White Paper

PRECISION TIMING FOR POWER LOSS EVENT RECONSTRUCTION

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Introduction

Today's modern power systems are becoming more essential to mission critical facilities as they grow in both size and complexity. Recently, there's been an increase in power outage events. Aging infrastructure, human error, rolling blackouts and an uptick in natural disasters such as fires and hurricanes all contributing to this ever-growing problem. Loss of power in these facilities is extremely costly and in the worst of cases, life threatening. For example, in the Data Center industry every 1 in 6 power outages can cost up to $1 million dollars, growing from just 1 in 10 as recently as 2019! Many of these power outages are not anticipated and worse, cannot be explained. The implementation of redundant backup systems may help reduce the overall number of outages, but no system is perfect. So, in many cases, it is not a matter of if there will be a power outage, but when.

During a power outage, the use of Intelligent Electrical Devices (IEDs) to monitor equipment and processes is essential for ensuring power reliability. When an outage does occur, monitoring IEDs helps to reconstruct what happened throughout the incident. During the analysis, it is crucial that all event timestamps recorded from the IEDs are aligned and have the most precise timing available especially when distinguishing between anomalies that happen milliseconds apart. However, this is difficult to achieve since various IED clocks require different methods of time synchronization and some devices don't have clocks at all. When the exact timing of events is incorrect, or there are 'blind spots' where events aren't captured, pinpointing the initial event, or the 'root cause' is time consuming, and in some cases, impossible. When restoring power in mission critical facilities, every millisecond counts. CyTime™ Sequence of Event Recorders from Cyber Sciences can keep IED clocks synchronized and provide input monitoring with precision timing to eliminate blind spots where events may otherwise not be captured, thus reducing power recovery time and costs.

Requirements for Time Syncing Devices

To sync IED clocks, a specific time protocol is required. Time protocols are used to synchronize devices to a single definitive time source. There are several time protocols used by IED's such as NTP and IRIG-B. Each IED may require a different time protocol making time synchronization across the power system complex and costly. Below is a brief description of the most common protocols used by IEDs in Electrical Power Monitoring (EPMS) equipment.

IRIG-B is the most widely used time protocol since its inception in the 1960's. It is usually distributed at 5V. Because it is not a strong signal, it presents limitations for synchronizing many devices over a long distance, resulting in a higher cost of implementation and a negative impact to scalability.

DCF77 was introduced in Germany in 1959. It can be distributed at 24V which makes it more suitable for time syncing many devices over longer distances. However, DCF77 is not as widely used and so may not be supported by many devices in the EPMS.

1per10 (one-pulse-per-ten-seconds) is a simple time protocol that uses one synchronizing pulse every 10 seconds to provide an accurate time reference for power system devices. This protocol provides 1ms time accuracy but is not widely used.

ASCII-RS485 is based on a simple time protocol and is communicated over RS-485 consisting of an on-time mark (OTM) transmitted once per second, followed by an ASCII representation of the date/time and time quality. This protocol is also not widely used and on average provides 1ms time stamp accuracy.

NTP: Developed in 1980, Network Time Protocol is intended to synchronize computers to within a few milliseconds of Coordinated Universal Time or UTC. It uses an algorithm designed to try and mitigate the effects of variable network latency. Because NTP assumes network communication is symmetrical (transmission and receive time are equal), timing can be adversely affected by asymmetric networks which use devices such as IEDs. In addition, these devices may implement NTP differently and have processors that give a time clock synchronization a lower priority over other tasks such as data collecting and alarming.

PTP: Like NTP, Precision Time Protocol syncs devices over the Ethernet. However, PTP addresses some shortfalls of NTP allowing for variations in network architecture. It offers the most precise timing, able to synchronize device clocks to within <100 microseconds across the network. It is not widely used for demand side applications but in recent years has been gaining adoption.

The comparison table below shows the difference between many of these time protocols and their implementation.

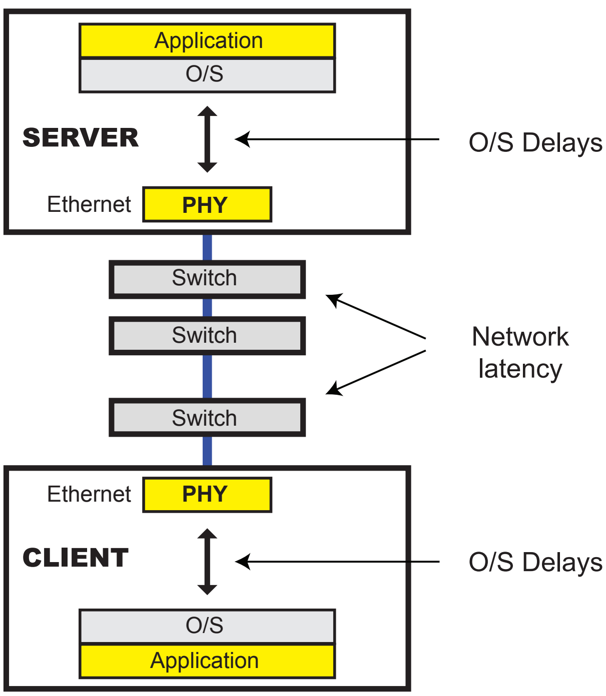
Protocol	Timeclock Accuracy	Media	Cost w/o SER	Cost w/ SER*	Pros	Cons
PTP	+/- .5 ms	Ethernet	$$	$	Highest accuracy, simple to deploy	Limited adoption
IRIG-B	+/- .5 ms	Serial	$$$	$$	Well adopted. High accuracy	Scalability due to cabling distance and device supported
DCF77	+/- .5 ms	Serial	$$	$$	Supports longer distances/ more devices	Limited adoption and scalability
NTP	+/- 10 to 100 ms	Ethernet	$	$	Low cost, simple to deploy, well adopted	Lower accuracy, subject to clock jitter and uncertainty
Modbus TCP/IP	+/- 1 s	Ethernet	$	$	Low cost, simple to deploy, well adopted	Lowest accuracy, subject to clock jitter and uncertainty impacted by network latency
ASCII RS485	+/- 1 ms	Serial	$	$	Low cost, simple to deploy	Limited adoption
1 per 10	+/- 1 ms	Serial	$$	$$	Required by some devices	Low adoption

*Cost of implementation using Cyber Sciences' Sequence of Events Recorders which does not require PTP enabled switches or additional boundary clocks. For more information, see *TN-101 SER System Design Guide*.

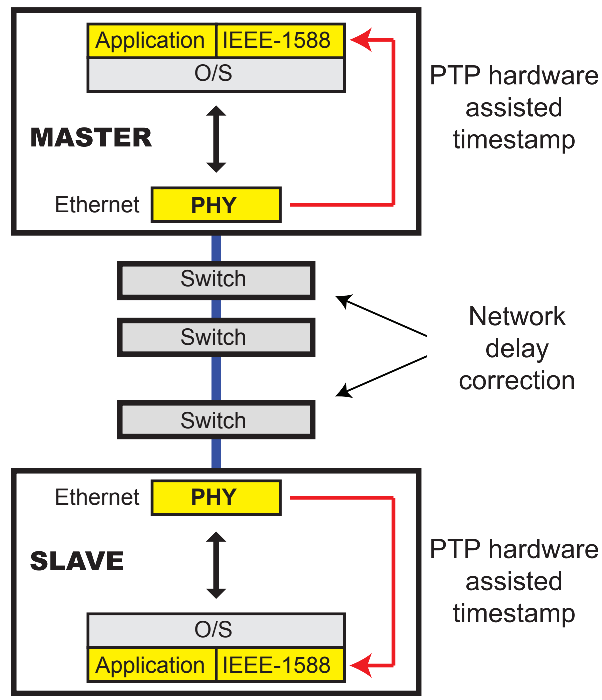
An EPMS can have thousands of IEDs which require a mix of all these time protocols distributed throughout the entire electrical system. Implementing time synchronization to all these devices over long distances requires a lot of planning, can be difficult to implement and is very costly. Many of these time protocols are wired serially adding additional costs and complexity in implementation and maintenance. PTP removes much of this complexity while providing the most precision timing available. While PTP was originally designed for supply side applications, it is now gaining adoption as the time sync protocol of choice in demand side applications where power systems are critical. Let's take a deeper look into Precision Time Protocol and how it can be used for event reconstruction.

Precision Time Protocol (PTP) (IEEE-1588)

The IEEE-1588 standard was first published in 2002, with revisions published in 2008 and 2019. PTP is intended for a broad range of applications. The IEEE 1588 standard defines PTP and outlines how to achieve precision time synchronization over Ethernet for critical applications. The biggest innovation of the 1588 standard is the introduction of hardware-assisted time stamping. This time stamping is embedded in the PTP messages using PTP derived Ethernet hardware. This is the key difference from NTP. This hardware assisted time stamping is wholly achieved within the IEEE-1588 physical interface (PHY) itself, providing zero loss of accuracy between the timestamp as it is sent or received, and the application layer as shown in the figures below.



Network latency is just one source of uncertainty in timestamps. Often more significant are the variable delays introduced by each device's operating system (O/S)



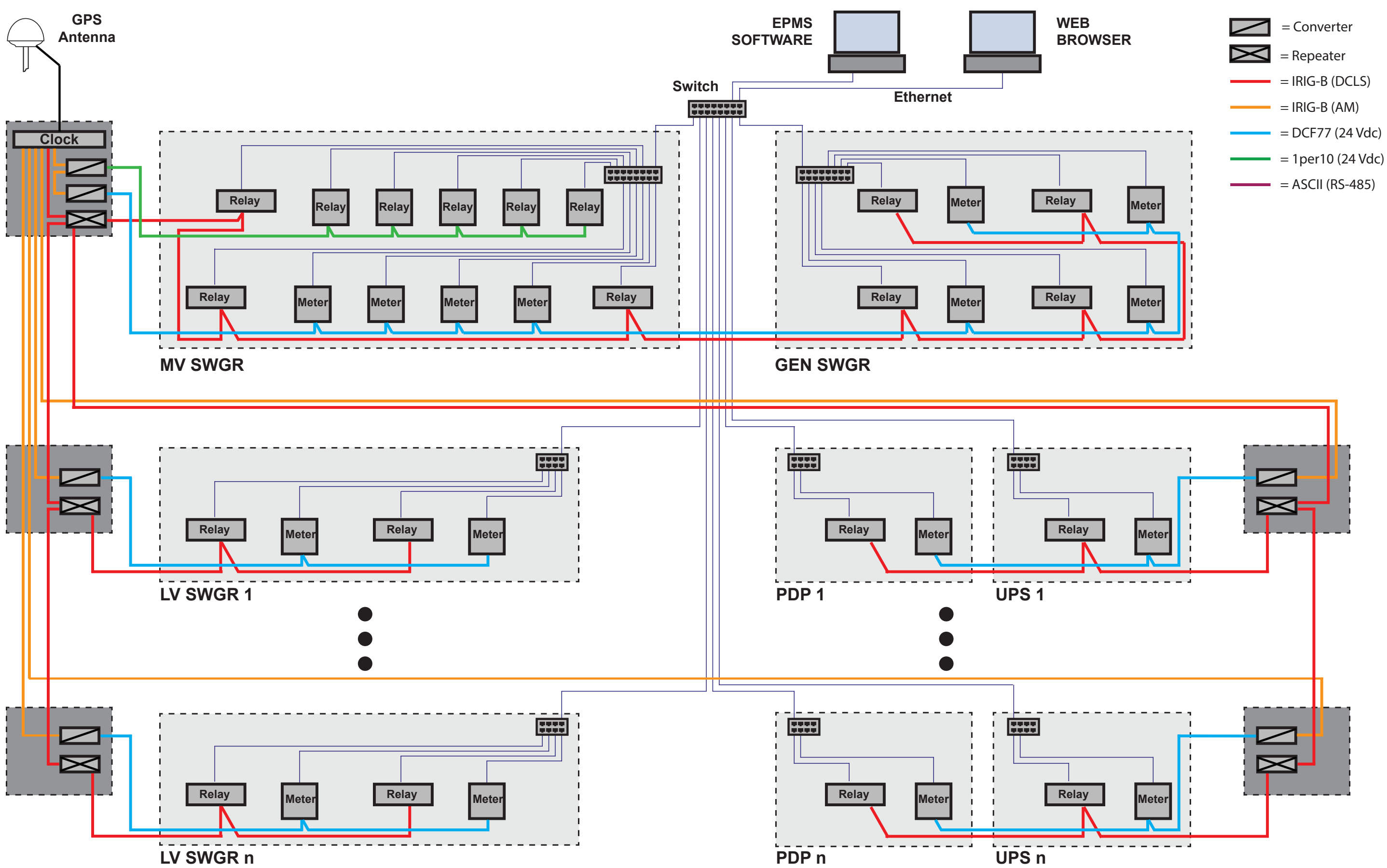
Special IEEE 1588 Ethernet hardware provides time-stamping in the Ethernet physical layer (PHY), with a direct link to 1588 code running at the application layer, eliminating device operating system delays.

Because PTP includes precise mechanisms to correct for network latency and operation system (O/S) delays in the network path from the master clock, through multiple levels of switches, and to the IED clocks, it eliminates much of the design complexity required to achieve precision timing found in NTP. PTP also provides the ability to have redundant master clocks and the ability to select the best master clock, or grandmaster clock automatically. In addition, PTP eliminates many of the previously mentioned issues with time synchronization in a power system such as design complexity, distance limitations, cost of implementation by providing the time protocol over an existing Ethernet network.

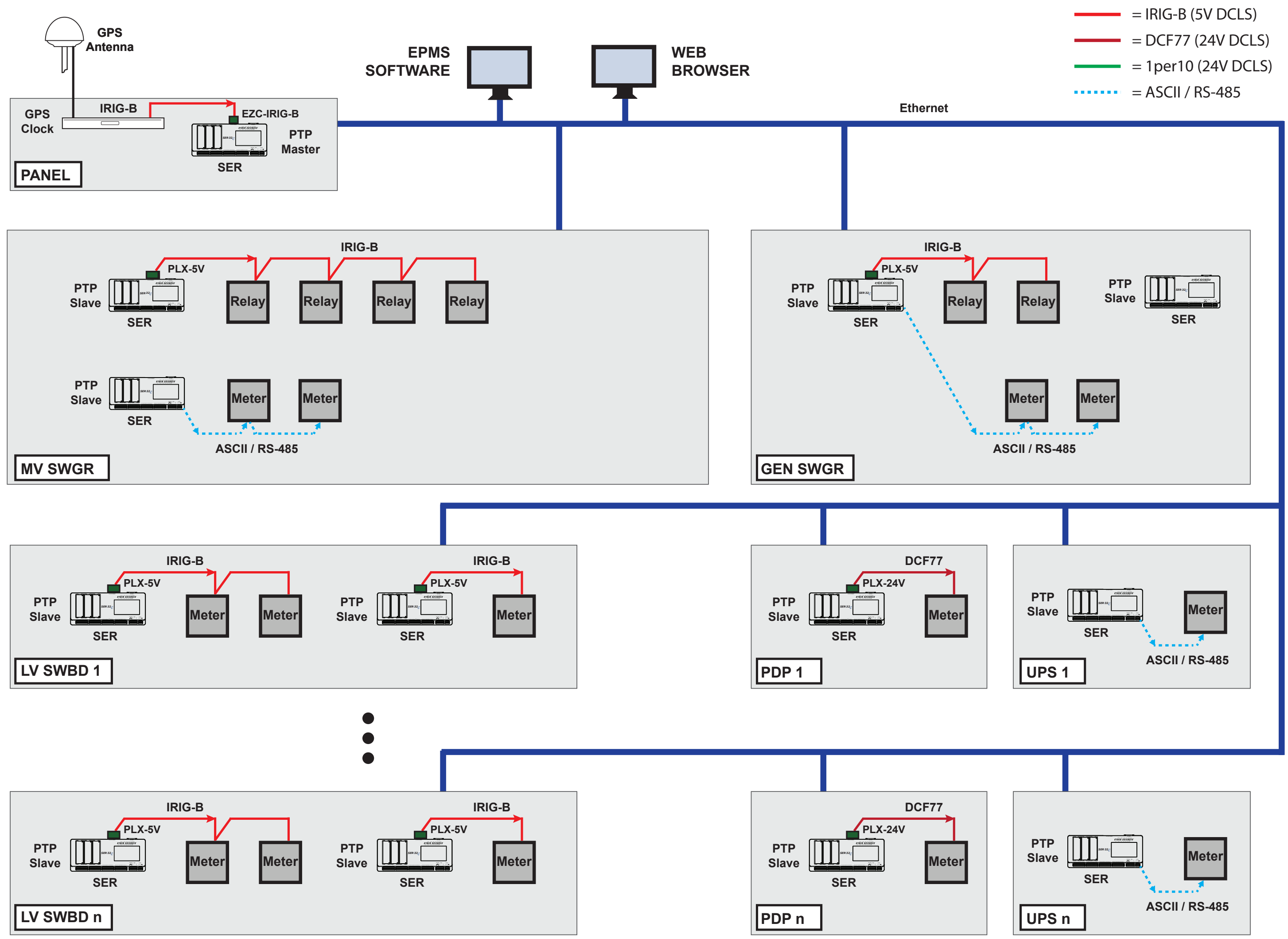
For PTP enabled devices, this protocol provides a solution which is simple to implement and cost effective. But what about all the devices that are not PTP enabled? Is there a solution which simplifies the implementation and cost of keeping all these devices time aligned with precision timing? CyTime™ Sequence of Event Recorders provides the answer to time synchronizing all device clocks no matter their time protocol or distance from the master clock.

System Architecture using Sequence of Events Recorders

As mentioned earlier, supported protocols vary depending on the device. In an EPMS with many types of devices over long distances and multiple buildings, achieving high resolution time synchronization across the entire system is not an easy task. The illustration below shows the challenges of supporting multiple protocols from differing devices in various pieces of equipment. Notice all the wiring that is required from the master time clock to all the devices, across each piece of equipment. Repeaters and converters are also required to achieve this goal.



The use of Sequence of Event Recorders eliminates much of this complexity by introducing a PTP time sync network. In the application shown below, the Sequence of Events Recorder PTP master receives the time from the master clock and then distributes it over Ethernet to downstream SER PTP slaves. From there, each SER PTP slave acts as a local time source for devices by supporting their specific protocols.



Here you can see how implementing time sync to various devices over multiple pieces of equipment is significantly improved. Wiring between the time source, devices and equipment is significantly reduced. Sequence of Events Recorders simplify the design, reduce implementation time and costs, increase scalability, and improve system maintenance.

With all the IEDs now time synchronized and aligned to one time source, everyday analysis of power data provided by the EPMS is more meaningful. It provides additional confidence when reviewing reports from backup power testing, control systems validation and operations, alarming, power quality analysis. During a loss of power, CyTime™ Sequence of Event Recorders are instrumental in event reconstruction.

The Simple Answer for Power-loss Event Reconstruction

In the event of an outage, SERs help to identify the initiating event or ‘root event’, as well as the resulting series of events or ‘cascading events’, all in chronological order. This helps to speed up reconstruction of the event, provides reliable data for analysis and results in faster restoration of power, lowering costs and increasing reliability which maintains reputations.

In addition to providing precision timing across the entire electrical distribution system, SERs also record input status changes to the millisecond from circuit breakers and switches that may not have a clock or support millisecond time stamping.

Here are examples of IEDs and how the SER interacts with them to help align all the events captured before, during, and after an incident.

- Meters: Various meters require different time protocols. The SER provides the time synchronization required by these meters including PTP. Providing precision timing to each of these devices ensures they are all synchronized to one time source and that their time stamp is reliable and precise.

- Uninterruptible Power Supplies (UPS): Every UPS has a performance spec that defines how long it takes to activate when external power fails. The SER can capture and report the actual time a given UPS takes to switch on. If activation time falls out of spec, the SER gathers that information, which can help pinpoint the UPS’s failure and how it contributed to a power outage.

- Automatic Transfer Switches (ATS): An ATS is an intelligent power switching device controlled by logic circuitry. When the usual power source fails, the ATS switches the load to another power source such as a standby generator. These switches can fail altogether, but more commonly, they may not act quickly enough to initiate backup power. The SERs monitor the switching time of the ATS to help determine if it still meets requirements or if maintenance may be required.

- Power Distribution Units (PDUs): As their name indicates, deliver AC power from an uninterruptible power supply (UPS), a generator, or utility power source to servers, networking hardware, telecom equipment, and other devices. The SER monitors the status of the PDU and records any changes from Normal to Bypass or Transfer status during routine maintenance or a power event. This helps to rule out the PDU as a point failure during a disruption in power.

- Protective Relays: Protective Relays detect the presence of a power event and operate circuit breakers that isolate the faulty system before the event causes damage. By monitoring the status of the relay along with the corresponding breaker, the SER shows the elapsed time between the relay command and the breaker response. This information is useful in verifying the equipment works as designed.

The additional monitoring of device inputs helps to eliminate blind spots where data may not be captured and the 1-ms timestamping of their status changes, adds assurance of knowing exactly how events cascaded throughout the system and in what order. The precision time aligned data from the IEDs along with the 1-ms time stamped input data from the SERs provide a more complete picture of what happened during the power incident. This eliminates the guesswork associated with event reconstruction saving time and money for power restoration. Not only is this useful during an outage, but also serves to verify configuration and operation of critical systems such as control schemes to prevent an outage from occurring.

Summary

When the power goes out, whether site wide, local to a room, or at a piece of equipment, time is precious in determining the cause of the outage and more importantly how to safely restore it. Any facility that has ever experienced an unplanned outage of any type knows it can take hours or days to get the system back up and running. Traditionally, performing event analysis required personnel to manually verify the equipment status and then using a process of elimination, determine the source of the power loss. Imagine an outage that starts with a faulty circuit breaker in a facility with thousands of breakers and hundreds of other pieces of equipment. Pinpointing which one failed first can be extremely difficult. With Cyber Sciences Sequence of Events Recorder, performing this analysis can be reduced from hours to minutes. With Sequence of Events Recorders, facilities can look at time aligned event data from the IEDs and SER input status monitoring, determining which piece of equipment failed first, and go directly to it for further investigation. By isolating the problem, the issue can be resolved, and power restored quickly. This helps save time, reduce costs, improve reliability, and decrease the impact to the company's reputation.

Whether the critical facility is a data center, hospital, airport, or R&D lab, Cyber Sciences can help maintain power reliability with solutions that are simple, affordable, scalable, and reliable.

For more information on how we can help you get more from your EPMS system, please visit our website at: cyber-sciences.com

References

[1] Kennedy, Robert A., P.E., "Hi-RES Time Synchronization in Modern Power Systems Using PTP (IEEE 1588)," September, 2017.

[2] Kennedy, Robert A., P.E., "Overview of DCF77 Time Protocol." September, 2017.

[3] Kennedy, Robert A., P.E., "Overview of 1per10 Time Protocol." September, 2017.

[4] Kennedy, Robert A., P.E., "Sequence of Events Recording (SER) System Design Guide." September, 2017.

[5] Uptime Institute (Rhonda Ascierto & Andy Lawrence), "Uptime Institute global data center survey 2020." July, 2020.

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