Increasing Power Transmission System Uptime

59551A GPS Measurements Synchronization Module

SmartClock Technology

Symmetricom
Heartbeat of the Net

Using wide-area synchronization for power system monitoring and control

As customers demand new services and more available power at ever-decreasing costs, competing power companies must employ advanced methods to maintain and expand power transmission systems. Reliable timing and measurement synchronization capabilities are the basis of power system analysis, monitoring, and control.

Precise timing is required for accurate, time-tagged sampling or measurement of power line/system status indicators such as bus voltage magnitude, phase angle, impedance, and a variety of disturbances, and other critical events. Synchronized clocks and equipment placed throughout an entire power system enhance the reliability of collected data, and provide important information that can only be derived through comparison of data collected at multiple locations.

While precise, accurate clocks and synchronization devices have long been available, they have been too expensive and difficult to maintain to allow generous placement throughout a power system. The availability of timing signals from the Global Positioning System (GPS) makes it possible to maintain consistently accurate time with significantly lower-cost clocks and synchronizing equipment.

Devices can be adequately distributed to synchronize an entire power system and to support network-wide real-time monitoring and control. The expanded information and control lets power utilities quickly and cost-effectively implement tools and procedures that increase power system uptime.

Transmission Line Fault Location

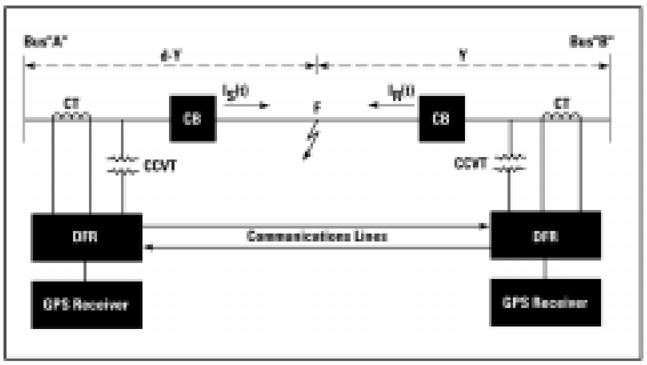
Electric power systems typically cover diverse and often rugged geographic terrain. The territory is usually large and includes generation sites (e.g., hydroelectric facilities) that are significant distances from load centers. Long transmission lines and difficult access complicate the task of fault location. Power companies need effective methods to quickly detect and precisely locate faults in this challenging environment. Search and repair crews can then be efficiently dispatched to minimize costly power disruption.

Traditionally, air and ground crews have depended upon visual inspection and fault recording devices to locate line faults. Both methods have shortcomings.

Inspection crews are frequently delayed or prevented from traveling because of adverse weather conditions—the same conditions that cause most transmission line faults. Additionally, faults not caused by icing, downed trees, or other physical disturbances, may not be visible to search crews. In this case, power companies have alternatively used impedance-based fault location methods.

Digital fault recorders (DFRs), effective tools in some cases, detect line faults by measuring the impedance of a line (i.e., line voltage and current) and comparing it to an unfaulted line. Newer DFRs, used in protective relaying, allow more complex fault location algorithms involving iterative techniques for solving non-linear equations (see Figure 1).

Figure 1. Fault Location System



Traveling Wave Detection for Locating Faults

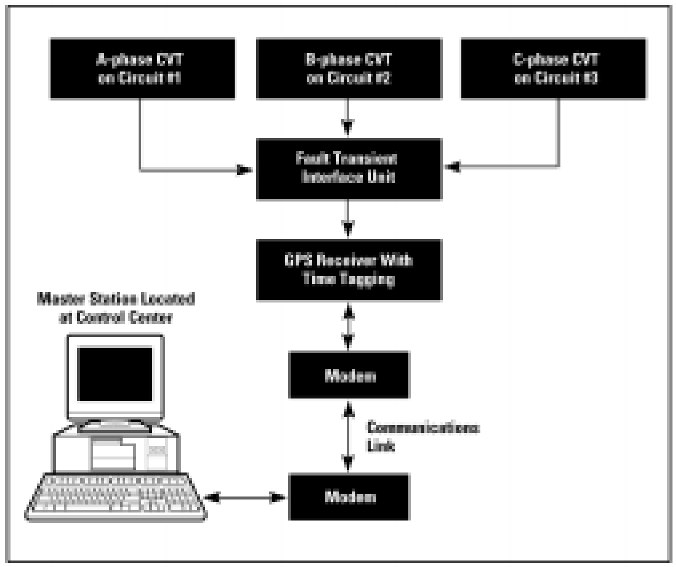
Traveling wave fault location, when used in conjunction with synchronization devices, is both reliable and cost effective. When a transmission line fault occurs, an abrupt change in voltage occurs at the location of the fault. The high-frequency impulse generated at that point—a wave traveling at close to the speed of light—moves along the transmission line in both directions away from the fault. By time-tagging the arrival of the wave at each end of the line, and then comparing the time difference, the fault can be immediately detected and accurately located.

The traveling wave method has several advantages compared with other methods of fault location. Because it relies strictly on the accurate time-tagging of traveling waves arriving at the end of transmission lines, it is not affected by variable load conditions such as ground resistance, or line couplings.

Calculations are also simplified by the provision of data at two transmission line ends. If data is available at only a single end, much information must be estimated (based on known line/wave behavior). Single-end data gathering requires more calculations to produce accurate readings. Taking readings from both line ends helps ensure that high-speed readings are not missed while the device is completing a previous calculation.

The traveling wave detection provides highly-reliable results. With fault location frequencies of 35 kHz to 350 kHz, the wave is not affected by series capacitor banks. A drain coil in series with a capacitive voltage transducer (CVT) ground connection forms a high-pass filter that couples only to the high-frequency traveling wave (see Figure 2). Since only the leading edge of the wave must be time-tagged, programmed temporary lockouts can prevent succeeding edges or reflections from appearing as additional faults.

Figure 2. Typical Substation Layout



GPS: Enabling Traveling Wave Measurements

Successful traveling wave fault location depends on precise timing. Devices must be accurately synchronized with each other and must deliver highly-stable timing in order to correctly time-tag wave arrivals at each end of each transmission line. GPS makes highly-accurate synchronization possible at a cost that is affordable for implementation throughout a large power system. GPS is continuously available throughout the world—even from the rugged geographies of large, remote power systems. Distance or adverse weather conditions do not hamper fault detection. With accuracy of 340 nanoseconds at 95-percent probability plus additional errors, GPS has the potential to meet the range required by power applications. For example, with Symmetricom SmartClock technology, GPS accuracy can be improved to the 110 nanosecond level.

Field-Proven Results

Many power companies have successfully field-tested the traveling wave method of fault location. A Canadian power company has for several years used a traveling wave location system on their 500 kV power system. After using a variety of other methods, including DFRs, the Canadian company has determined that the traveling wave system offers the best results and reliability.

In its pilot program, GPS timing receivers are placed at four substations. The topology provides built-in redundancy for detection of traveling waves. It also provides for fault location coverage even during servicing. The system has consistently met performance goals, including a fault location accuracy of within one tower span (roughly 300 meters). The success of this implementation is prompting installation of GPS-based timing devices throughout the company's transmission system, as well as at the company's system control center.

Additional Timing Applications for Power Systems

In addition to traveling wave fault location, synchronized timing is critical to a range of applications that in other ways improve power system uptime. Investments in synchronous measurement systems can be leveraged for:

Precise Sequence of Events (SOE) Reconstruction

In order to correctly analyze various disturbance data recorded throughout a power system, all events must be correctly time-tagged with accurately synchronized clocks.

Adaptive Relaying

Adaptive relaying techniques make real-time adjustments to power system protection functions to best match the current system conditions. Adaptive relaying collects system data from periodic snapshots of the power system. Synchronized measurements taken throughout the system provide an accurate picture of the current power environment and are critical for effective system adjustments.

Phasor Measurement Units (PMUs)

PMUs measure voltage and current, and can repeatedly calculate watts, vars, frequency, and phase angle during a power line cycle. Synchronized time is critical for collecting samples and evaluating the wide-area system effects and impact of disturbances across critical lines including system buses.

Real-Time Dispatching and Load Scheduling

Many major power networks are linked together by tie lines that share and distribute power loads. In order to successfully complete a power transfer, systems must be synchronized so that changes are introduced simultaneously on all lines.

Stability Control

Synchronized measurements are used to track the status of a power system in an attempt to control transient swings or predict other types of instability. Control actions are of utmost importance immediately after a disturbance, and therefore require reliable measurements for both detection and response.

Dynamic Braking

Dynamic braking is used to prevent the burning of excess energy from system generators. Brakes are applied to stabilize power swings, especially after detection of a disturbance. Synchronized measurements detect faults and are used as inputs to determine the appropriate amount of braking to be applied to control the swing.

Remote Terminal Units (RTUs)

RTUs are used in Supervisory Control and Data Acquisition (SCADA) Systems. Synchronized timing capabilities can greatly enhance the functionality of RTUs without increasing the cost of their placement at power substations.

Precision Timing

Timekeeping devices were originally based on absolute time—i.e., the time directly related to the rotation of the earth around the sun. Expressed in days, hours, minutes, and seconds, the time was derived from astronomical observations. Because it requires complex solutions to maintain accuracy with this method (the earth's rotational parameters vary and are affected by solar activity), international research and timekeeping laboratories around the world now cooperate and use atomic clocks to perform the measurements that provide the basis for the Universal Coordinated Time (UTC) scale.

To synchronize with absolute astronomical time, UTC is periodically updated with appropriate additions of leap seconds. The designated UTC laboratories, such as the U.S. Naval Observatory (USNO), provide primary standard time sources or synchronization references.

All modern clocks keep time based on relative time intervals. The clocks measure the time between two events, such as the width of a pulse, and depend on an oscillator that produces consistent pulses or time intervals. To maintain on-going accuracy, most clocks used in precision applications have to be periodically synchronized with a primary standard time source such as an atomic clock. On-going timing accuracy requires a high-quality oscillator and an available synchronization source.

Oscillator and Synchronization Requirements

Quartz clock technology facilitates affordable solutions for applications that require the placement of clocks at many sites or points on a network. The ongoing accuracy of these clocks, however, is dependent upon the availability of a reliable external synchronization source.

Rubidium or cesium atomic clocks are expensive, but can maintain accurate time for long periods after synchronization. These clocks suit installations where an external synchronization source is not frequently or easily accessible (e.g., remote ground locations or submarines), or in applications that warrant the expense of the solution.

Traditionally, synchronization was accomplished using traveling clocks that were synchronized to a primary standard source like the USNO and physically transported to the on-site atomic clock. This method is prohibitively expensive and inconvenient for many sites.

Other methods, including satellite transmissions of timing signals from VLF systems, GOES weather satellites, and LORAN-C transmissions, are more accessible and usually less expensive. But transmissions are susceptible to unpredictable daily variations and weather conditions, and are not always available to every geography.

GPS and Power System Applications

Now fully operational, the Global Positioning System (GPS) makes it possible to install highly-accurate, inexpensive quartz-based clocks and easily synchronize these clocks with a primary standard time code. Developed by the United States Department of Defense, GPS is a worldwide satellite system that provides navigation, positioning, and timing capabilities for both military and civilian applications.

The GPS system distributes 24 satellites that complete two earth orbits per day. The satellites usually carry two cesium and two rubidium clocks for synchronized timing output that is specified to be accurate to within 1 microsecond UTC. Access is free, no authorization is required, and the signals are constant and receivable virtually anywhere on earth.

While GPS receivers have been available for over ten years, newer products have improved receiver components and are able to take advantage of the more continuous availability of GPS. These products provide inexpensive, but highly-accurate timing and synchronization capabilities and meet a host of application requirements in power system fault location, monitoring, and control. The low cost, small size, and high accuracy of the devices make them well-suited for liberal distribution throughout a power system.

Symmetricom GPS Synchronization Solutions

The 59551A GPS Measurements Synchronization Module is based on advanced GPS technology. It provides a low-cost synchronization foundation for monitoring wide-area transmission systems, or for real-time monitoring and control.

The time base for the 59551A is a highly precise quartz oscillator such as the 10811D, a highly-reliable crystal component characterized by low sensitivity to temperature changes, low phase noise and well-understood aging characteristics. Integrated with the quartz oscillator, SmartClock algorithm boosts the performance of the 59551A, making it approach the performance of a rubidium-based solution with accuracy of 110 nanoseconds at 95-percent probability.

The SmartClock algorithm compares the oscillator frequency with the GPS reference signal. By "learning" the aging behavior and the environmental effects on the oscillator over time, SmartClock adjusts the oscillator output frequency accordingly and significantly improves accuracy.

A holdover mode ensures accurate synchronization in the unlikely event of satellite signal loss or interruption. SmartClock will continue to maintain time and frequency with less than 8.6 microseconds loss in accuracy for up to 24 hours of GPS signal loss. See Figure 3.

Figure 3. SmartClock holdover

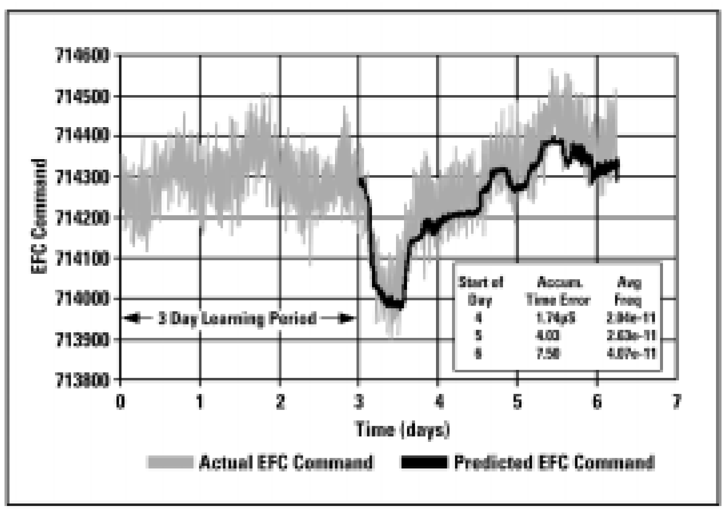


Figure 3 gives typical data illustrating the effect of SmartClock. All of the data are taken with the unit locked to GPS. During the first three days, SmartClock used the GPS reference to "learn" the aging and temperature behavior of the quartz oscillator. The light, shaded line is the actual digital steering command sent to the oscillator to keep it synchronized with GPS time.

The heavy solid line is the computed performance of the quartz oscillator starting with Day 4 using the corrections provided by SmartClock. The dominant effect during the predicting period are changes due to external temperature. If the GPS signal had not been present, the oscillator would have been steered in holdover by SmartClock using the corrections that it had determined.

Holdover performance can be computed from the difference between the actual steered performance, and the predicted performance. The data for the first three days in holdover are shown in Figure 3.

The low cost of the 59551A makes monitoring wide-area transmission affordable.

Time tagging, included with the 59551A, facilitates a variety of applications including fault location, network disturbance analysis, and detailed sequence-of-events analysis. Events can be time-stamped (with a 100-nanosecond resolution), recorded, and down-loaded to a computer system for review.

Input/output capabilities of the 59551A allow its use with a variety of existing event and fault recorders. Standard functions include time tagging of conditioned TTL input signals, IRIG-B output, and an Alarm BITE output that indicates a system fault or loss of satellite lock. Symmetricom also provides fiber optic distribution systems (the 59552A Fiber Optic Distribution Amplifier and the 59553A Fiber Optic Receiver) that transmit signals and timecodes through noise immune filters to measurement and control instruments.

The low cost of the synchronizing devices makes it feasible to place one at each of the critical points in a power system. By synchronizing multiple points in the distribution network, reliable and meaningful field data can be collected, and crucial system performance and operating characteristics can be extracted.

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