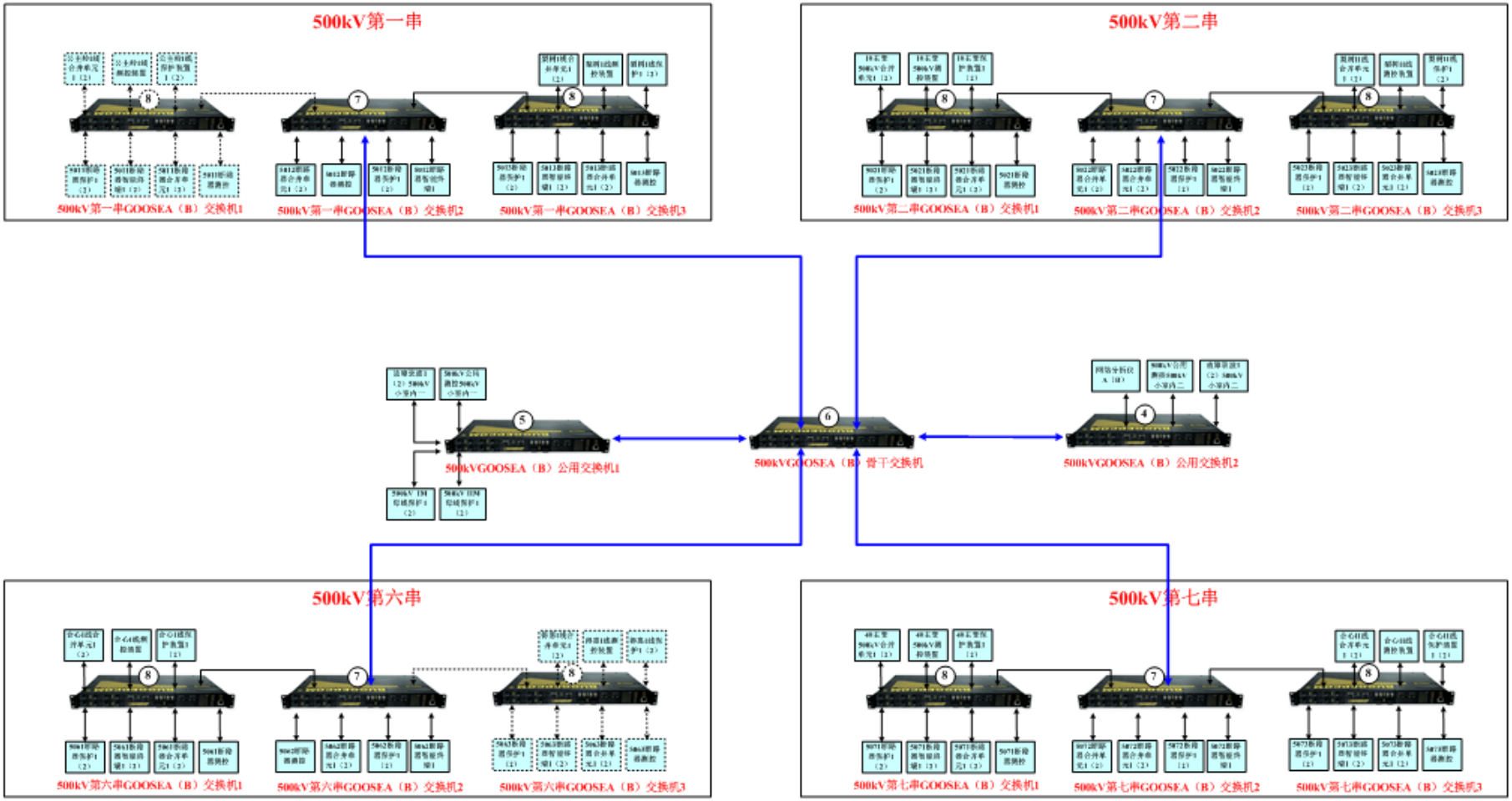


World Biggest HV Substation with IEC 61850 Process Bus and IEEE 1588v2 Time Synch

- Changchun Nan 500kV Smart Substation
  - 10 x 500kV lines, 16 x 220kV lines, 4 x 1000MVA transformers
- End User: Northeast China Power Grid Company
- Protection relays, merging units and NCITs
- Logically separate Process Bus and Station Bus
  - IEEE1588v2 at Process Bus, SNTP at Station Bus (cheaper)
- Ethernet communication network: +160 switches
  - Could be lower if higher IEEE1588v2 port density available
- Commissioning in progress 2011/2012



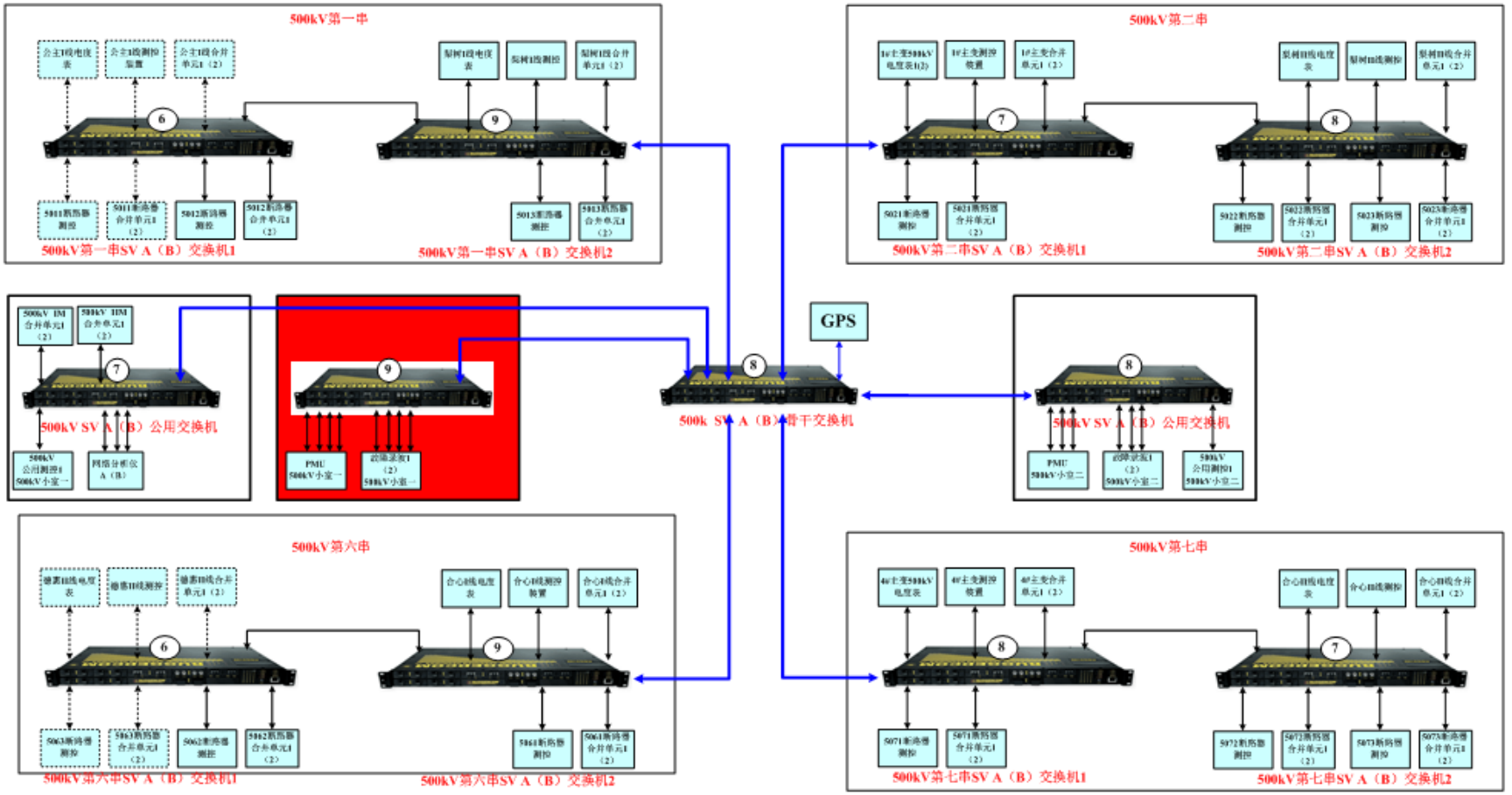
GOOSE in 500kV Ethernet Network



长春南500kV GOOSE交换机配置

本期共26台：

Sampled Values in 500kV Ethernet Network



长春南500kV SV交换机配置

本期共24台：
单交换机（16台）：具备2个1000M多模级联光口，7个100M多模光口
公用交换机（6台）：具备2个1000M多模级联光口，7个100M多模光口
中心交换机（2台）：具备16个1000M多模光口

Commissioning Site for 500kV Process Bus Substation

Projects Outcome - Energy Automation Requirements for IEEE1588v2

- Guaranteed 1us accuracy is enough (for today's applications)
- Local conversion from IEEE1588 to NTP, IRIG-B or PPS in the "last meter" to support non-1588 end devices
- Shall be resilient to dynamic topology changes
- Shall deal with situation of synchronization islands (temporary loss of Grand Master in certain segments of the network or different segments of network synchronized by different masters)
- Shall have relatively light-weight to minimize latency impact on high priority user traffic
- Shall ensure deterministic jitter

Questions?