

# White Paper

## *Shedding Light on a Black Art*

# GPS Time Synchronisation

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### Synopsis

This paper sheds light on the “black art” of GPS time synchronisation. It highlights the advantages of using GPS time synchronisation to optimise asset utilisation and simplify fault analysis across and between networks.

Practical issues involved in the design of reliable and effective GPS time synchronisation systems for use in power utility substations are examined. Various approaches are overviewed and the effects of the unique substation environment are highlighted. The importance of galvanic isolation in overcoming these effects and delivering highly reliable and consistent time-stamps on measured data is demonstrated with practical examples.



### About Tekron

Tekron International is a leading developer of exceedingly accurate GPS clocks and time synchronization solutions for use in industrial applications.

Tekron GPS clocks are simple to install and use and are extremely rugged, attributes that are a prerequisite in the often extreme environments in which the clocks are installed.

Tekron GPS clocks have been installed in thousands of power stations & substations across the globe, where they prove invaluable in assisting power companies to operate efficiently, minimizing downtime and increasing the accuracy of control decisions.

With a Tekron GPS clock you can be confident that you can set it up and walk away.

## Introduction

The Northern Hemisphere was shocked in 2003 with multiple blackouts first in North Eastern USA and the adjacent Canadian Provinces, then in London, then Birmingham, followed by Italy, France, Scandinavia and even Malaysia. Despite assurances by the CEO of National Grid in the UK that blackouts like the one in the USA could not happen “here”, London suffered one of its worst ever outages. Are these events simply a string of “coincidences”?

Two common themes have emerged following the blackout events of 2003:

The first is that power system grids all over the world are being operated with less reserve capacity than ever before as utility owners strive to gain the best possible economic returns from their existing assets.

The second is that the management and supervisory systems set up to operate and control the power systems are struggling to cope with the increasingly complex grid interconnections demanded by the deregulating energy markets.

The NERC/US-Canada Power System Outage Task Force report on the North American blackout on August 14 2003 notes that, in many cases, data collected from sub-station equipment was not time-stamped at all, and in other cases, the time stamps recorded were not synchronised across the network.

One of the primary recommendations of the report is that power utilities should take steps to ensure that power plants and substations control and supervisory data recorders are synchronised by signals from the Global Positioning System (GPS)<sup>1</sup>

Time synchronisation significantly simplifies fault analysis in the aftermath of a fault situation even between networks. In addition, it also increases the accuracy of control decisions by automatic control and protection equipment in the power network, therefore allowing optimal utilisation of network assets. This paper sheds light on the “black art” of time synchronisation.

## Background

The synchronisation of the AC power grid is of primary importance to grid operators. Lack of synchronisation between generators can result in large amounts of energy being dissipated within the grid system with spectacular and catastrophic damage to assets and possible danger to human life. These major synchronisation issues have been addressed in power system design since the earliest days of electrical energy use and techniques for synchronising generation to the grid are generally well established and executed.

However, somewhat less attention has been paid to the need for synchronisation of the protection, control and supervisory equipment that is an essential part of a modern power utility substation. Historically, primary protection equipment was designed to trip supply at a substation based on local operating conditions exceeding a set of pre-defined criteria. Protection relays were largely electromechanical devices. Automatic recording of data from such devices was simply not available – nor was it seen as particularly important, as the supply grid was a relatively simple network with minimal interconnect paths.

Growth in demand, together with privatisation and increasing de-regulation have led to a vastly more complex grid structure in which power can be switched to flow over multiple different paths on a second by second basis. The factors influencing power flow paths within the grid are no longer related solely to technical issues of demand, generation, and optimised grid use, but also to external market issues such as the spot price of power generation offered from competing generating companies. Consequently, the need for closer monitoring and control of power utility network assets over a wide area arises, and continues to grow.

## **Current and Emerging Practice**

While the basic function of a protection relay remains the same today as it has always been, modern protection relays and other IED (Intelligent Electronic Devices) installed in sub-stations offer a host of monitoring and control functions that can generate large amounts of real time data about the operating state of the power system. In addition to the obvious parameters such as voltage, current and frequency, real-time measurement and recording of phase-angles, transients and other parameters relating to power quality is now a practical reality.

In an ideal world, such data would be captured by standardised SCADA (Supervisory Control and Data Acquisition) equipment located in each substation and transmitted to a central control point - the Regional Control Centre for the power company - where decisions, both automatic and manual, could then be made to ensure the continued safe, secure and high quality delivery of power over the grid network in the region.

In addition, the field data would be sent on to a National Control Centre and there combined with similar data from many other Power System Operators to form an on-going real-time picture of the instantaneous state of the National Grid.

For this ideal to be even remotely realisable, it is necessary to ensure that the incoming real-time field data be captured together with an accurate indication of the date and time of day that each data point relates to – i.e. a timestamp. The various system design approaches that are used to try and achieve this are discussed below.

## Approach 1: Control Centre Reference Clock

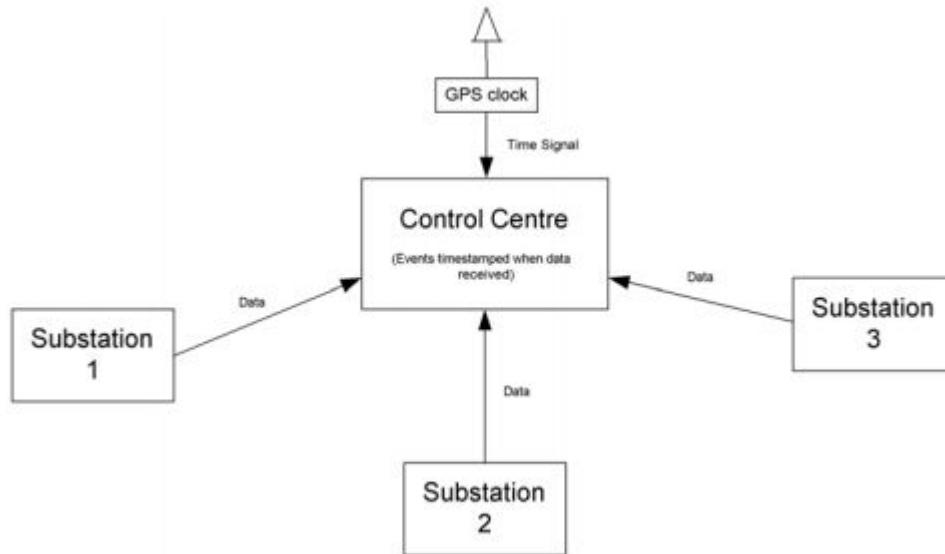


Figure 1: Control Centre Reference Clock  
Accuracy = hundreds of milliseconds (10-1secs)

The first-generation response to the issue of time-syncing substation data involves a single clock acting as a master time reference and located in the control centre. Each incoming data message from SCADA equipment located in individual substations has a timestamp added to it as it is received at the control centre.

This system has the obvious advantage of requiring investment in just one accurate clock per control centre and as control centres are usually manned, they typically provide office-like environments in which a commercial-grade GPS-controlled clock can be readily deployed.

However, the accuracy of the timestamps relative to the event that generated the data is dependent on several factors. If the communications links between each of the substations and the control centre are always predictable in terms of the delays between transmission and reception, then a fixed offset is able to be made to the timestamp to approximate the transmission delays and hence provide an approximation of the time an event actually occurred.

Unfortunately, real SCADA communication systems are not usually so predictable. Typically, within each substation, data from a number of sources (Protection Relays, IEDs) is combined in a communications data concentrator, and then transmitted to the central control location - often in response to a polled request from the control centre. This method of operating is known as "store and forward" messaging.

Depending on how many substations are being polled, how much data needed to be transmitted from each substation, how fast each transmission channel is, and what the channel error rate is like, the delays can vary by hundreds of milliseconds to seconds or even tens of seconds. In addition, the communications protocols used within the substation to gather the data from the originating equipment to the concentrator adds further timing uncertainty.

In practice, time-stamping at the control centre is not reliably accurate enough to be of practical use in control decision-making – in fact – it is often misleading, as the very presence of a timestamp implied an accuracy that is simply not valid.

## Approach 2: System Wide Time Signal Propagation

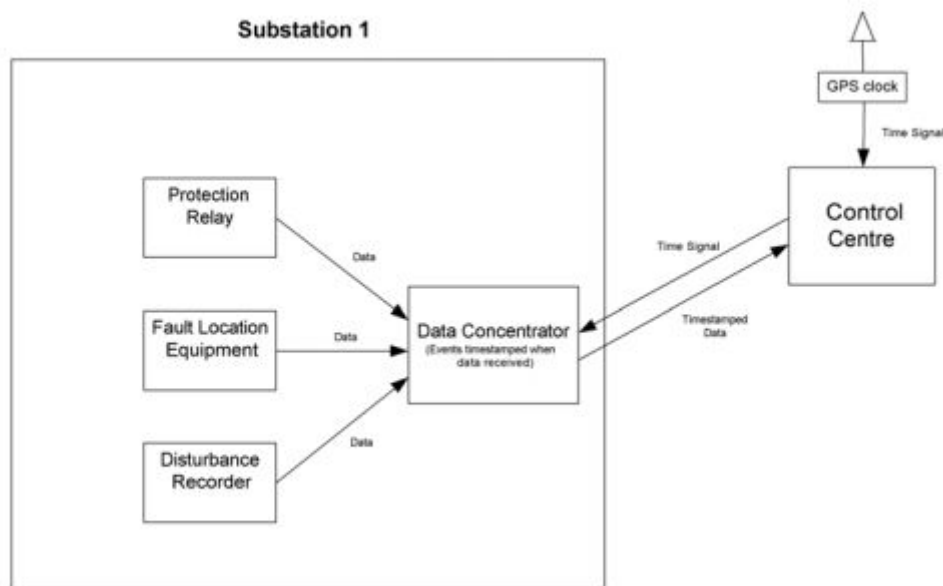


Figure 2: System Wide Time Signal Propagation

Accuracy = tens of milliseconds (10-2secs)

The second generation approach to time synchronisation attempts to reduce the margin of error by applying the timestamps at a point closer in time and space to the actual event.

This is achieved by having the data concentrators in each substation maintain accurate time, and then applying the time stamps to the data as it arrives at the concentrators from the equipment in the substation.

The concentrators receive synchronisation signals from the central control point periodically to assist them to maintain their internal time. Using this method, the data concentrators in different substations can be synchronised to within a few tens of milliseconds or better depending on the communications technologies used. This approach requires a more intelligent concentrator than Approach 1. The timestamp accuracy obtained can be considered sufficient for some situations, but is usually well short of the sub-millisecond accuracy required to track modern IED state changes, and also well outside current recommendations for the industry.

### Approach 3: Individual Substation GPS Clocks – Data Concentrator Time Sync

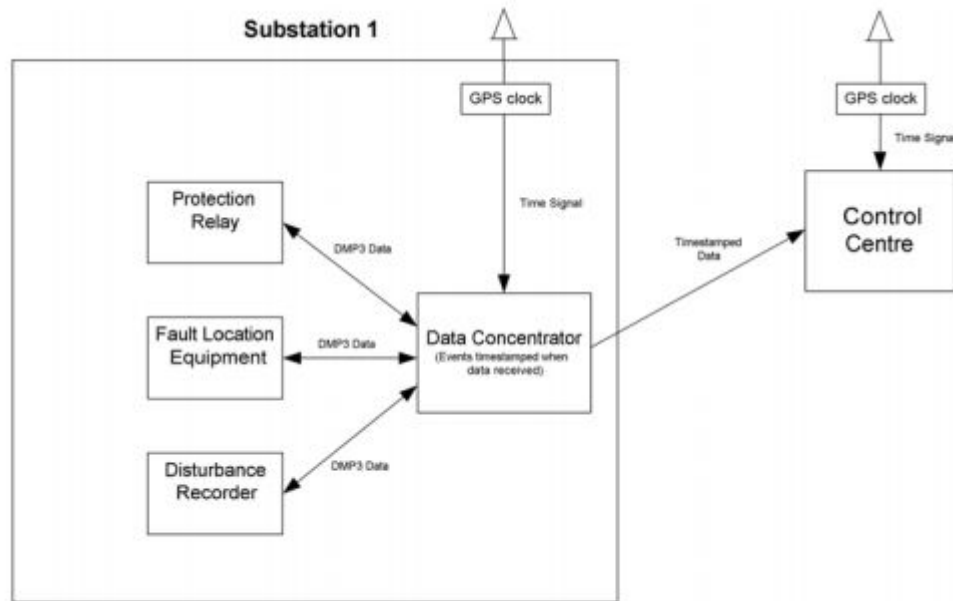


Figure 3: Individual Substation GPS clocks – Data Concentrator Time Sync  
Accuracy = milliseconds (10-3secs)

The advent of relatively cheap GPS-controlled clocks means that it is now economically viable to deploy a time source that effectively offers close to atomic clock performance in each substation, thus making possible network wide, continent or even world-wide synchronisation.

Many substation installations have just used the GPS clock to provide an accurate time source for the data concentrator in the sub-station, replacing the synchronisation signals from the control centre.

While this configuration is an easy practical upgrade from that of Approach 2, in most cases, it fails to deliver reliable results.

The reasons for this are that this approach still relies on the substation data concentrator to either apply time stamps to incoming data, or to resend time information out to attached equipment over the substation internal communications links. In most situations, the communication paths between the concentrator and the other devices use protocols that are indeterminate. That is, data transmission delays between devices may vary depending on the volume of data that is moving across the network at any given moment. Although some link protocols in common use (such as DMP3) do allow for the propagation of time information, they do NOT guarantee a high degree of time precision on the data transmitted.

While systems configured in this way may deliver satisfactory time-stamping performance under normal conditions, it is when the internal substation communications links become heavily loaded with data originating from multiple devices simultaneously that concentrator-based time stamping becomes compromised reducing the accuracy of the timestamps applied to the incoming data to milliseconds or tens of milliseconds. Communications traffic peaks are most likely to occur when power system conditions are changing rapidly – such as in fault situations – precisely the kind of events that are important to track accurately.

In summary - the moments when reliable performance from the time synchronisation system is critical are the same moments that this approach is most at risk of failing to deliver.

#### Approach 4: Individual Substation GPS Clocks - Dedicated Time Sync Bus

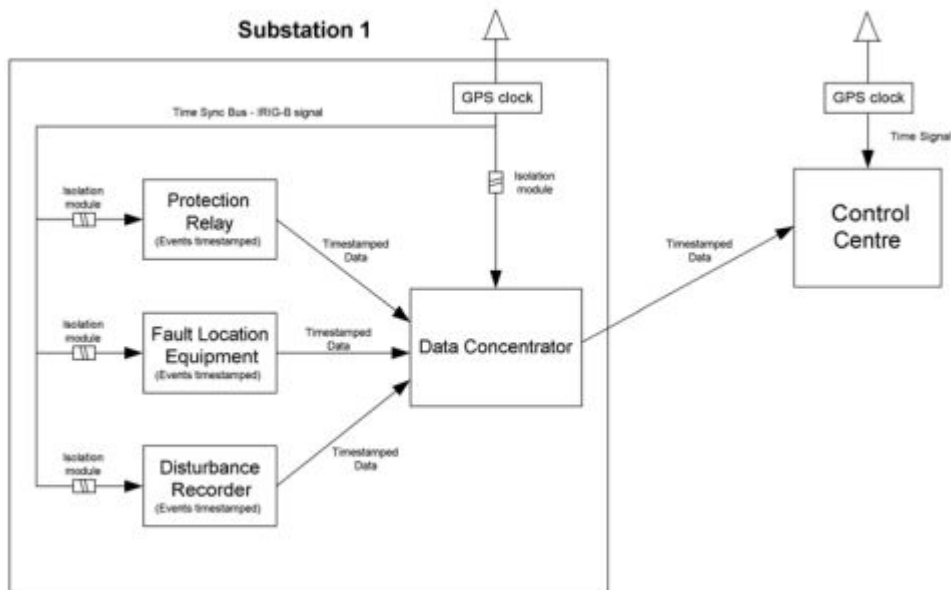


Figure 4: Individual Substation GPS clocks – Dedicated Time Sync Bus

Accuracy = microseconds (10<sup>-6</sup> secs)

The investment in an accurate GPS-controlled clock in each substation is best utilised by the installation of a dedicated time synchronisation bus system delivering time signals directly to all “front-line” equipment such as protection relays and IED equipment.

With such a system in place, time stamping is done at the precise point in time and space that an event is first detected, and the timestamp becomes an integrated part of the data associated with the event.

While subsequent communication delays may still result in the data arriving at control points at some varying later time, the data already carries with it full details as to the precise time of the actual event – not an estimate.

Practical time sync bus systems can deliver microsecond accuracy, providing the precise timing required for the latest synchro-phasor measurement techniques.

It is now economic to provide a bus system of this nature combined with ethernet time server functionality in a single compact package that caters for both existing and emerging synchronisation requirements in substations and elsewhere.

## Time Sync Signal Bus Implementation

Most modern Protection Relays and IED can be fitted with an input port to accept a time synchronisation signal – the most common being the IRIG-B time code. (See Appendix for more detail on the IRIG-B time code).

A time signal bus can be realised by using a single-pair cable carrying the time code signal from the GPS-controlled clock output to all of the equipment that requires synchronisation on a “multi-drop” basis. That is, the synchronisation port on each piece of equipment is connected across the two-wire line (via an isolation module) so that the line drives all of the equipment in parallel. (See Fig. 4) As the time code is a unidirectional signal (transmitting from the GPS clock) it lends itself to this simple “one to many” approach.

However, there are some key issues to be addressed in the time sync bus system design to ensure reliable results.

### a) Bus Loading

In a typical installation, there may be ten, twenty or more devices to be driven by the timing signal. Each device presents a load to the bus, and all the loads combine to present a total loading to the GPS clock source.

Different makes and models of equipment can have different input port specifications, so it is important that the total load be calculated with reference to each device’s specification, and that a clock source be selected that can drive the total bus loading while maintaining full output signal level. If isolation modules are used to drive groups of equipment in each rack or bay then obviously this calculation is much simplified.

### b) Noise Immunity

Within the substation, metallic signal paths are subject to possible interference due to electromagnetic noise. Time code signals are usually low level (e.g. 0-5V), so relatively small voltage spikes induced on to the two-wire line are sufficient to render the signals unusable.

Good noise immunity can be achieved by ensuring that the two-wire bus is “balanced” with respect to station earth potential. In this case, provided that the two wires of the bus feature close electromagnetic coupling (a characteristic of twisted pair cables), any noise voltages are induced identically into both wires and are thus “invisible” to the receiving equipment.

### c) Galvanic Isolation

During earth fault conditions in a substation, large, short duration earth currents can occur. Such currents can cause the earth reference potential to vary dramatically across the station, sometimes by hundreds of volts or more. Communication and control signaling lines that signal with respect to station earth cannot operate reliably or safely under these conditions.

It is important therefore, that such signals are isolated from ground, and, depending on substation layout, further isolation may be required on signal lines as they are distributed across different bays and racks. Without “between bays” isolation, it is possible that an equipment failure in one bay could be promulgated to equipment in other bays via the interconnecting control signaling cables.

Galvanic isolation also provides balanced line conditions, thus providing the bonus of good noise immunity of the signals. Fig. 4 shows an IRIG-B time signal distribution system providing synchronisation signals to both control equipment and high voltage protection equipment while preserving isolation between them.

Optical fibre can also be used to convey time synchronisation signals – thus overcoming both noise and isolation issues. However, optical fibre cannot be used in a “multi-drop” configuration. Systems configured with optical fibre must therefore either provide individual fibre drives to every piece of equipment – a logistical challenge if there are large numbers of devices to be synchronised, or use repeater devices at every point where a drive output is required. While optical repeaters for purely digital signals are now relatively inexpensive, if analogue (AM modulated) timing signals are required to match equipment input specifications, the expense of the optical signaling equipment usually makes their use non-economic in this application.

## Contact

I welcome feedback on this paper.

If you would like to discuss this paper or would like information on Tekron's products, please feel free to contact us at the email address below or through our website.

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## Appendix

### IRIG-B Time Synchronisation Code

Although the synchronisation bus can carry many forms of time signal, the IRIG-B time code is the most widely used synchronisation signal within substations.

The basic form of IRIG-B consists of a pulse-width modulated digital data stream at the rate of 100 pulses per second. The leading edge of each pulse is precisely positioned in time on the incremental 10mS point within the second, while the pulse width modulation conveys time and date information repeating within each 100 pulse frame i.e. once per second. There are a number of variations of IRIG-B time codes in common use. IRIG-B time codes are defined using a 4-character descriptor: "B x y z", and "x", "y" and "z" have meaning as follows:

B	x	y	z
[format]	[modulation type]	Frequency/resolution]	[coded expression]

"B" denotes IRIG-B

"x" designator, modulation type has three possible values:

- 0 = Unmodulated, also called DC level shift
- 1 = Amplitude Modulated (AM) sine wave
- 2 = Modified Manchester modulated

The "y" designator, frequency/resolution has values as follows:

- 0 = no carrier / index count interval (commonly used with IRIG-B)
- 1= 100Hz carrier (not used with IRIG-B)
- 2= 1000Hz carrier (commonly used with IRIG-B)

The "z" designator, coded expression has values as follows:

- 0 = BCD, CF, SBS
- 1 = BCD, CF
- 2 = BCD
- 3 = BCD, SBS

BCD = Binary Coded Decimal format = basic time-of-year information (does not include year information).

CF = Control Function = additional information including year information (eg IEEE1344 extensions or AFNOR extensions).

SBS = Straight Binary Seconds = seconds-of-day in binary format.

The valid combinations in use for IRIG-B are: B00z, B12z and B22z.

### **B00z (DC level-shift IRIG-B)**

B00z (DC level-shift IRIG-B) has been favoured for use with new equipment in substations because, although it cannot be used for wiring runs of more than about 100 metres, it offers good timing accuracy. As long as the GPS clocks outputs are isolated and therefore balanced this effectively eliminates problems due to induced noise that can cause difficulties using this form of time code in sub-stations. This code can also be easily transmitted over fibre. Demodulation is not required, so the code can be very simply received and used by connected equipment. The B00z signals are already being used for synchro-phasor timing.

### **B12z (Amplitude Modulated IRIG-B)**

B12z (Amplitude Modulated IRIG-B) has historically been widely used. Because this modulation is a 1Khz sine-wave, timing accuracy is inherently limited by the wave shape. This is, therefore, the least precise of all of the IRIG-B varieties, but has been in common use because, with no DC content in the signal, it lends itself to transmission over long distances. The sine-wave zero-crossing transitions have to be placed very precisely by the GPS clock (within a few microseconds of absolute UTC time), so that very good precision can still be obtained provided that the receiving equipment employs a reasonably sophisticated demodulator (e.g. PLL) to recover the timing accuracy. Sub-millisecond accuracy is achievable.

### **B22z (Modified Manchester IRIG-B)**

B22z (Modified Manchester IRIG-B) while not yet in common use, gives the best of both worlds. It retains the razor sharp accuracy of B00z, using a 1Khz square wave, but with phase modulation rather than DC level shift. With no residual DC level, it is, therefore good for driving over long distances as well. Demodulation using PLL techniques is relatively straightforward.