



White Paper – Data Communication in Substation Automation System (SAS)

Time synchronization in substation automation

1. Time Synchronization

1.1 What is Time Synchronization in Substation Automation?

Substation automation is a mission-critical task and electric power utilities must synchronize across large-scale distributed power grid switches in a substation to enable smooth power transfer and maintain power supply integrity. Precise time synchronization is therefore required to ensure that substation devices have accurate clocks for system control and data acquisition, etc. Time synchronization is especially important for time stamping of sampled values (IEC61850-9-2) of current, and voltage values require accurate clocks inside the merging units.

Time synchronization is used to precisely synchronize internal (time) clocks in IEDs, MUs, protection/control units, Ethernet switches and wherever processes need to be synchronized in substation automation. Time synchronization helps to achieve accurate control and precise global analysis of network response and when, where and why any faults have occurred.

In substation automation, the following applications require time synchronization:

- Transmission of Ethernet protocols like GOOSE and MMS
- Real-time data acquisition from IEDs, RTUs and MUs
- Real-time process control of equipment like protection relays
- Fault recording for fault and performance analysis

Generally there are two kinds of time synchronization in substation automation: direct time synchronization and synchronization over LAN.

1.2 Which Protocols can be Applied for Time Synchronization in Substation Automation?

Normally the internal clock within network devices will be synchronized according to a synchronization time server that is connected to a GPS (Global Positioning Satellite) or a redundant satellite. Depending on the substation network application, synchronization time for events and faults can range from sub-microseconds to milliseconds. Factors effecting time synchronization accuracy depend on the protocol, traffic load, communication media and cable distance of the network.

For Direct Time Synchronization

Traditionally direct time synchronization with the end device can be realized via dedicated wiring with fiber, coax or twisted pair cables to transport the timing signals. Normally only one time server device is required for a time synchronization task. Because the port number in the time server device for direct synchronization is restricted, only a limited number of the devices can be synchronized. Direct time synchronization is normally implemented for the IEDs at bay and process level in substation automation. Standard protocols for direct time synchronization in substation automation are GPS, IRIG-B and 1PPS.

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GPS

GPS stands for Global Positioning Satellite. The GPS system is highly redundant and can be used for direct time synchronization or as a time source for other time protocols. An antenna for each IED or switch is required for direct time synchronization with a GPS. The GPS system is capable of delivering timing accuracies of within ten nanoseconds of coordinated universal time (UTC).

IRIG-B

IRIG-B stands for Inter-range instrumentation group time codes B and is the industry standard for GPS time synchronization. IRIG-B can be applied in a substation for power quality and system stability monitoring, sequence of events recording and accurate time stamping for revenue billing (1 ms). IRIG-B time code can only be transmitted via dedicated twisted pair or coax cable and it is not a low-cost solution for time synchronization. IRIG-B needs an external time source. The accuracy of time sampled values depends on availability and quality of time synchronization can be in the microsecond range (typ. 100 µs).

1PPS

1PPS stands for one pulse per second. It is a high-precision time pulse from precision clocks like a GPS receiver that very precisely indicates the start of a second. 1PPS is sent to every user over separate lines and entails an enormous additional wiring effort. The accuracy of time synchronization of 1PPS can be in the micro-second range (typ. 1 µs).

For Time Synchronization over LAN

Time Synchronization over a LAN (Local Area Networks) synchronizes devices via an Ethernet network and can enlarge the number of devices driven through one Ethernet cable. It reduces the cabling infrastructure and cost by transporting all time synchronization information together with data communications over the same Ethernet communication medium.

Normal standard protocols are SNTP for synchronizing IEDs at station level and IEEE 1588 PTP for synchronizing IEDs at bay and process level.

SNTP

SNTP stands for Simple Network Time Protocol. It is basically NTP but lacks some internal algorithms that are not needed for all types of servers. It is widely distributed in LANs or on the Internet. SNTP allows accuracy of time synchronization into the millisecond range (typ. 1-10 ms). SNTP is suitable for a station bus but does not achieve the accuracy required by a process bus with GOOSE and SV messages.

IEEE 1588 PTP

PTP stands for Precision Time Protocol and is a future-proof standard Ethernet protocol described in the standards IEEE 1588 and IEC61588 for time synchronization. It is a cost-efficient solution and can be applied on the basis of the existing Ethernet network in a substation. IEEE 1588 applies master/slave time synchronization mechanisms and supports hardware time stamps.

IEEE 1588 has two versions and they are not directly compatible. IEEE 1588 v2 is required mostly for IEC61850-9-2 Process Buses or IEEE C37.118-2005 Synchrophasors in substation automation and can be converted to IRIG-B. Distributed clocks in end devices can be synchronized with IEEE 1588 v2 in the sub-microsecond range (type 30-50 ns).

1.3 What is the Benefit of IEEE 1588 v2?

IEEE 1588 is used for time critical applications such as Substation automation and offers many benefits for utility vendors:

High Availability Solutions

IEEE 1588 v2 use Best Master Clock Selection Algorithm (BMC). The master clock in a substation can receive time synchronization messages

from other potential master clocks. All clocks can operate using the same information and therefore arrive at consistent results. Fast resynchronization can be achieved when system changes occur.

At the same time, IEEE 1588 v2 prevents error accumulation in cascaded topologies, supports fault tolerance and enhances the flexibility of the system.

Low Cost Solutions

IEEE 1588 v2 can use an existing Ethernet network and reduce cabling costs. Its unicast message has shorter frame sizes in order to reduce the bandwidth consumed by the network traffic messaging and requires minimum processor performance. It is easy to implement in IEDs, multicast Ethernet and other multicast capable networks with low cost and simple maintenance.

High Precision Solution

IEEE 1588 v2 synchronizes clocks with differing precision and resolution. It achieves network clock synchronization accuracy in the sub-microsecond range.

1.4 How does IEEE 1588 PTP Work?

IEEE 1588 PTP has two versions, PTPv1 (IEEE 1588-2002) supports ordinary clock (OC) and boundary clock (BC) mechanisms; PTPv2 (IEEE 1588-2008) supports ordinary clock (OC), boundary clock (BC) and transparent clock (TC) mechanisms.

In version one for boundary clock mechanisms, a radio clock or a GPS receiver controls a ground master clock (GM). The ground master clock determines the time base for the system and synchronizes the respective slave clock (BC in the transmission switch or OC in the end device) directly connected to it in each step. In the slave clock, one port serves as a PTP slave port to an upstream master clock, and the other ports serve as PTP clock masters to downstream PTP clocks.



At first, the time difference between the master and the slave is corrected (offset). Then the delay time between slave and master is measured by delay request and delay response. In the end, the time in the slave or end device is synchronized according to delay time and offset. Best PTP synchronization performance can be achieved by minimizing the number of nodes between the grand GM (grand master) device and the OC (ordinary clock) slave IED device.

In version two for transparent clock mechanisms, transparent clocks correct the "residence time" of the network device like an Ethernet Switch. The "residence time" is the time delay incurred by a packet passing through the Ethernet switch and can be calculated by the time stamp between egress and ingress. This residence time is accumulated in a correction field to realize time synchronization.

Since transparent clocks are stateless they have no impact on the reconfiguration time of ring topology networks for example. Each switch in the path appears to be a "wire" which does not skew the time calculation for packets passing through them. This avoids the accumulation of jitter and thus reduced accuracy when using many cascaded switches.

The IEEE 1588-2008 standard supports two types of transparent clocks, namely: End-to-End (E2E) and Peer-to-Peer (P2P).

End-to-End TCs only measure the time taken for a PTP event message (those that get time stamped) to transit the bridge and provide this information to the receiving clocks in the correction field.

Peer-to-Peer TCs use the peer delay mechanism and measure the port-to-port propagation delay time between two directly connected ports sharing the same communication technology. The peer delay mechanism is independent of the state of a port (master or slave). It operates separately in both directions of the link.

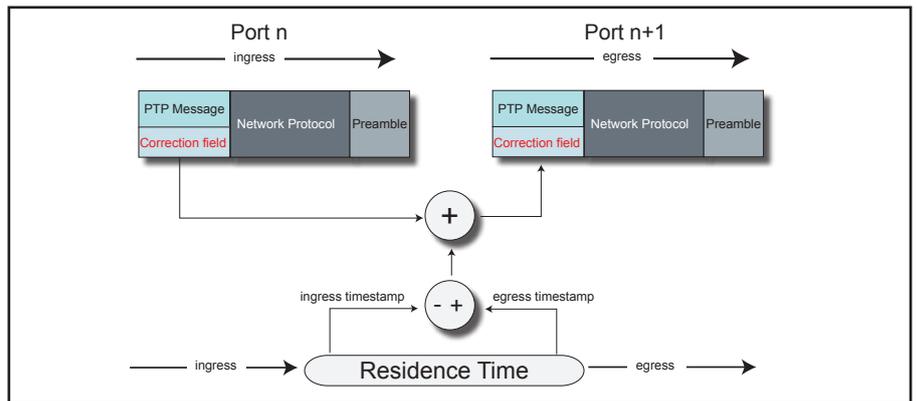


Figure 1: PTPv2 – Residence time

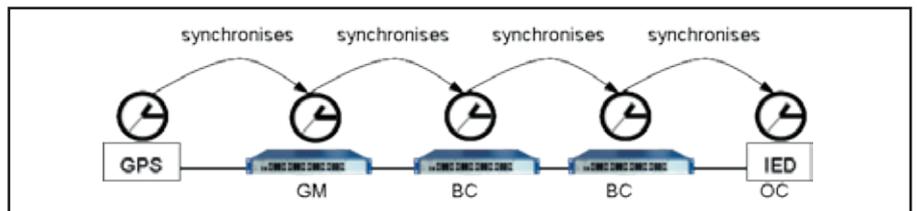


Figure 2: PTPv1 – BC

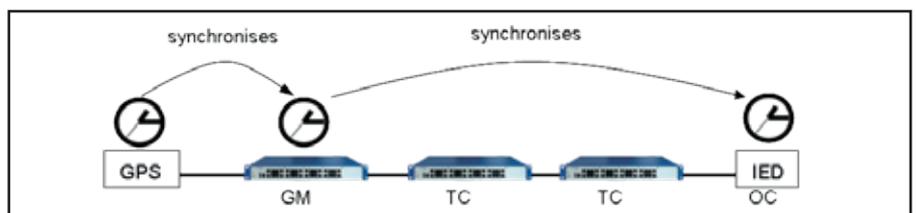


Figure 3: PTPv2 – TC

1.5 How to Apply Time Synchronization in Substation Automation

Time synchronization for a station bus and a process bus has different requirements. Figure 4 shows one example of how to realize time synchronization with different time protocols in substation automation. As shown in the figure, precise time is provided by a GPS to a time server unit as a precise time source for communication devices like switches or IEDs. Normally a redundant time source from another time satellite can be applied to enhance system reliability.

Star topology is very common for time synchronization in a station bus and a process bus. Normally time synchronizations for IEDs at bay and process level are implemented separately. However, a common precise time source can be applied.

SNTP is implemented to synchronize the switches and other remote devices, monitoring PC and control system at station level. According to the accuracy requirement in a substation, time synchronization with IEEE 1588 PTPv2 TC mode is applied for the IEDs at bay and process level with IEEE 1588 switches from process level. Because there are no IP packets in a process bus, transmission protocol IEEE 802.3 is used for PTP messages. IRIG-B and 1PPS require separate cable and synchronize the IEDs (e.g. IED-1 and IED-5) at bay and process level. In order to achieve high availability of time synchronization, some point-to-point communication (e.g. IED-1 to IED-7) between IEDs and MUs can be applied without any communication switch.

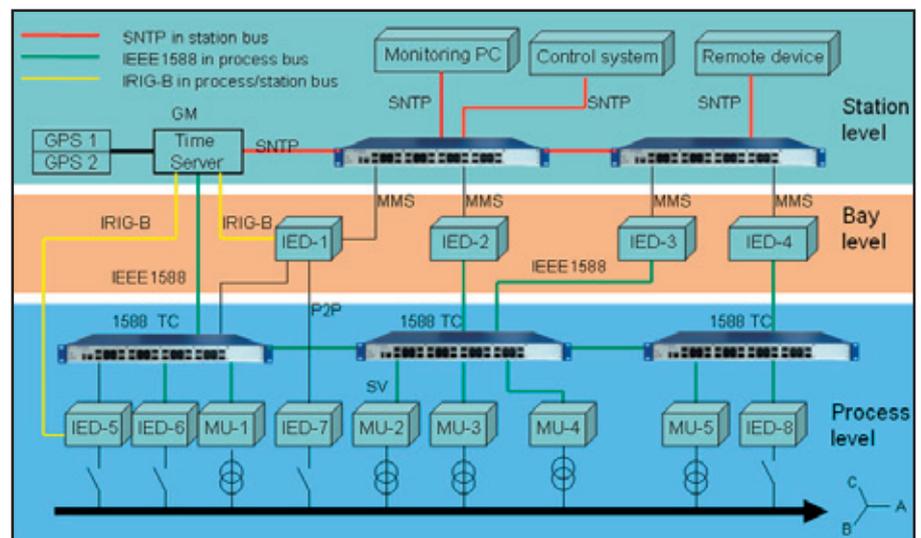


Figure 4: Time synchronization in substation automation

1.6 Summary and Outlook

As the future-proof time synchronization protocol, IEEE 1588 improves the reliability of the substation network. Hirschmann™ developed the first Ethernet switch with IEEE 1588 protocol and offers a wide product portfolio supporting IEEE 1588v2 and other time synchronization protocols, e.g. the MICE, MACH, RSP and Embedded Ethernet Switch (EES) families. Hirschmann™ switches with time synchronization features can fulfill the application requirements of utility vendors.

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Andreas Dreher, Dirk Mohl, Markus Seehofer
3. IEC 61850-90-4 Technical report: Network Engineering Guidelines, 2012
4. Hirschmann Service and Support: <http://www.beldensolutions.com/de/Service/index.phtml>



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Appendix: Further Support



Technical Questions and Training Courses

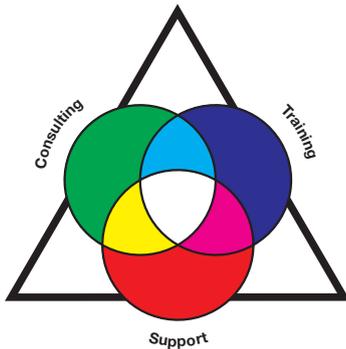
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