Enhancing Timekeeping in the Power Industry Through Multi-Constellation Global Navigation Satellite Systems

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1. Introduction

The power industry relies on accurate timekeeping for the reliable operation of the power grid. The synchronization of clocks across the grid is essential to ensure that all generators, switches, and other devices are coordinated with one another. Traditional methods of timekeeping, such as using atomic clocks and Time Code Generators (TCG), have limitations in terms of their cost and availability.

Global Navigation Satellite Systems (GNSS) have become a popular method for time synchronization in power grids due to their low cost, high accuracy, and availability. This paper discusses the benefits of using Multi-Constellation GNSS systems for timekeeping in the power industry.

2. Existing GNS Systems

There are four primary GNS systems in operation today are GPS, GLONASS, Galileo, and BeiDou. There are also several land and satellite-based augmentation systems, the most interesting of them being QZSS.

All GNS systems provide time in addition to position. In general, at least four satellites are needed to compute a solution. If a *survey-in* (determining the receiver's antenna location before computing solutions) is performed and if the position of the antenna is fixed (typical for applications in power systems), solutions can be computed with less than four satellites, but this somehow cumbersome and rarely done by end-users.

2.1. GPS

The Global Positioning System (GPS) project, originally Navstar GPS, was started by the U. S. Department of Defense in 1973 and is operated by the United States Air Force.

The first prototype spacecraft was launched in 1978 and the full constellation of 24 satellites became operational in 1993.

Advances in technology and new demands on the existing system have led to ongoing efforts to modernize the GPS and implement the next generation of GPS Block IIIA satellites, the first of which was launched in December 2018.

2.2. GLONASS

The Russian Global Navigation Satellite System (GLONASS) was developed at the same time with GPS but suffered from incomplete coverage of the globe until the mid-2000s.

The satellites are located in middle circular orbit at 19,100 km (11,900 mi) altitude with a 64.8° inclination and a period of 11 hours and 15 minutes. GLONASS's orbit makes it especially suited for usage in high latitudes (north or south), where getting a GPS signal can be problematic.

The constellation operates in three orbital planes, with eight evenly spaced satellites on each. A fully operational constellation with global coverage consists of 24 satellites, while 18 satellites are necessary for covering the territory of Russia.

2.3. Galileo

Galileo is a GNSS created by the European Union through the European Space Agency and has been in operation since 2016.

The first Galileo satellite to be part of the operational system was launched in 2011. By July 2018, 26 of the planned 30 active satellites (including spares) were in orbit.

The Galileo system has a greater accuracy than GPS, less than 1 m when using broadcast ephemeris (GPS: 3 m) and a signal-in-space ranging error (SISRE) of 1.6 cm (GPS: 2.3 cm, GLONASS and BeiDou: 4–6 cm) when using real-time corrections for satellite orbits and clocks.

Since Galileo was designed to provide the highest possible precision (greater than GPS) to anyone, the US was concerned that an enemy could use Galileo signals in military strikes against the US and its allies.

The frequency initially chosen for Galileo would have made it impossible for the US to block the Galileo signals without also interfering with its own GPS signals. The final Galileo system uses different frequencies than GPS allowing blocking or jamming of either GNSS without affecting the other.

2.4. BeiDou

BeiDou is a Chinese Satellite navigation system.

The first BeiDou system consisted of three satellites which, beginning in 2000, offered limited coverage and navigation services, mainly for users in China and neighboring regions. BeiDou-1 was decommissioned at the end of 2012.

The second generation of the system became operational in China in December 2011 with a partial constellation of 10 satellites in orbit. Since December 2012, it has been offering services to customers in the Asia-Pacific region. Within this region, BeiDou is more accurate than GPS.

In 2015, China launched the third generation BeiDou system (BeiDou-3) for global coverage. The first BDS-3 satellite was launched in 2015 with global services being provided from December 2018. The 35th and final satellite of BDS-3 was launched into orbit on 23 June 2020.

3. Different Time Scales and their Compatibility

Apart from Galileo, all GNS system time is based on the Coordinated Universal Time (UTC) and is corrected for leap seconds. Leap seconds are added to UTC periodically to keep it in sync with the rotation of the Earth, which is gradually slowing down. However, this correction can introduce errors in timing measurements, especially over long periods of time.

The Galileo System Time (GST) based on the International Atomic Time (TAI), which is the most accurate time scale available and is maintained by a network of atomic clocks around the world. GST is synchronized with TAI and is accurate to within a few nanoseconds.

GST is not corrected for leap seconds and is a continuous time scale. This means that it can provide more accurate and consistent time synchronization for applications that require high precision, such as financial transactions, telecommunications, and scientific research.

Overall, the Galileo System Time is a valuable feature of the Galileo GNSS system for applications that require high precision timing measurements. Although not needed for applications in power systems, it provides a more accurate and consistent time reference than other GNS systems.

The different timescales can be handled by modern receivers. For applications in power systems, all the time is provided as UTC, which can then be converted to local time as and if needed.

4. Enhancing Time Keeping

Ideally, the antenna for a satellite clock should be mounted so that it has an unobstructed view of the sky. This allows the receiver to track multiple satellites, reducing the time spent in *holdover* (the time when there are not enough visible satellites to compute a solution) to a minimum.

Things are less than ideal for several reasons. Among them:

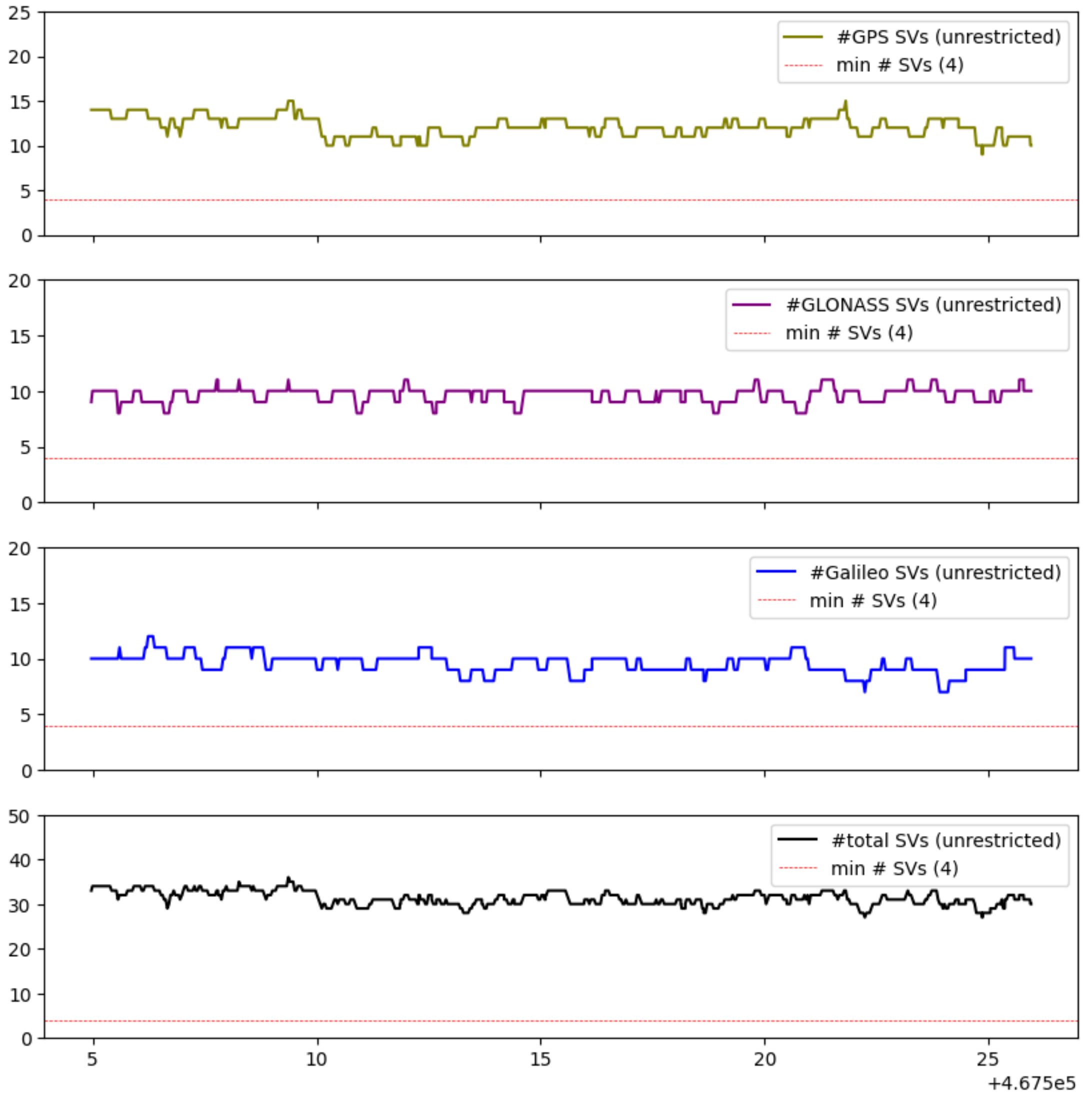
- Clear view of the sky is restricted by neighboring buildings, trees, or mountains.
- Antenna mounting position is limited, for example mounted on a wall instead of on the roof.
- Weak radio-frequency signal due to long antenna cables or degraded antenna performance over time.

One of the ways of compensating for a badly positioned antenna is to use a *multi-constellation* GNSS receiver i.e., a receiver able to process signals originating from more than one GNSS.

5. Observations

We collected ephemerides data broadcast by GPS, GLONASS and Galileo satellite vehicles (SVs) over a 25-hour period starting at 10:00 UTC on 2 May 2023.

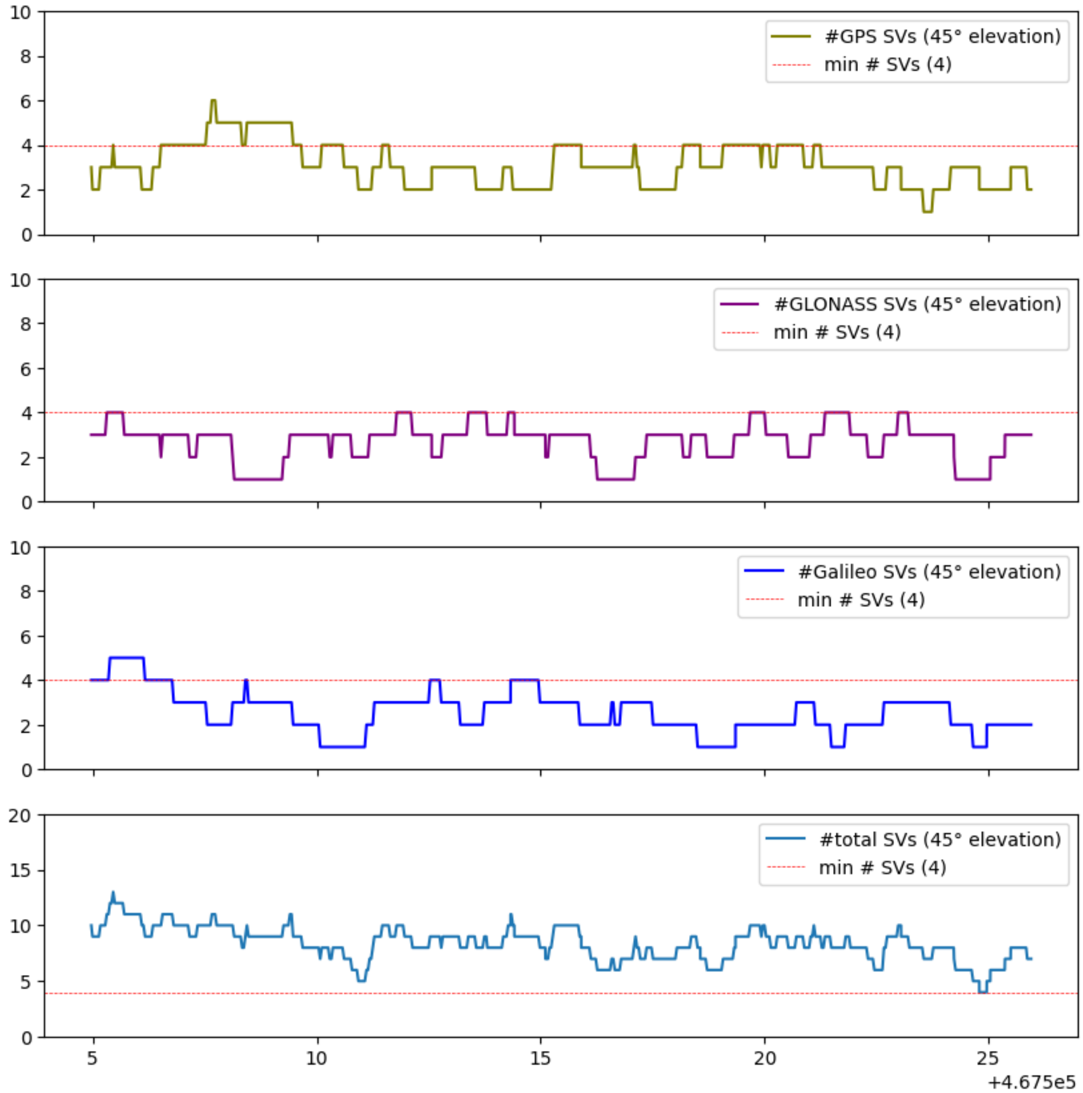
The number of potentially usable SVs (i.e., above the horizon) for each constellation and in total is shown below.



As can be seen, under ideal conditions, each of the constellations by itself provides plenty of enough SVs for a GNSS receiver to operate.

We then increasingly restricted the view of the sky by raising the minimum elevation above the horizon required for the satellite to be considered in the solution.

The result for an elevation of 45° is shown below. As can be seen, even under such extreme conditions, a multi-constellation receiver would still be able to compute a solution for the whole period of time considered.



Finally, we artificially limited the clear view of an antenna (see photo below) and operated it over a period of several days where the GNSS receiver stay locked during all the time.

6. Conclusion

Multi-Constellation GNSS systems have the potential to enhance timekeeping in the power industry by increasing accuracy, availability, and reliability. Each system has its strengths, and using multiple constellations can provide a more robust and accurate time synchronization solution.