IOT-PMU. HOW TO IMPROVE THE OBSERVABILITY ON THE DISTRIBUTION NETWORKS

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ABSTRACT

This paper addresses the introduction of IoT-PMU device in the distribution networks as an extra source of information. The IoT-PMU concept combines Phasor Measurement Unit (PMU) functionalities with the ability to communicate by protocols used in Internet of Things (IoT), the design is implemented in a minimal functional device. The presented implementation is hardware agnostic and could be transfer to any general-purpose hardware, could even be included as an additional function in the current protection relay product. This paper shows the performance of the IoT-PMU concept regarding phasor, magnitude, angle and frequency measurements accuracy.

INTRODUCTION

The worldwide success of Internet of Things concept and the increasing number of IoT platforms, devices and networks, it is a great opportunity for electric sector. Nowadays, with the introduction of the Distributed Energy Resources (DER), the electric vehicle and the prosumer concept, the complexity level of the Distribution System has considerable increased [1]. Because of that, the distribution level management request extra information of the real status of the network, new type of measurements and sensors. For that aim, the application of IoT concept will significantly improve the observability of the distribution network.

Traditional monitoring of power grids was ensured by Remote Terminal Units (RTU), which provide real/reactive power flows, real/reactive power injections and voltage magnitude measurements, the introduction of PMU by Phadke (1983) offers additional measurements such as voltage and current phasor measurements. PMU can provide very accurate data since they are synchronized from the common Global Positioning System (GPS) radio clock [2]. In addition, the classical approach relies on a three-level architecture: the PMU as data source, deployed across the electrical network, the Phasor Data Concentrator (PDC) for collecting data and an analytics layer [3]. Conventionally the PMUs are widely implemented at the transmission network level but not in the distribution grid due to significant cost of the system and the size of the distribution level compared with the transmission.

Due to new presented scenario, the distribution networks are taking over more tasks that have been reserved for transmission networks in the past, so the supervision is also important for the distribution level [4]. Moreover, based in PMU monitoring, a complete set of possible applications are useful in the area of distribution networks such as Angle/Frequency Monitoring, Post-Mortem-Analysis, Voltage Stability Monitoring, Improved State Estimation, DG/IPP Applications, Power System Restoration [4].

Therefore, the massive deployment in the distribution network of PMUs with the capacity to send the information to the IoT platforms will enable the development of new applications that will result in an efficient distribution management.

Advanced Distribution Management System (ADMS) enables the creation of high-performance network models [5]. With the ADMS there is the possibility to visualize the current state of network based on SCADA telemetry combined with state estimation for all non-telemetered equipment to provide systems operators with greater network awareness. Owing to this technology it is possible to accurately model all elements of the network for better load forecasting, fault location prediction, energy loss reduction and equipment failure prevention [5].

The emerging IoT technology is proposed in this paper as the appropriate technology for massively collect the PMUs information coming from the distribution grid. The presented system will benefit of the progress in the development of IoT components such us connectivity, device management, data base, processing, action management, analytics, visualization, tools, and external interfaces [6]. In particular, the scalable storage of device data, the IoT communication protocols and the opportunity to perform complex analysis are key factors of the application of IoT technology to the proposed system.

In this scenario, the paper present IoT-PMU system, that, due to the intrinsic nature of the IoT communication infrastructure and its limitations, does not pretend to offer a real-time operation solution but rather aims to extract additional information. Steady state monitoring is assumed to be the way to exploit the presented system, then the update rate could be relaxed up to one frame per second offering valuable additional information from the distribution grid. Therefore, added value of IoT-PMU will rely on the improvement of the Management System providing new real relevant information of the network system, that will serve not only to enhance models but also to better understand the network behaviour, optimise resources as well as maximise the use of the existing infrastructure.

PMU IMPLEMENTATION

This paper describes the design of PMU's prototype, connected to the IoT platform and analyses the results obtained after test campaign. To collect the data, used for the analysis and results exposed in the present paper, a real scenario composed of three PMUs have been developed, deployed in different locations and connected to the IoT platform.

The PMU design is described as the sum of the following blocks as shown in the figure 1: main controller, acquisition board (analog to digital front-end conversion), and ethernet WIFI IoT controller. Besides, three external devices are also necessary: a Global Positioning System (GPS) device, a transducer to connect with the electrical network and a +5V external power supply.

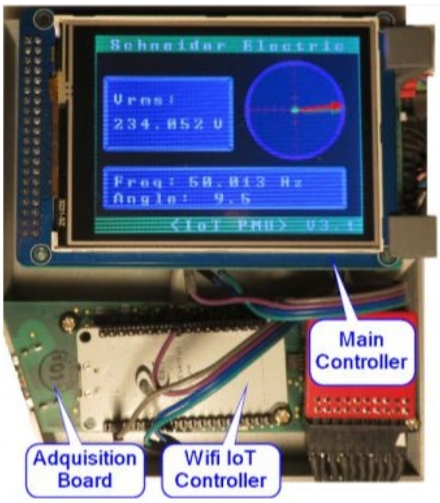

Fig. 1 PMU Prototype. Block Description.

The synchronization GPS device is responsible for providing the exact clock to the system. The accuracy of the synchronization port is about ±100ns. The GPS generates two different signals: a Pulse Per Second (PPS) and an asynchronous serial message in NMEA-183 format including the following fields: Universal Time Coordinated hour (UTC), date, geographical coordinates, etc. The main controller is able to adjust its internal clock according with the UTC hour adjusting the phase of its internal clock.

The acquisition board is composed of an analog front-end that includes an analog to digital conversion. This board is responsible for conditioning, sampling, and converting the input signal. The input signal is directly connected to the voltage transducer, responsible to convert the external voltage from 230Vrms to 1 Vrms and provide the needed isolation. The analog to digital converter used is the ADS131E8 from Texas Instruments [7]. This device includes up to 8 simultaneous analog input acquisition channels, so up to four voltages and four currents can be acquired at the same instant.

The main controller is ARM Cortex-M3 SAM3x8E from Microchip [8]. This device is responsible for controlling the acquisition board, to synchronize its internal clock with the GPS, and to send the final calculations to the Ethernet WIFI IoT controller. The device receives the interrupts from the GPS and synchronize its internal main clock. All the analog samples are stamped in a regular pace, with the internal clock previously synchronized in phase with the GPS.

The sampled rate of the analog input signal is configured to 4 KHz, so each 250 microseconds a new sample is received and marking with the correspond UTC data stamping. This sampled rate offers up to 80 samples per cycle. The main controller is also preforming all the RMS and phasor calculations (voltages and currents). In this first software release, a simple zero-crossing algorithm and linear interpolation was used to calculate the angle of the phasor, however, the results have been really promising.

Finally, the ethernet WIFI IoT controller is receiving the phasor calculations from the main controller, filtering and sending them to the IoT platform. A ESP32 from Expressiff [9] was chosen to implement this task. This device is a dual core microcontroller with embedded WIFI interface. The device is generating MQTT messages necessary to connect with the IoT platform and, at the same time, ensuring that the data has been correctly delivered.

The figure 2 shows the functional PMU prototype, completely assembly, with its connections to the auxiliary devices (external GPS, transducer and power supply).

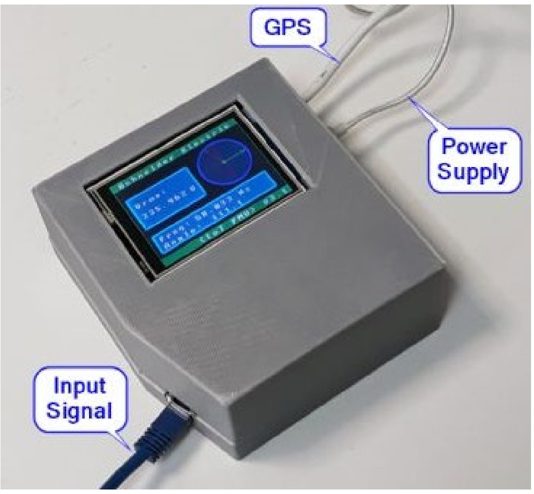

Fig. 2 PMU Prototype.

The PMUs were tested and calibrated with Omicron 256 [10]. After that, the error results were the following: magnitude error < 0.2%; phase error < 0.1 degree; frequency error < 1 mHz.

Accuracy requirements are fulfilled with a large margin, giving more than enough confident to perform the PMU – IoT analysis.

IOT TEST AND RESULTS

In order to verify the behavior of the presented system, several tests were implemented in different specific locations (subsequently referenced as nodes). In this first stage, the tests were implemented in the low voltage network, due to the easy access to this environment, a second stage of this analysis is scheduled in the medium voltage network.

The location 1 was chosen as the reference node, and the other different locations were compared with this reference. The locations were chosen considering the distance from the reference node (location 1) and ease of prototypes installation and the correct coverage of the GPS receiver. As a result, the chosen locations are shown in the following figure 3 and table 1.

Fig. 3 Location distributions.

The distance between nodes are: Cartuja to Montequinto, line sight 8.68Km, Stadium and Laguna line sight 0.89 Km and about 112Km of line sight between Seville and Cadiz. Taking as the reference node as Montequinto (Seville).

Table 1, Node locations.

Province	Node #	Nodes Names
Seville	1	Montequinto
	4	Cartuja
Cádiz	2	Stadium
	3	Laguna

It is important to remark that all the connections were done in monophasic mode, so dephase of ±120º was expected. Besides, because depending on the ground connection (based on standard IEC 60364), dephase of ±180º could also be expected.

Regarding the IoT platform, note that the first analysis was focused on the reliability of the IoT network and the accuracy of the results. This made it possible to relax the requirements at the level of IoT network infrastructure reducing the reporting rate to 1 second during the experimentation phase.

The first experimentation was performed between nodes 1 and 4. Under these conditions several tests were carried out with the results shown in the figure 4.

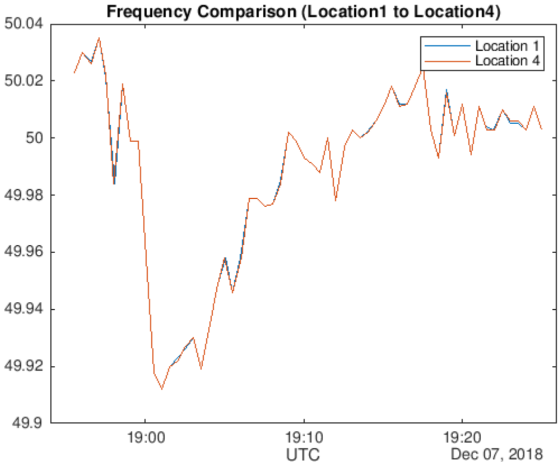

Fig. 4. PMU Frequency comparison node 1 vs 4.

As it was expected, the frequency of the system is the same independently of the phase where the device is connected. As shown in the figure 4, both devices made the same frequency measurements, with minimal calculation deviation.

Voltage comparison was also carried out, as shown in the figure 5, but no conclusion could be reached due to lack of knowledge of the topology of the low-voltage electrical network between the two nodes.

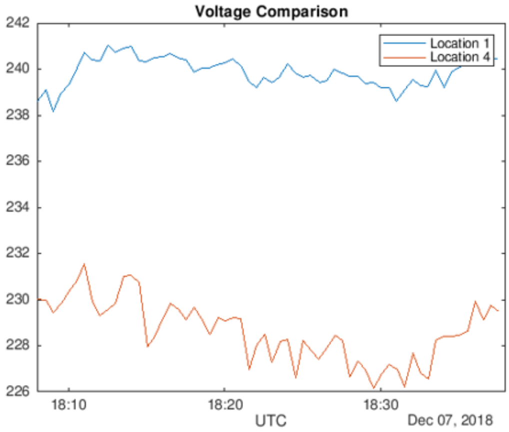

Fig. 5. PMU Voltage comparison node 1 vs 4.

However, the most important parameter to compare is the dephase between nodes. According to the observation the different of phase this parameter keeps quite invariant and constant along the time between two nodes as shown in figure 6.

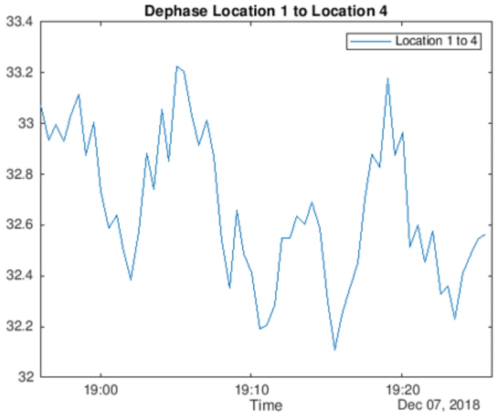

Fig. 6. PMU Dephase comparison node 1 vs 4.

A constant dephase was observed between location 1 vs 4 of about 32.6º, in steady state. During larger period of tests, the observations presented some minor deviations respect the central value, however, these variations must be associated to the low voltage grid as the deviation disappears when same node is observed with two different PMU prototypes. Further investigation could give more information about this phenomenon.

Similar constant dephase were measured in other locations obviously, different dephase values were measured, but in general, the behavior was the same. This does mean that the dephase seems to be quite constant between nodes, as long as network is in steady status.

After this first results, some additional tests were done adding new nodes to the experiment. The following table include the list of nodes for this new experiment: location1: Montequinto (Seville), location 2: Estadio (Cadiz), location 3: Laguna (Cadiz).

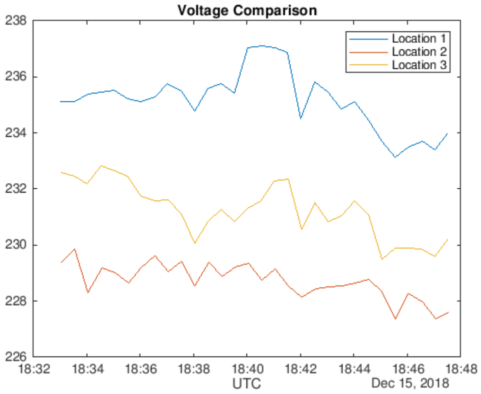

Fig. 7. PMU Voltage comparison nodes 1, 2 and 3.

The three phasors were compared offering the results shown in figure 7. Although different, the waveforms seem to follow some similar aspects.

In the figure 8 the three frequencies have been compared. With minimal differences, the frequency is measured well at all three nodes, and the comparison shows the correct measurement of all three devices.

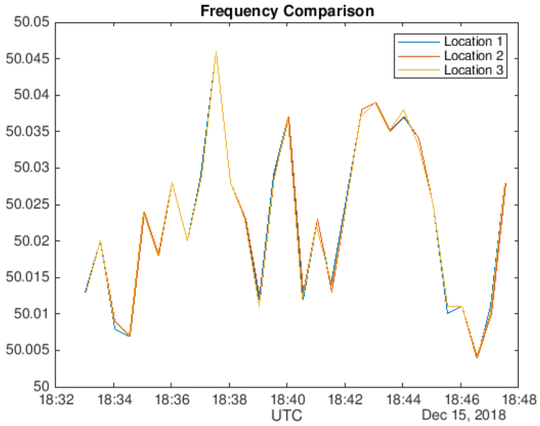

Fig. 8. PMU Frequency comparison nodes 1, 2 and 3.

Finally, in the following figure the phases of the three locations are compared. It is clearly observed that the phase in each node shows a similar waveform shape, so if the first phase differential is calculated, it is detected that the phase differential remains constant when the grid is in a stable state as shown in figure 9.

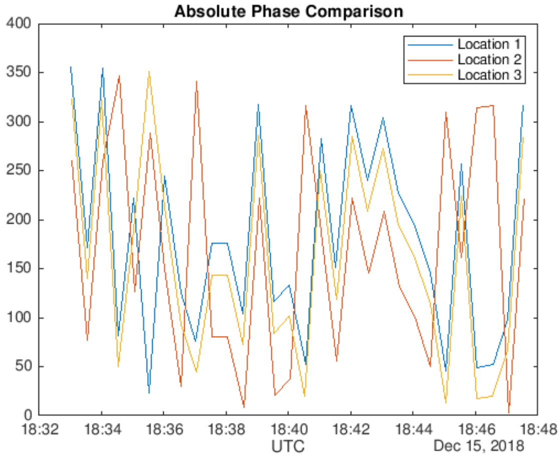

Fig. 9. PMU Phase comparison nodes 1, 2 and 3.

As a conclusion, the dephase between location 1 and 2 (Montequinto – Estadio) shows a value of 95.2º and remains stable, as shown in figure 10. In a similar way, it is observed the difference between locations 1 and 3 (Montequinto – Laguna) where a dephase of about 32º was observe as shown in figure 10.

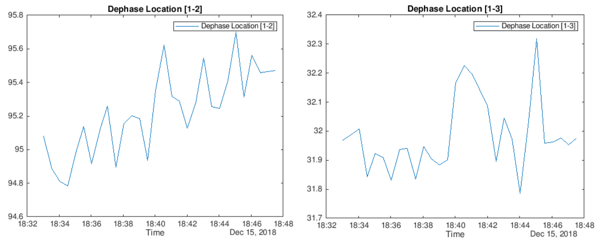

Fig. 10. PMU Dephase comparison nodes 1 vs 2 and 1 vs 4.

IOT PLATFORM

The proposed platform to connect, collect, analyses and take actions is EcoStruxure^{TM} Grid [11], which is Schneider Electric’s IoT-enabled, plug-and-play, open, interoperable architecture showed in figure 11. The concept includes from Connected Products to Edge Control, and Apps, Analytics and Services which enables the PMU data collections from the PMU devices using MQTT communication protocol, store the data, analyze and exploit the information and the needed end to end cybersecurity.

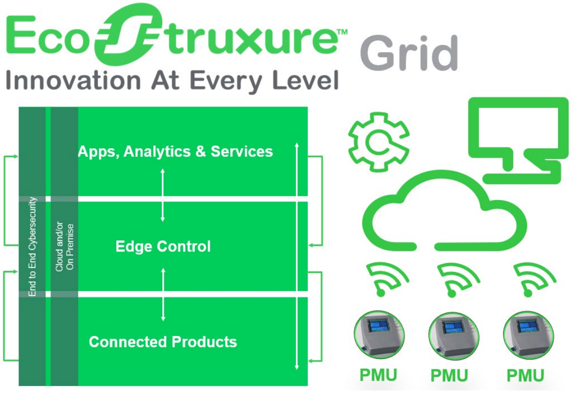

Fig. 11. EcoStruxure^{TM}.

CONCLUSIONS & FUTURE WORK

This paper describes the design of PMU’s prototype, connected to the IoT platform, the deployment and the promising results of test campaign based on the deployment of PMU prototypes in the distribution network connected to IoT. The results show a measurement accuracy (phase, magnitude, angle and frequency) perfectly comparable with PMU devices already deployed in the transport network, with the advantage that the implementation can be exported to any general-purpose hardware or to an existing device. This fact allows to have price expectations lower than those of the current market for this type of devices, which would allow a massive deployment in the distribution network to improve its observability.

The IoT platform and MQTT protocol have showed a reliable means of communication however, some limitation has been found regarding the reporting rate. Nevertheless, none deviation has been observed regarding faults in the communication network.

Finally, it is expected that in the future, the way that the PMU will operate in the distribution networks will be completely different from that currently used in the transmission networks. Therefore, applications will focus more on the steady state monitoring via state estimation and fault detection. Thus, it seems reasonable to reduce the reporting rate to 1-10 frames per second and increase the number of reporting nodes [12].

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