Preliminary Special Reliability Assessment Whitepaper:

Extended loss of GPS Impact on Reliability

Findings: *The U.S. Global Positioning Satellite (GPS) system provides space-based positioning, navigation and timing (PNT)[1] information through coordinated signal transmissions, which are received and used by a robust land-based receiver and communication infrastructure. The goal of this whitepaper is to provide a preliminary assessment of the current and future considerations on the use of GPS technologies and potential effects on bulk power system reliability from its long- or short-term disruption (loss or impairment).*

With the current penetration of GPS applications, this high-level preliminary assessment finds that, while the disruption of GPS capabilities could make some electric industry processes less efficient, system operations and bulk power system reliability will not be affected. However, if future designs include substantial application of GPS, a built-in vulnerability could exist. Therefore, this assessment recommends that each organization should develop a master plan on their use of positioning, navigation and timing technologies to ensure that if the use of GPS increases, systems are designed to so that reliability-critical applications are not affected from its disruption.

Background: The electric industry uses GPS for three principal purposes – timing (e.g., synchronization of devices and events), location (e.g., mapping, surveying and navigation) and asset tracking (e.g., fleet management). Over the past decade, industry has increased its use of GPS-based applications (See Appendix I for more background on GPS systems in the U.S.).

Failure modes: There are a number of ways that GPS can be lost or impaired. Interruption may be long-lasting or short-duration, depending on the mechanism of failure and resiliency of the system. There are two categories of interruption:

1. Natural:
   a. Space weather can interrupt service for a period of time (days) or, potentially, permanently damage satellite equipment
   b. Collision of satellites with other objects in orbit

[1] http://www.pnt.gov/

2. Man-made
    a. Interference causing unintentional disruption. For example, some radio bandwidth at frequencies close to the GPS bandwidth could interfere with the signal.[2]
    b. Jamming or spoofing of communications from space-based PNT resulting in the disruption of single or multiple GPS receivers from stationary or mobile sources. (due to the low received signal strength of satellite transmissions, they are vulnerable to jamming by land-based transmitters).[3]

Intentional jamming or interference of GPS signal can cause unexpected, shorter term, and seemingly random disruptions. Until detected, and neutralized, certain local areas may not have sufficient visibility, unless design considerations account for this potential. Spoofing, interference or intentional data corruption of GPS signals can also disrupt its normal operation. To address these activities, timestamp data quality screens at the PMUs and concentrators may be needed to evaluate whether the time stamps look reasonable or might reflect false information.

If space-based PNT is lost, impaired or information becomes untrustworthy, a number of capabilities dependent on GPS could be affected. The effects could be mitigated or replaced through the use of terrestrial (earth-bound) technologies such as cable television, cell or landline phones, traditional radio, landline or cable-based internet connections, fiber connections if these technologies are not dependent on GPS for base station signal synchronization, along with the use of earth-based weather predicting technologies. Most of these technologies do not have the same level of time resolution provided by satellites, though some terrestrial technologies can provide adequate granularity.

Remedy for these space-based PNT disruptions range from months (satellite replacement takes six months or longer) to days (space weather settles, identify and neutralize man-made attacks). While remedial actions are taken, some PNT-dependent civilian-oriented capabilities may not be available.

Current Uses of GPS in Power System Disturbance Analysis: One other application of GPS time data is for disturbance analysis. GPS clocks are the typical synchronization method used to maintain the time within 2 milliseconds of Coordinated Universal Time, as required in PRC-018-1.[4] If events of interest occur during long-term loss of the satellite PNT systems, the ability of forensic analysis teams to analyze each major system disturbance to determine its root cause would be impaired. Alternative methods would slow the event analysis process as data collection and review would be less granular as well as more staff intensive.

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[2] http://www.pnt.gov/interference/lightsquared/

[3] http://www.computerworld.com/s/article/77702/Homemade_GPS_jammers_raise_concerns?taxonomyId=017

[4] Standard PRC-018-1 — Disturbance Monitoring Equipment Installation and Data Reporting, R1.1: Internal Clocks in DME devices shall be synchronized to within 2 milliseconds or less of Universal Coordinated Time scale (UTC)

Current Bulk Power System Operational Impacts: Based on the current penetration and reliance on GPS, if space-based PNT is disrupted, applications such as weather forecasting, management of company assets and some back-up company communications may be disrupted. Therefore, some electric industry processes would be less efficient, the basic operation and reliability of the bulk power system would not be affected.

Current and Future applications of Phasor Measurement Units: Power system operations have fundamental requirements for time and frequency to enable the delivery of supply through power transmission and distribution to consumers. In the future, time synchronization devices may become commonplace in energy management systems (EMS), power plants and substations to enable distributed networks of instruments that must work together to precisely measure and take action to address common events.

For example, to measure bulk power system conditions, PMUs have been placed on some key portions of the grid to provide operators real-time power system measurements that are time-stamped with the GPS signal. Phasor technology is nearing production-grade; there will be in excess of a thousand PMUs installed and networked in North America as part of the DOE Smart Grid Investment Grants program. These phasor data make it possible to compute high-resolution information such as current, voltage, phase-angles, and frequency, providing operators with a more complete picture of the system state to better manage bulk power system reliability. Numerous sophisticated phasor data applications are being used or contemplated for bulk power system operations. For instance, the Bonneville Power Administration (one of the sub-recipients) is implementing a control scheme using synchrophasor data as part of their project. Additionally, the Federal Electricity Commission (CFE) in Mexico implemented a synchrophasor-based generator shedding remedial action scheme that went into service several years ago. PMUs are becoming integrated into systems that are in service in North America and around the world. Synchrophasor-measurement-based situational awareness and automatic controls are already deployed in parts of North America to improve operational reliability, and more are coming on line.

As mentioned above, the electric industry is testing the use of PMUs to support power system operations such as monitoring variable generation or to detect small signal stability conditions and provide local control of generating units. The current generation of PMUs is predominately using GPS for time stamping and telemetry.

As these applications become more integrated into routine bulk power system operations in 3 to 5 years, careful decisions are needed on the suitability of GPS for use in reliability-critical activities. Otherwise, extended loss of GPS would initially challenge these abilities until alternate time synchronization mitigation measures have been established:

1. If PMUs are used in place of SCADA systems for state estimation, decision-making (automated or manual) based on system conditions could become impaired if GPS-based time clock synchronization fails. Without real-time GPS signals or some alternate time synchronization method, state estimation would need to revert to the less accurate, but still reliable SCADA readings that are now generally in use today.
2. Some new remedial action schemes and other protection and control functions are being designed to respond to PMU-measured granular conditions of the power system. If phasor systems lose GPS signals, the protection schemes may not function as desired. For example, Bonneville Power Administration is expected to install its first PMU-based remedial action scheme in the coming year. However, the application of PMUs for wide-area remedial action schemes has not been widely deployed:
    a. **GPS and Protection:** Traditional system protection schemes do not rely on GPS to operate. Protection schemes sense locally (with adequate granularity) the condition of the system via potential, capacitance coupled voltage, and current transformers. Pilot schemes typically use point-to-point communication (power-line carrier, microwave, fiber, etc.) to share data.
    b. **PMU and Protection:** High and extra high voltage protection schemes must detect faults within 1 or 2 cycles (primary protection). Phasor data cannot be shared across a wide-area network without compromising the speed of protection. Significant efforts have and are currently being made to improve back-up and stability-related protection schemes (these schemes have a longer time-window to operate), though they are still in research.
3. Quick, real-time location of operation and maintenance assets (e.g., the utility fleet vehicles that use GPS-based fleet management services) would be impaired. These response activities would be required to revert back to the use of maps and more frequent reports.

Organizations responsible for the bulk power system may require increasingly granular time-synchronized measurements of system conditions in the future for a variety of applications such as communication networks providing grid conditions, analytical information supporting operations, market analyses and dispatch instructions. Wireless networks may also depend on the accuracy and granularity provided by GPS. For example, Network Time Protocol (NTP) provides ~ 1 millisecond accuracy. If GPS is used for these applications, signal loss or impairment will cause clock drift, and equipment, such as synchrophasors, will become less accurate or function incorrectly. Depending on the application requirements, the consequences could be unexpected functionality or no functionality.

In the future, operators may need to establish operating data handling guidance for how to sort and triage incoming data and develop algorithms to measure the quantity of data that is corrupted before the application results become untrustworthy, and necessary alternative actions taken. Both jamming and spoofing may call for automated device/application/network-to-operator and inter-operator alert tools to notify users of adverse changes in the status of the GPS-related data and tools. For example, if the GPS fails to send time signals, many PMUs would still collect data but, as clocks drift, will not be able to accurately time-stamp those data, which means that it will be difficult to synchronize and match one PMU's data against another's. On loss of GPS timing, relative[5] clock drift of 46 microseconds represents one degree of phase angle measurement error.

Therefore, if future designs include substantial application of GPS, a built-in vulnerability could exist. This can be overcome by careful planning and design to ensure that reliability-critical applications are not overly reliant on GPS signals.

Detection and potential design considerations:[6] From a planning perspective, design options should be considered to support operational applications. For example, many substations are equipped with GPS clocks, and all these clocks are linked through satellite communications. These clocks are often also capable of autonomous operation when the satellite link is lost, with some performance degradation over time. In the future, wide-area synchronization could be possible through the use of local GPS receivers. Design considerations for such an application could be attained through interconnection of all the clocks, perhaps in a ring formation, so that the loss of one GPS receiver or satellite links can be off-set by comparing drift and keeping all clocks on the same time. Some organizations currently use terrestrial distribution of time suitable for synchrophasors, transported via the multiplexed fiber-optic communications systems.[7]

Some PMUs are also being designed with on-board, high-precision electronic clocks that maintain time-synchronicity for temporary interruptions of space-based PNT. As is the case with the substation GPS, those clocks would suffer some performance degradation for an extended interruption of PNT. A number of design solutions have been proposed to support overall system clock synchronization and back-up functions, and can be considered when future time-synchronized applications become more extensive. For example:

1. Redundant clock sources with failover

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[5] Synchrophasors are most commonly used to gather information made up of measurements from many substations – sometimes in close geographic proximity such as one end of a line to the other, sometimes over the breath of the interconnection. The relative time error among the clocks at each measurement location is used to determine the time synchronization accuracy.

[6] www.selinc.com/WorkArea/DownloadAsset.aspx?id=6391

[7] See http://www.selinc.com/ICON/ notes web page*: "Economical, Precise Time Distribution: Distribute time over a wide-area network (WAN) with better than 1 microsecond accuracy so that very accurate relative time is maintained in the event of a GPS failure."*

2. Redundant clocks providing back-up to each other
3. Ring interconnection for wide-area synchronization
4. PMUs with back-up clock functionality

Depending on the importance of PNT on the substation activities and use of intelligent electronic devices to manage their functions, the appropriate design of clock synchronization can be deployed to support potential disruption. However, in any system that provides time accurately when the GPS system is not functioning, a clock is required at one point in the system that has been synchronized to the GPS (or other UTC time standard source) and has a very good holdover oscillator.

In the future, operators should become aware of the potential for disruption of space-based PNT, and the bulk power system impacts, if any. Alerts and bulletins from governmental agencies can serve to inform operators of the loss, impairment, or untrustworthiness of space-based PNT, ensuring that appropriate operational procedures are taken to support bulk power system reliability.

Conclusion: With the current penetration of GPS applications, this high-level preliminary assessment finds that, while the disruption of GPS capabilities could make some electric industry processes less efficient, current system operations and bulk power system reliability will not be affected. However, if future designs include substantial application of GPS, a built-in vulnerability could exist. Each organization should develop a master plan on their use of positioning, navigation and timing technologies to ensure that if their use increases, systems are designed to ensure that reliability-critical applications of positioning, navigation and timing are not impacted from long- and short-term GPS disruptions.

Recommendation: Two high level recommendations are:

1. In cooperation with the U.S. DOE and DHS, a demonstration of a set of timing systems technology applications, which are not dependent on GPS timing, should be tested over a geographic footprint similar to a large Transmission operator to assess implications and potential failure modes of these timing applications. This demonstration is necessary to provide the insight to develop a strong organizational master plan on the suitable application of technologies that are dependent on precise timing, such as synchrophasors, compared to the potential risk to reliability.

2. Assign the development of a document that provides elements of a master plan on the use of positioning, navigation and timing technologies for bulk power systems to the North American Synchro-Phasor Initiative (NASPI) Forum. This document should be reviewed by NERC's technical committees and the Electricity Subsector Coordinating Council.

Appendix I: GPS Defined

The GPS[8] is a satellite-based navigation system using a network of 24 orbiting satellites, enabling users to determine their 3-D (Three Dimensional) differential position, velocity and time. GPS satellites circle Earth twice a day transmitting signal information to Earth. Receivers use this information and triangulation to accurately calculate precise locations. In addition to longitude, latitude, and altitude, the GPS provides a critical fourth dimension, time. Each GPS satellite contains multiple atomic clocks that provide very precise time data to the GPS signals. GPS receivers decode these signals, effectively synchronizing each receiver to the atomic clocks. This enables users to determine the time to within 100 billionths of a second without the cost of owning and operating atomic clocks. In particular, because the identical time signal is delivered to every receiver simultaneously, all of those receivers and their associated devices become time-synchronized.

GPS is owned and operated by the United States Government as a national resource; and the Department of Defense (DoD) is the steward of GPS. The National Space-Based Positioning, Navigation & Timing Executive Committee was established by presidential directive in 2004 to advise and coordinate federal departments and agencies on matters concerning the GPS and related systems. The DoD is required by law to *"maintain a standard positioning service (as defined in the federal radio navigation plan and the standard positioning service signal specification) that will be available on a continuous, worldwide basis,"* and *"develop measures to prevent hostile use of GPS and its augmentations without unduly disrupting or degrading civilian uses."* The executive committee is chaired by the deputy secretaries of defense and transportation. Membership includes equivalent-level officials from the departments of state, commerce, and homeland security, the Joint Chiefs of Staff, and NASA. Components of the Executive Office of the President participate as observers to the executive committee, and the FCC chairman participates as a liaison.

GPS has become a widely deployed and useful tool for commerce, scientific uses, tracking, and surveillance. For example:

1. Wireless telephone and data networks use GPS time to keep all of their base stations in perfect synchronization.
2. Digital broadcast radio services use GPS time to ensure that the bits from all radio stations arrive at receivers in lockstep.
3. Companies worldwide use GPS to time-stamp business transactions, providing a consistent and accurate way to maintain records and ensure their traceability.

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[8] http://www.pnt.gov/

a. Major investment banks use GPS to synchronize their network computers located around the world.

b. Large and small businesses use automated systems that can track, update, and manage multiple transactions made by a global network of customers.

4. The U.S. Federal Aviation Administration (FAA) uses GPS to synchronize reporting of hazardous weather from Doppler Weather Radars located throughout the United States.

5. Organizations use GPS to locate and dispatch their vehicle fleets. For example, the electric industry can use GPS to locate and dispatch trouble crews.