ESTABLISHING TRACEABILITY OF SYNCHRONISED PHASOR MEASUREMENTS AT THE NATIONAL LABORATORY LEVEL

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Introduction

The generation, transmission, and distribution of electric power is one of the most fundamental and critical infrastructures of a civilised society. Recent events have shown the vulnerability of electric power systems to both extrinsic and intrinsic events, their effects often cumulative and potentially resulting in catastrophic cascading failures.

Synchronised phasor measurements, or ***synchrophasors*** [1], have recently emerged as one technology which has the potential to improve post-mortem failure analysis, and even to hold out the possibility of one day anticipating incipient failures, making possible the taking of remedial actions before failures reach the catastrophic, system-wide level.

However, present state of the art does not allow these measurements to be traceable to national laboratories. This is a fundamental requirement before any emerging technology becomes widely accepted.

National and international measurement standards

When we purchase a measuring device, we expect the manufacturer to state its accuracy and to provide an explanation, if asked, as to how that figure was determined. Mostly, we just take for granted that somewhere there is a 'god of the volt' which makes sure that all of our voltmeters, for example, perform to the same standards.

In science and technology, the English word "standard" is used with two different meanings: as a widely-adopted written technical standard, specification, technical recommendation or similar document (in French, "norme"); and also as a (physical) measurement standard (in French, "étalon") [2]. In this paper, we are primarily concerned with the second meaning of the term.

Working quietly behind the scenes, standards laboratories at the national level (such as the National Institute of Standards and Technology in the USA) and in the offices of our industry work together to make sure that all voltmeters are calibrated to a universal reference. As technology advances, newer and better standard devices are developed at the national laboratories, providing the possibility of ever-improving fundamental accuracy.

Over the years, for example, the national standards for frequency and time have changed from high-performance ovenised quartz oscillators, to the so-called 'atomic clocks' based on cesium-beam oscillators, to hydrogen masers. Standards for length were once based on a metal metre-bar stored at the International Bureau of Weights and Measures (known by its French acronym BIPM) in Paris; length is now defined in terms of the wavelength of a specific spectral line of an isotope of krypton. For voltage, batteries of electrochemical cells have been superseded by solid-state Josephson-junction arrays.

The national laboratories work together to ensure that standards maintained in one nation agree within certain, usually very small, limits to similar standards maintained by other national laboratories. Thus, the entire world agrees on, for example, the definition of the volt. Collectively, such standards can truly be viewed as 'international standards.'

Traceability

The International Vocabulary of Basic and General Terms in Metrology [2] defines traceability as:

> The property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.

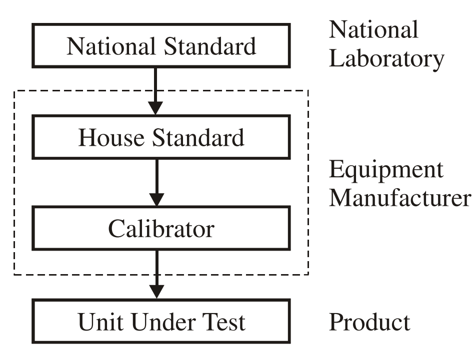

Figure 1: *Simple traceability chain.*

Establishing traceability is done using a series of 'artifacts,' each of which is calibrated against a device of higher performance, all the way up to a national laboratory. Figure 1 shows a very simple traceability chain. Detailed records, including calibration dates of all artifacts used, are kept by standards laboratories for each calibration performed.

Through this method, traceability to the national standard is established, and the uncertainty (commonly, and somewhat improperly, called errors or accuracy) of the unit under test (UUT) relative to the national standard can be estimated (see figure 2). Estimating uncertainty is a science unto itself, with numerous methods used in different circumstances. Expert metrologists often differ in their opinions as to the most appropriate method to use.

National standard uncertainty	**0.01%**
Stability of house standard	0.005%
Comparison uncertainty	0.01%
House standard uncertainty	**0.025%**
Stability of calibrator	0.01%
Comparison uncertainty	0.015%
Calibrator uncertainty	**0.05%**
Stability of UUT	0.05%
Comparison uncertainty	0.02%
UUT uncertainty	**0.12%**

Figure 2: *Example uncertainty calculation.*

The artifacts used to establish traceability must have suitable performance for the task. Generally, this requires good stability under the conditions of use. The closer the artifact is to the national-laboratory level, the greater the stability required. Note that it is ***stability***, and not ***accuracy***, which is required. A stable artifact can have its fixed errors measured by a calibration laboratory (even if these errors are quite large, which is usually not the case), and then it can be used as a reference for subsequent calibrations at a lower performance level. Any fixed errors are simply added as an offset when the artifact is used.

National laboratories make available to industry a wide range of calibration services. While these services are not inexpensive, in most cases the laboratories operate on only a partial cost-recovery basis. This is because national standards are viewed by their sponsoring governments as a critical part of the infrastructure of a modern economy. They enable the fair exchange of known amounts of goods between buyer and seller, and facilitate the exchange of technical information within a universal framework. Without such standards, modern economies could not function.

Traceability in the electric power industry

The most obvious example of traceable measurements in the electric power industry is revenue metering. Both customers and utilities expect that billing for energy delivered will be fair and accurate. Traceability to national standards of power (watts) and time (seconds, or hours) ensures that this is the case. Every watt-hour meter, along with the instrument transformers and other devices used with it to meter electric energy, is calibrated by its maker, using a calibrator that is traceable to a national laboratory.

This process is almost invisible to the everyday user. Field technicians are generally aware of the need to calibrate watt-hour meters on a certain schedule, using a specified calibrator. They don't need to think about why that calibrator is accurate enough to do this.

There are, of course, standards for most everything that is measured in any industry, including voltage, current, and frequency, to name a few. Regulatory agencies often establish minimum levels of accuracy that must be maintained in commerce, as well.

Synchrophasor measurements

Synchrophasors [1] are basically measurements of ac voltage (or current) and absolute phase angle, made at a particular point in an electric transmission or distribution system. ***Absolute phase angle*** is phase angle relative to a fixed, universal reference. [1] defines this reference to be a cosine wave at nominal power system frequency, generally 50 or 60 Hz, with its positive maximum coincident with the on-time occurrence of the standard one pulse per second (1PPS) signal (see figure 3) which is maintained by national laboratories as part of Co-ordinated Universal Time (again in French, UTC). These national laboratories participate in the International Bureau of Time (BIH, also in Paris), ensuring that UTC maintained by the various laboratories is in agreement. Generally, agreement is held to a fraction of a microsecond.

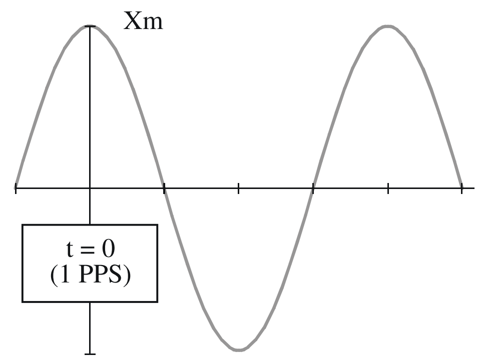

Figure 3: *Reference cosine wave.*

Synchrophasor measurements have been made practical on a large-scale basis by the advent of modern satellite-based position- and time-determination systems. The best known of these is the Global Positioning System (GPS) operated by the United States Department of Defense. Others include the Russian GLONASS system and the European Space Agency's GALILEO, now in development.

Systems such as these can provide sub-microsecond timing anywhere in the world at low cost. This is important because it makes possible the 'universal reference' described above for absolute phase angle.

Synchrophasor traceability

There are existing national standards for voltage and time, as described above. There are also standards for phase angle between two sinusoidal signals of the same frequency [e.g., 3]. However, there is presently no national standard for absolute phase angle. Development of such a standard is necessary so that synchrophasor measurements can be guaranteed accurate and traceable.

Presently, each maker of a Phasor Measurement Unit, or PMU, must devise his own method to generate the synchronised 50 or 60 Hz reference signal described above. This is somewhat analogous to having each maker build his own wet cell as a reference for voltage. In theory at least, all of these devices should agree within some margin of error. However, there is no way to know with certainty the magnitude of this error, nor to arbitrate possible disagreements when discrepancies are found. This is the function of national standards and the traceability process.

Until now, most PMUs installed by a single company and in a given system have been of the same make and type. This makes inter-operability across makers moot. However, the PMU function is now being incorporated in various meters [e.g., 4] and relays [5] as well as by companies offering single-function PMU products [6, 7]. Utilities and independent system operators reasonably expect that these products should be able to operate in the same network using the same standards, with similar and comparable results. However, testing has shown that there are discrepancies in excess of what might be expected [8].

Synchrophasor standardisation

Working Group H11 of the Communications Sub-Committee of the IEEE Power Systems Relaying Committee (PSRC) has been updating the earlier IEEE Standard 1344-1995 [1] to enhance the inter-operability of compliant devices. The new standard will be known as IEEE Standard C37.118. As of this writing, the working group has completed technical development and is preparing the new standard for the balloting and approval process.

While this standard attempts to better address potential sources of disagreement between PMUs, and it defines the universal reference as described above, the working group members recognise the fact that there is no national *physical* standard ("étalon") for synchronised phase angle. They are also aware that a document such as a consensus standard (i.e. the new IEEE Standard C37.118) cannot create a physical, measurement standard such as those maintained by national laboratories.

Definition of the proposed new standard

The proposed new measurement standard for ***synchronised absolute phase angle*** should provide for generation and measurement of a 50 or 60 Hz voltage (optionally also a current) synchronised to 1PPS-UTC with the positive maximum of the signal coincident with the on-time occurrence of the 1PPS signal. The levels of these signals should include low levels, e.g. 1 to 10 volts rms as well as typical power system voltages, e.g. 120 or 240 volts rms. Currents, if supported, would be in the 1 – 5 amperes rms range. The national laboratory should be able to calibrate both sources, which generate a synchronised power-frequency signal; and measurement devices, which measure a power-frequency signal against a UTC reference.

The level of uncertainty should be less than 0.025 degree, to allow for transfer of calibration to user equipment at the 0.1 to 0.5 degree level.

Other capabilities, including phase angles other than zero degrees; different frequencies; and alternate signal levels could also be useful, depending on the difficulty of developing them.

Calibration artifacts

There will also be a need for stable calibration artifacts. The market for these would be very small, so it is doubtful that it would be profitable to build a product specifically for this purpose. Perhaps existing PMUs or other test instruments would be stable enough to allow their use as calibration artifacts.

Conclusion

Standards: Part of the critical infrastructure

National standards facilitate the exchange of goods and information on a common basis. They form a fundamental part of the fabric of a civilised society. For the most part, they do their job in the background, and most of us are not aware of their function, much less their importance. Only when there is a ‘missing link’ do we become aware of the problems that can result.

As technology advances, from time to time new standards are needed. When this happens, industry and the public sector should work together to define the need.

For synchronised phasor measurements to be widely deployed, a new (inter-) national measurement standard for ***synchronised absolute phase angle*** is required. This will allow enhanced interoperability of various makers’ equipment in the field, delivering the potential for improved power-system reliability at lower capital and operating cost.

References

[1] "IEEE Standard for Synchrophasors for Power Systems," IEEE Standard 1344-1995; The Institute of Electrical and Electronic Engineers, Inc., New York, New York, USA.

[2] "International Vocabulary of Basic and General Terms in Metrology" (VIM), second edition; International Organisation for Standardisation, Geneva, Switzerland, 1993[1].

[3] "NIST Calibration Services Users' Guide," NIST Special Publication 250; National Institute of Standards and Technology, Gaithersburg, Maryland, USA, 1998.

[4] Technical Data, Model 1133A, Arbiter Systems, Inc., Paso Robles, California, USA.

[5] Technical Data, Model 421, Schweitzer Engineering Laboratories, Inc., Pullman, Washington, USA.

[6] Technical Data, Model 1690, Macrodyne Inc., Clifton Park, New York, USA.

[7] Technical Data, Model RES 521, ABB Power Technologies AB**,** Substation Automation Products, Västerås, Sweden.

[8] J. Depablos, V. Centeno, A. Phadke, and M. Ingram, "Comparative Testing of Synchronized Phasor Measurement Units." Presented at IEEE Power Engineering Society Annual Meeting, Denver, Colorado USA, June 2004

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[1] This work is a collaboration of the following organisations:

International Bureau of Weights and Measures (BIPM)
International Electrotechnical Commission (IEC)
International Federation of Clinical Chemistry (IFCC)
International Organisation for Standardisation (ISO)
International Union of Pure and Applied Chemistry (IUPAC)
International Union of Pure and Applied Physics (IUPAP)
International Organisation of Legal Metrology (OIML)