Victor PALLARES-LOPEZ[1], Antonio MORENO-MUNOZ[1], Juan Jose GONZALEZ DE LA ROSA[2], Miguel GONZALEZ REDONDO[1], Rafael REAL-CALVO[1], Isabel MORENO GARCIA[1], Aaurora GIL DE CASTRO[1], Francisco DOMINGO PEREZ[1]

University of Cordoba (1), University of Cadiz (2), SPAIN

Synchrophasor for Smart Grid with IEEE 1588-2008 Synchronism

Abstract – *We propose a new synchronized technique for Smart Grid. A PTP-Based IEEE 1588-2008 Global System has been defined. Specifically for PMUs with synchronism needs up to the microsecond range, for Energy Measurements System (EMS), for Intelligent Electronics Devices (IEDs) and for automated real-time control systems called Special Integrity Protection Schemes (SIPS). This new Electronic Devices comprise two main technologies; a Single-Board-RIO and a Compact-RIO integrating the acquisition and synchronization with IEEE 1588-2008. For tasks such as PTP master a NI PCI_1588 card and a Symmetricom's XLI IEEE1588 GrandMaster system for test. For the essays we have defined one experimental system for high precision Synchronism.*

Streszczenie – *w artykule zaproponowano nową technikę synchronizacji w sieciach typu Smart Grid. Zdefiniowany został system globalny oparty na PTP IEEE 1588-2008. Szczególnie jednostki Phasor Measurement Units (PMU) stosowane w układach Energy Measurements System (EMS), Intelligent Electronics Devices (IEDs) i w układach sterowania w czasie rzeczywistym typu Special Integrity Protection Schemes (SIPS) wymagają synchronizacji w czasie kilku mikrosekund. Te nowe układy elektroniczne składają się z dwóch głównych technologii: Single-Board-RIO i Compact-RIO integrujących w jednej strukturze układy akwizycyjne i synchronizacyjne zgodne z IEEE 1588-2008. W układzie testowym do realizacji zadań serwera Precision Time Protocol (PTP) zastosowano kartę NI PCI_1588 oraz jednostkę Symmetricom XLI IEEE1588 GrandMaster. Opracowany został także system testowy z synchronizacją wysokiej precyzji.(**Synchronizator do sieci Smart Grid zgodny z IEEE 1588-2008**)*

Keywords: Embedded System for Smart Grid, PTP-Based IEEE 1588, PMU, Synchrophasor, Intelligent Electronics Devices, IEC61850.
Słowa kluczowe: Systemy wbudowane do sieci Smart Grid, PTP-Based IEEE 1588, PMU, synchronizator, Inteligentne Układy Elektroniczne, IEC61850

Introduction

Currently the systems for protecting the electrical grids and the systems for measurement the electrical parameters tend to be based Electronic Systems Embedded [1], among which include the Phasor Measurement Units (PMUs). This is fundamentally due to the significant benefits that this approach entails, such as the continuing increase in the flexibility and sophistication of these systems, and reducing costs involved in both their design and their operational use.

One of the key aspects in the design of these devices are the response times for different events, in each case is given by the sum of time to capture the signal, the processing time to calculate the parameter associated with the event, and finally, if necessary, the execution time of the action to take as a result of the magnitude calculated.

Of all these times is usually the most critical processing time [2], so we have to design our electronic system ensuring the worst case from the point of view of time, this will be found between those parameters that involve rapid response times a significant computational burden.

In the article "*Data - The Power Behind the Smart Grid*" published in "*IEEE Smart Grid Newsletter - August 2011*" and posted by Jeffrey Katz emphasizes in one important aspect "*…the effective use of smart grid data is to have an architecture that considers an environment of distributed intelligence; this is essential due to split-second timing and non-ubiquitous high-speed communications. Coordination of solutions must be evaluated. This endeavor falls under the rubric of what's known as system of systems research. A particularly important aspect is emergent behavior– unforeseen correct actions of individual systems that work to counter the overall goal. For example, one can imagine a demand response system taking different action than a transient stability control system in reaction to the same renewable generation problem. To support research in to this area, high fidelity grid simulation is being used as a vehicle to understand these issues before projects progress beyond the pilot phase*" [3].

Based on these new trends our research group at the University of Cordoba decided to focus its research on the evaluation of techniques for detecting disturbances in the grid with distributed systems working in real time. This work is a clear example of the line of research. In this case we have focused our attention on the study of synchronization for distributed measurement systems [4].

The synchrophasor are the usual solution when you need high accuracy in applications of Wide Area Monitoring [5]. The following sections analyze the current state of standards for synchrophasors, future prospects and our work based on their future development.

I. Synchrophasor for Smart Grid

Synchrophasor measurements are key information needed by system operators to assess the status of the power grid. Using data from Phasor Measurement Units (PMUs), received by phasor data concentrators (PDCs), grid operators will be able to have better visibility of power grid operations and respond to grid disturbances earlier to prevent major blackouts [6].

Two Standards are related to communications of phasor measurement unit (PMU) data and information. IEEE C37.118 was published in 2005 for PMUs. IEC 61850 has been substantially developed for substations but is seen as a key standard for all field equipment operating under both real-time and non-real time applications. The use of IEC 61850 for wide-area communication is already discussed in IEC 61850-90-1 in the context of communication between substations; it is only a small step to use it as well for transmission of PMU data. The models for PMU data need to be defined in IEC 61850. This work seeks integration study with experimentally test [7].

Possible Applications of Wide Area Monitoring with Synchrophasors are; Angle/Frequency Monitoring, Voltage Stability Monitoring, Improved State Estimation, Distributed Generation and Independent Power Producers Applications and Power System Restoration.

Our work is focused on using PMU measurements for Angle and Frequency Monitoring. These measures are taken to increaser the observability of electric networks. This is useful also in an increasing number of distribution networks because the trend shows they take over more tasks that have been reserved to transmission networks. Therefore more dynamic comes into the distribution network caused by fluctuating renewable generation (wind, photovoltaic). The continuous measuring of the synchrophasors in such a distribution system supports the understanding of the dynamic behaviour. It can be used to determine the power balance in a distribution network.

There are also a small, but increasing, number of applications in test or operation where synchrophasors are used in automated real-time control systems called special integrity protection schemes (SIPS). In this line focus some of our research and specifically in systems of measurement and detection of events working in real time.

II. Synchronism with Software-Based IEEE 1588-2008.

This work proposes a new synchronized technique for Smart Grid. A PTP-Based IEEE 1588-2008 Global System has been defined and an Experimental PTP-Based System has been developed to provide synchronized on substation for phasor measurements.

As discussed, Timing is an essential element to all test, control, and design applications and should be a key consideration in any system. Timing and synchronization technologies allow the correlation or coordination of events in time and maximize the value the system provides. In data acquisition, these events can be multiple samples or samples between multiple systems. Timing is important because it helps you coordinate or compare the acquired data signals with time, so you can relate the signals to each other.

Synchronization precision and the distance between the system nodes are the two parameters we have to take into account in designing a timing and synchronization scheme. System designers must account for the limitations created by these variables because as transmission distance increases, it is more difficult to share signals between systems to keep them synchronized [2].

To have a high precision of synchronization, we must have a clock with high frequency and accuracy, which can degrade as the distance between chassis, or nodes, increases. The IEEE 1588-2008 standard achieves the highest levels of precision timing systems over 1km apart. Only the GPS synchronization is more. The distance does not affect the quality of sync but we need to install a GPS in each of the measuring points.

We need another method of conveying the clock and trigger signals from the master node to the other slave nodes in the system. This method, examined later with the experimental system for test (see Fig.3).

At present, synchronized measurements based on an accurate time reference, e.g. GPS (Global Positioning System), provide the missing link now allowing more efficient use of phasor data [8]. This phasor meters are very geographically dispersed through wide areas and still capture electrical waveforms on a synchronized way with a precision up to the microsecond range. The synchronization requirements are very close to the ones imposed to systems working with a unique clock.

For example, synchrophasor Standard [9] imposes critical synchronism requirements. To keep TVE Level-0 (highest) below 1% threshold, highest phasor angle error allowed is 0.57°, on a 50Hz nominal frequency for electrical network (all data from now on, referenced to 50Hz nominal frequency networks). A time error of 10µs corresponds to a phase error of 0.18°. Furthermore, our technical proposal integrates a variety of features in order to reduce to a minimum synchronism errors in the signal sampling and conversion process [10].

On the other hand the IEC61850 is better described as a communication system than a protocol. It includes parts for modeling of the components and the system, description of data types and classes, abstract service definitions, specific mapping for system implementation, and conformance testing.

IEC 61850 v1 only included communication within the substation, so connection to the control center was informational only and did not include 61850 services.

With the completion of section 90-1 in 2009, methods for direct communication with 61850 outside of a single substation became a part of the standard and are fully described and supported.

Integrating IEEE C37.118 with IEC 61850 will help to remove overlaps between the standards, which may impede development of interoperable equipment and systems.

IEEE C37.118 is intended to support applications, for example, protection. IEC 61850 is suitable for system-wide applications that require higher publishing rates [7].

A standards-based approach for time synchronization that addresses the requirements from all applications will support interoperability and facilitate implementation of new Smart Grid applications.

III. Harmonization of IEEE C37.118 with IEC 61850 and Precision Time Synchronization.

There are significant differences in scope and content of the two standards. IEEE C37.118 includes communication as well as measurement requirements and is also intended to support applications such as protection. IEC 61850 is suitable for system-wide applications that require higher publishing rates. The approach including possible models for PMU data needs to be defined in IEC 61850 [6].

Common time synchronization will be a key for many Smart Grid applications. The IEEE 1588 standard will be a key element to achieve that synchronization and PC37.238 standard is developing for application of PTP to Electric Power [11].

It is possible to use a similar approach for the transmission of PMU and PDC data but the capability needs to be formally defined in IEC 61850. PC37.239 standard defines a Common Format for Event Data Exchange (COMFEDE) for Power Systems [12].

IV. PC37.239 for Common Format for Event Data Exchange.

This standard defines a common format for the data files needed for the exchange of various types of power network events in order to facilitate event data integration and analysis from multiple data sources and from different vendor devices. The flexibility provided by digital devices in recording network fault event data in the electric utility industry have generated the need for a standard format for the exchange of data. These data are being used with various devices to enhance and automate the analysis, testing, evaluation, and simulation of power systems and related protection schemes during fault and disturbance conditions. Since each source of data may use a different proprietary format, a common data format is necessary to facilitate the exchange of such data between applications. This will facilitate the use of proprietary data in diverse applications and allow users of one proprietary system to use digital data from other systems [12].

V. PC37.238 for application of PTP to Electric Power.

This standard specifies a common profile for use of IEEE 1588-2008 Precision Time Protocol (PTP) in power system protection, control, automation and data communication applications utilizing Ethernet communications architecture [11].

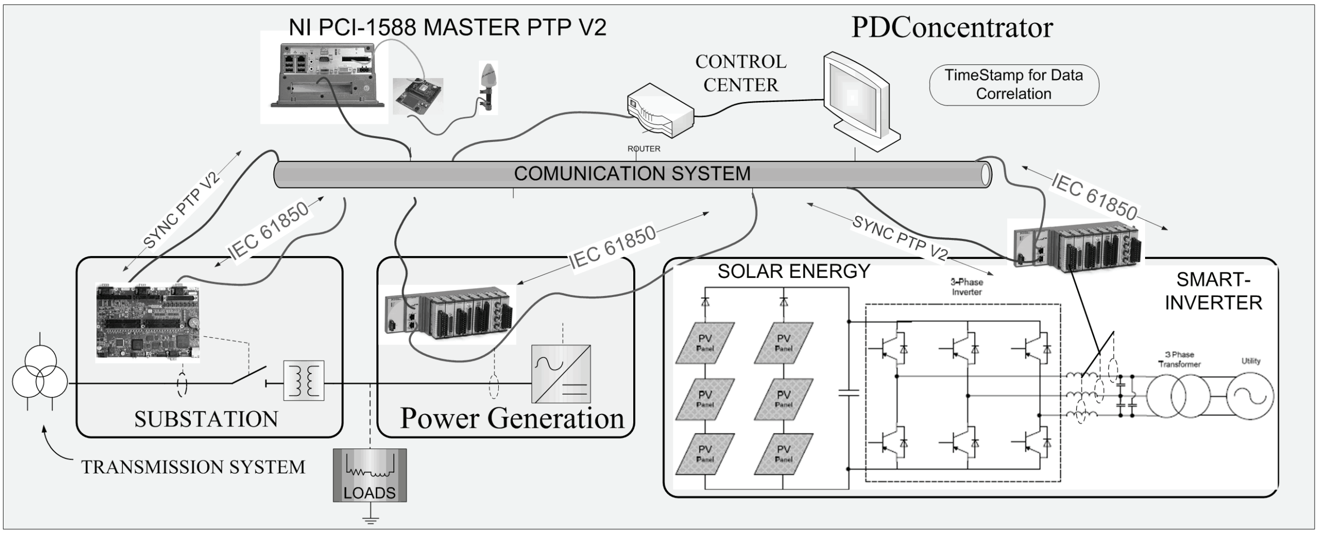

Fig.1 PTP-Based Global System.

The profile specifies a well-defined subset of IEEE 1588-2008 mechanisms and settings aimed at enabling device interoperability, robust response to network failures, and deterministic control of delivered time quality. It specifies the preferred physical layer (Ethernet), higher level protocol used for PTP message exchange and the PTP protocol configuration parameters. Special attention is given to ensuring consistent and reliable time distribution within substations, between substations, and across wide geographic areas.

VI. Ptp-based Global System for Synchronized Event at Smart Grid.

Proper time synchronization across Interconnections is a very important function for many reasons. Common time synchronization will be a key for many Smart Grid applications. The IEEE Std 1588™ standard will be a key element to achieve that synchronization. This standard is available to achieve highly accurate synchronization over a communication network. Many applications related to Smart Grid require time synchronization.

At present, phasor measurement units (PMUs) can be considered as SMT devices commonly used in power system applications [14]. A significant advantage of using SMT is that all measurement signals are attached with a high-accuracy time stamp, which will facilitate the transition from a conventional measurement system, based on SCADA, towards a more intelligent measurement system using synchronized measurements from geographically distant locations. This feature is essential to develop the Smart Grid concept.

Thus, for synchronizing Smart Grids the use of a PTP-based global system (see Fig.1) can provide a secure communication channel with a delay that does not compromise the correct operation of the global system. This would imply the advantage of reusing the infrastructure of existing telecommunications networks to transmit synchronism information between PMUs. The Fig.1 shows an example of generic application of PMUs in Smart Grids.

Multiple IEDs sharing data or control commands results in new distribution protection, control and automation functions. This has the potential to supersede and eliminate much of the dedicated control wiring in a substation, plus costly special purpose communication channels between the stations and power network.

This standardization enables the integration of the equipment and systems for controlling the electric power process into complete system solution, which is necessary to support utilities processes. Ensure the interoperability of equipment and systems by providing compatibility between interfaces, protocols and data models. With IEC61850's standardization of data acquisition and description methods, integration efforts are reduced [15].

The data concentration function also requires supporting a wide range of communications protocols. And they should support the newer standard protocols for both IEDs and SCADA masters. Standard protocols such as DNP3™, IEC 60870-5 and IEC61850 (including GOOSE) may be needed now or in the future. When applicable, both serial and LAN formats should be specified. User-friendly features such as configuration templates for all protocols can reduce the configuration time considerably [16].

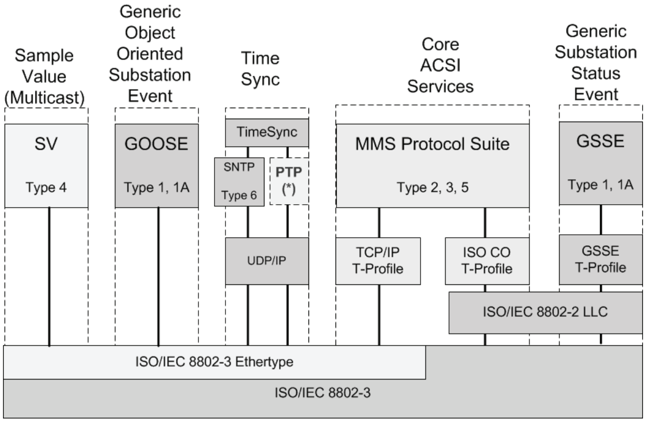

Fig.2 Protocol Mapping Profile.

In addition Network Time Protocol (NTP), Simple Network Time Protocol (SNTP), and the Precision Time Protocol (PTP) may be required to allow time synchronization over the network.

We also study the possibility of adding functionality to transmitting GOOSE messages on an Ethernet network and the integration of the PTP protocol for synchronizing tasks Fig.2 as proposed in the paper [15]. This scheme represents the IEC61850 PROTOCOL MAPPING PROFILE.

The OMICRON IEDScout software was used to detect and subscribe GOOSE messages on the network. Several GOOSE messages that were transmitted on the network were detected by the EDScout software.

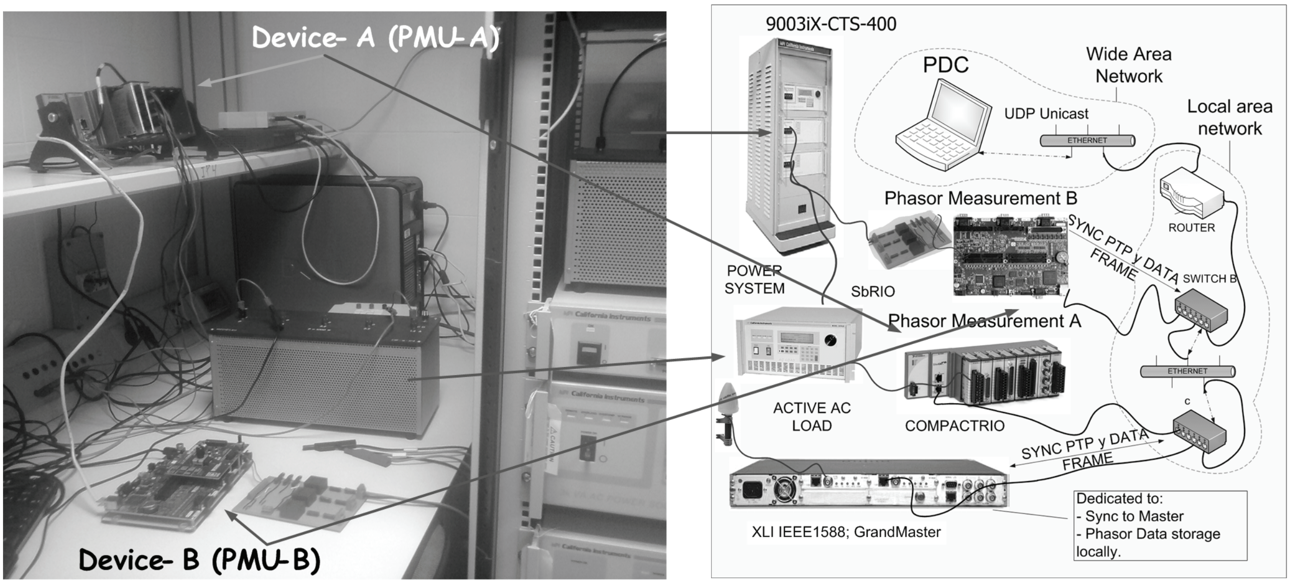

Fig.3 Phasor meters synchronization method.

VII. Experimental System for Synchrophasors Test.

With this system (see Fig.3) reproduced in the laboratory many of the disturbances that occur in an electrical grid; imbalance between phases, frequency variations, harmonic injection, etc.. The programmable three-phase AC source can be synchronized externally to start with a pulse when it is generated each phenomenon. In short, we can validate and calibrate all measures to detect each type of disturbance with high accuracy.

The system is composed of tree instruments of high precision for coordinate testing. The PMUs are connected to the output of the programmable source (9003iX of California Instruments) and capture the voltage and current phasors.

For calibration of each of the experimental Slaves: this system is based in the XLi's Time Interval/Event Time (TIET) feature can be used to measure PTP synchronization across timing networks.

It has been designed to provide highest stability level to the A/D conversion process. System has been over-dimensioned to provide enough room for future analysis, grid management and protection features. Main system components have been selected to comply "Level-0" IEEE 37.118 requirements:

To test our algorithms two embedded system **one NI Single-Board-RIO and one NI-RIO 9074**; Simultaneous 6-channel, 16-bit ADC, operating up to 50k Samples/s and FPGA synchronism.

To measure the stability of timing signals from the PTP slave one **GrandMaster XLI IEEE1588**;

AC/DC power sources 9003iX-CTS: Programmable three-phase AC source with a maximum power of 9K VA.

Active AC Load: The 3091LD is designed to provide precisely controlled, non-linear loads for testing AC power generation equipment.

In the following sections explain the test procedure and the tasks of each team:

- *AC/DC Power Sources for Experimental Tests*.

An AC/DC power sources 9003iX-CTS with a high performance power analyzer. In an instant of time generate a phase shift in one of the channels. We calculate the time from the instant the disturbance occurs and the instant when the disturbance is captured by the PMU. With this method, we can determine the individual quality and quality in simultaneous capture of phasors.

The same slave transmits to the central device the frames as the norm Synchrophasor Standard [13].

- *The 3091LD AC Load for Experimental Tests*.

The AC Load can simulate high crest factor and variable power factor load conditions. This provides an effective method of testing AC system and can significantly increase product reliability.

Traditionally, many of these systems are tested using resistive load banks. This approach does not simulate real-world conditions such as switching AC/DC converters found in many AC powered products. This type of conventional testing does not fully exercise the equipment under test (EUT) under worst case operating conditions.

- *Grand Master XLI IEEE1588 for calibration.*

Fig.3 shows how the phasor meters units are synchronized with a Master-PTP V2 who acts as the central system. This system is an evolution of "*An IEEE1588-BASED system for synchronized PMUs and protective relaying functions*" [17]. This is equipped with a standard RJ-45 connection for Ethernet communication (up to 100 Mbps). In section VIII we explain in detail the method for estimating the stability of the clock with integrated timer (Time Interval/Event Time).

This Master oversees and manages the synchronism of a set of PTP slaves connected to a standard Ethernet network. PTP Master sends multicast synchronism packets "sync and Delay_req" to every slave unit in order to synchronize their local clocks with the master unit one. PTP master local clock gets stabilized in turn from the Ultra small, low-power and highly sensitive GPS receiver. PTP transceivers provide PPS signal for synchronism of remote units, which use it as a basis for phasor estimation and data transfer [18],[19].

- *Synchronism Method.*

The NI-RIOs works as a PTP-Slave and provides a PPS signal with the high stability. This signal enables us to re-synchronize sampling (see Fig.4) and "Data Frame" sending processes by asking PTP master exact PPS timestamp. "Data Frame" messages enclose phasor, time and frequency information.

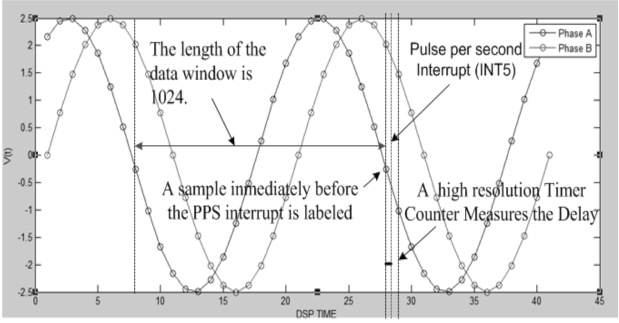

Fig.4 - Synchronism method

The NI-sbRIO-9631 CLK module provides a real-time clock. This clock can be used to measure the passage of time, as well as to add timestamp messages to event logs. Both the high resolution times are stored as 64-bit values. The 64-bit counter (FPGA I/O functions) is implemented using a Single-Cycle Timed Loop (SCTL) which guarantees that all operation will execute in one clock pulse at 40MHz internal time-base.

Also we can emphasize that with this system we appraise the deviation in microseconds between the pulse per second and the most nearby sample with a timer of high resolution. This displacement adds to the received TimeStamp.

- Data sampling and processing issues

“Level-0” complaint requirements force us to use high data sampling rates. First estimations lead us to consider a data sampling range among 256 and 1024 samples per cycle (12.8KSamples/s to 50KSamples/s).

Data sampling rate must be kept as low as possible, since it considerably increases, the already high computational load required for correlation DFT and FFT phasor estimation methods [20]. When nominal frequency remains constant, phasor estimations for N samples per cycle can be obtained [21] on a continuous basis from a correlation DFT. Between sampling and sampling are calculated each of the terms of the DFT to guarantee the processing in real-time.

An electrical disturbance has effect on several analysis windows, first with the quality factor increasing to reach a maximum and then again decreasing until an acceptable value is reached [21],[22].

Voltage and current phasor estimations, timestamp, measured frequency and frequency deviation with regard to analysis window data are informed on a regular basis (25 or 50 data frames per second sending rates). The information is transmitted by a channel UDP Unicast. A central team receives the frames of two experimental IEDs.

VIII. GrandMaster for Experimental Test

The standard “XLI IEEE1588 Grand Master Clock, as can be seen on Fig.5, provides a complete implementation of a Precise Time Protocol (PTP) “ordinary clock” over a dedicated IEEE 1588 card. The IEEE 1588 card can be configured to operate as a PTP grandmaster or as a PTP slave.

As a PTP grandmaster, the IEEE 1588 card typically synchronizes PTP slaves on the network to International Atomic Time (TAI). The XLi IEEE 1588 Clock derives TAI from the Global Positioning System (GPS). In addition, Symmetricom designed the XLi IEEE 1588 Clock so the user can distribute Coordinated Universal Time (UTC) or user-entered time over PTP.

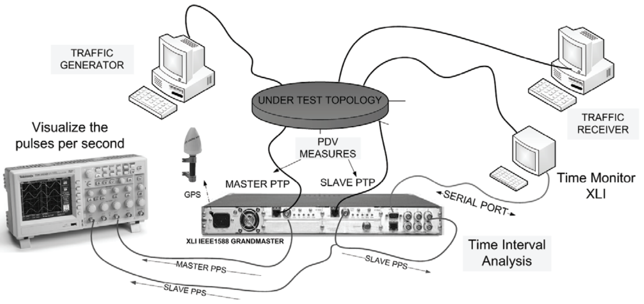

Fig.5 Network Measurement Test Set-up

The XLi’s Time Interval/Event Time (TIET) feature can be used to measure PTP synchronization across timing networks. The XLi IEEE 1588 Clock is characterized by the following nominal specification: Frequency Output Accuracy; $<2x10^{-12}$, Frequency/Timing: Allan Deviation, Stability; $1x10^{-9}$ @ 1sec, $2x10^{-10}$ @ 1000sec y $1x10^{-12}$ @ 1 day. The XLi comes with the standard TCVCXO oscillator described below. The stability of the following oscillators is dependent on the reference source (GPS). GPS characterized by Tracking Up to 12 satellites with TRAIM, Position Accuracy Typically < 10m when tracking four (4) satellites, TRAIM Mask 1µS, 1PPS Accuracy UTC-USNO ±30ns RMS 100ns Peak by a PPS accuracy within 15ns to GPS/UTC.

Synchronization performance depends on several factors, including, but not limited to Slave oscillator quality and PLL control [19], networking equipment, network traffic levels and network topology. System designer generally cannot easily modify slave oscillator and control. However, PTP settings and network design are under the control of the system designer.

Through careful network design, synchronization performance of measurement systems can be maintained. Network characterization is an important step for determining the fitness for high performance synchronization. Two parameters that aids the characterization process are “Packet Delay Variation” (PDV) and Slave PPS Time Error. PDV measures variations in the master to slave packet delay at the physical layer of the network. Measuring slave PPS time error from the hardware-generated PPS signals provides direct observation of master-slave end-to-end synchronization. Errors can be viewed using a frequency counter, oscilloscope or a grandmaster equipped with an integrated time interval measurement input “XLI IEEE 1588”.

When system behavior degrades in such a way that TVE threshold is surpassed, phasor estimations cannot be correlated with the ones coming from points with better stability conditions. To prevent or reduce stability issues, alternative network topologies can be evaluated:

Share synchronism and data paths but using only PTP switch. Existing studies [19],[24] demonstrate that with PTP switch and a flat network topology both communication paths can be unified.

The use of ordinary switches or router should be avoided in critical timing application where sub-microseconds or better accuracy is needed. In these cases Transparent Clocks (TCs) and Boundary Clocks (BCs) should be utilized. This work [25] investigated about advantages from the use of these devices using the IEEE 1588-2008.

Conclusions

With experimental PTP-based V1 system [17], substation events could be synchronized within 12 microseconds. TVE requirements [9], limit time error to be lower than 31µs. Nevertheless with a slave PCI-1588 for test recovers its stability around 150ns. The tests are very similar to [10], [26] with a PXI system.

We also study the possibility of adding functionality to transmitting GOOSE messages on an Ethernet network with IEEE 1588-2008 synchronization.

With experimental PTP-based V2 system proposed in this paper we hope to achieve accuracy within some 2 microseconds. Some important enhancements [25], among others, are: enablers for increased accuracy higher timestamp resolution, shorter sync intervals, correction field, rapid reconfiguration after network topology changes, fault tolerance, unicast operation and new mappings (for example, PTP directly on Ethernet MAC layer, without IP/UDP).

ACKNOWLEDGEMENTS

This research was supported partially by the Company Telvent Energy, Spain, through the project Malaga SmartCity under contract number 12009028. SmartCity's budget is partly financed by the European regional development fund (ERDF) with backing from the Junta de Andalucía and the Ministry of Science and Innovation's Centre for the Development of Industrial Technology. The authors would like to thank the Spanish Ministry of Industry, Tourism and Trade for funding the Project TSI-020100-2010-484 which partially supports this work. Our unforgettable thanks to the Spanish Ministry of Science and Innovation for funding the research project TEC2010-19242-C03-02(-3).

REFERENCES

[1] Moreno-Muñoz, A., De La Rosa, J.J.G., Real-Calvo, R.J., Pallarés, V. (2010). "Embedding measurement in Distribution Automation Systems". IEEE International Symposium on Industrial Electronics, art. no. 5637698, pp. 3722-3727.

[2] Moreno-Muñoz, A. (2007). Power Quality: Mitigation Technologies in a Distributed Environment. Springer.

[3] Jeff Katz; the Chief Technology Officer of the Energy and Utilities industry at IBM, Smart-grid-newsletter August 2011, http://smartgrid.ieee.org.

[4] Pallares-Lopez, V.; Moreno-Munoz, A.; Gonzalez-Redondo, M.; Real-Calvo, R.; Garcia, I.M.; de Castro, A.G.; Perez, F.D.; de la Rosa, J.J.G.; "Deterministic Ethernet synchronism with PTP-base system for synchrophasor in Smart Grid"; Compatibility and Power Electronics (CPE), 2011 7th International Conference-Workshop; Page(s): 22 – 27.

[5] Pallares-Lopez, V.; Moreno-Munoz, A.; Gonzalez-Redondo, M.; Real-Calvo, R.; Garcia, I.M.; de la Rosa, J.J.G.;" Synchrophasor integration in IEC 61850 standard for SmartGrid and synchronism with PTP-base system", Industrial Electronics and Applications (ICIEA), 2011 6th IEEE Conference on, Page(s): 1507 – 1512.

[6] NIST Special Publication 1108; "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0". Janury 2010.

[7] PAP13 61850 C37118 Harmonize and Synchronization; "Time Synchronization, IEC 61850 Objects/IEEE C37.118 Harmonization (6.1.2, 6.2.2)". 2009.

[8] Andrea Carta, Nicola Locci, Carlo Muscas, Member, IEEE, and Sara Sulis, Member, IEEE, "A Flexible GPS-Based System for Synchronized Phasor Measurement in Electric Distribution Networks", IEEE transactions on instrumentation and measurement, VOL. 57, NO. 11, NOVEMBER 2008

[9] IEEE 37.118-2005. IEEE Standard for Synchrophasors for Power System.

[10] Marco Lixia, Carlo Muscas, Sara Sulis: "Application of IEEE 1588 to the Measurement of Synchrophasors in Electric Power Systems", ISPCS 2009 International IEEE Symposium on Precision Clock Synchronization for Measurement, Control and Communication Brescia, Italy, October 12-16, 2009.

[11] PC37.238™/D5.6 2 Draft Standard Profile for Use of IEEE 3 Std. 1588 Precision Time Protocol in 4 Power System Applications. February 2011.

[12] IEEE PC37.239™/D05 2 Draft Standard for Common Format for 3 Event Data Exchange (COMFEDE) for 4 Power Systems. May 2010.

[13] IEEE Std 1588-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems. (2008) The Institute for Electrical and Electronics Engineers, Inc., New York.

[14] Martin, K. E., Hamai, D., Adamiak, M. G., Anderson, S., Begovic, M., Benmouyal, G., et al. (2008). Exploring the IEEE standard C37.118-2005 synchrophasors for power systems. IEEE Transactions on Power Delivery, 23(4), 1805-1811.

[15] Yang Liu, R. Zivanovic and S. Al-Sarawi, C.Marinescu and R. Cochran, "A Synchronized Event Logger for Substation Topology Processing", Power Engineering Conference, 2009. AUPEC 2009. Australasian Universities Publication Year: 2009 , Page(s): 1 - 6.

[16] Erich W. Gunther, "Cybectec Substation Gateways", SmartGridnew.com, Publication Year: Nov 5, 2008.

[17] Pallarés-López, V., Moreno-Muñoz, A., De La Rosa, J.J.G., Real-Calvo, R. (2010). "An IEEE1588-BASED system for synchronized PMUs and protective relaying functions". SPEEDAM 2010 - International Symposium on Power Electronics, Electrical Drives, Automation and Motion, art. no. 5542201, pp. 593-598.

[18] P. Ferrari, A. Flammini, D. Marioli, S. Rinaldi, A. Taroni: "Synchronization of the Probes of a Distributed Instrument for RealTime Ethernet Networks", IEEE ISPCS 2007, 1-3 Oct. 2007, pp. 33-40.

[19] C. Na, D. Obradovic, R. L. Scheiterer, G. Steindl, and F. J. Goetz: "Synchronization performance of the precision time protocol in Industrial Automation Networks", IEEE Transactions on Instrumentation and Measurement, Vol. 58, No. 6, June 2009.

[20] Lee Barford, Member, IEEE, and Jeff Burch. "Fourier Analysis From Networked Measurements Using Time Synchronization". IEEE Transactions on Instrumentation and Measurement. vol. 56, no. 5, october 2007

[21] Synchronized Phasor Measurements and Their Applications. A.G. Phadke • J.S. Thorp. EDIT. Springer, 2008. ISBN: 978-0-387-76535-8.

[22] DSP Applications Using C and the TMS320C6x DSK. Rulph Chassaing. EDIT. JOHN WILEY & SONS, INC., 2002. ISBN 0-471-22112-0.

[23] Lee Barford, Member, IEEE, and Jeff Burch. "Fourier Analysis From Networked Measurements Using Time Synchronization". IEEE Transactions on Instrumentation and Measurement. vol. 56, no. 5, october 2007.

[24] J.-C. Tournier, Xiao Yin, "Improving Reliability of IEEE1588 in Electric Substation Automation", ISPCS 2008 – International IEEE Symposium on Precision Clock Synchronization for Measurement, Control and Communication, Ann Arbor, Michigan, Sept. 22–26, 2008.

[25] Jiho Han, Student Member, IEEE, and Deog-Kyoon Jeong, Senior Member, IEEE:" A Practical Implementation of IEEE 1588-2008 Transparent Clock for Distributed Measurement and Control Systems". IEEE transactions on instrumentation and measurement, vol. 59, no. 2, february 2010.

[26] Andrea Carta, Nicola Locci, and Carlo Muscas, Member, IEEE: "A PMU for the Measurement of Synchronized Harmonic Phasors in Three-Phase Distribution Networks". IEEE Transactions on instrumentation and measurement, vol. 58, no. 10, october 2009

***Authors**:*
Prof. Víctor Pallares-Lopez,(E-mail: vpallares@uco.es),
Dr. Antonio.Moreno-Muñoz, (E-mail: amoreno@uco.es),
Prof. Miguel Gonzalez-Redondo, (E-mail: el1gorem@uco.es),
Prof. Rafael Real-Calvo, (E-mail: rafael.real@uco.es),
Mrs. Isabel. Mª. Moreno-Garcia, (E-mail: p92mogai@uco.es),
Prof. Aurora Gil de Castro, (E-mail: agil@uco.es),
Mr. Francisco Domingo Perez (E-mail: p62dopef@uco.es)
Electronics and Electronic Technology Area, Department of AC, Electronics and TE. University of Cordoba. SPAIN
Dr. J. Jose. Gonzalez de la Rosa,
(E-mail: juanjose.delarosa@uca.es),
Electronics Area, Department of ISA, TE and Electronics. University of Cadiz. Algeciras. Cadiz. SPAIN.