Development and Experimentation of Traceable Characterization Methods for Medium Voltage Instrument Transformers for PQ and PMU Applications.

Letizia Palma Sara

The International Electrotechnical Vocabulary defines Power Quality (PQ) as "the characteristics of the electric current, voltage and frequency at a given point in an electric power system, evaluated against a set of reference technical parameters". Therefore, a PQ disturbance can be identified as a change in the electric current, voltage, or frequency that interferes with the regular operation of electrical equipment and may result in failure or disoperation of customer equipment.

The term "Power Quality" appeared in a scientific paper for the first time in 1968. In 1990, a study conducted by The Electric Power Research Institute evidenced that poor PQ costs the U.S. 26 billion annually.

PQ measurement is traditionally performed at the Low Voltage (LV) level; however, in modern power systems, it is also gaining importance at Medium Voltage (MV). The interest in the PQ measurement at levels different from the low ones is due to the advance in the technology of switching devices and power converters that are now designed also to be directly connected to MV grids. Power converters are widely employed in distributed generation systems based on renewable energy sources and in non-linear loads. To reduce CO2 emissions and global warming problems, the generation of energy from renewable sources is increasing more and more, and with it also the number of power converters installed in MV grids. These devices significantly contribute to injecting PQ disturbances, making PQ a critical task in MV systems.

The monitoring of PQ at MV requires using Instrument Transformers (ITs) to scale MV voltage and current to suitable signals that can be fed to the input stage of PQ analyzers. Thus, assessing PQ disturbances at the MV level strongly depends on the performance of the ITs that belong to the measurement chain. For practical and economic reasons, this task is often entrusted to inductive ITs already installed in MV substations for metering and protection applications. However, currently, there are no specific standards dealing with ITs employed for PQ measurements. This issue has been partially addressed in the scientific literature, and it has been highlighted that inductive ITs suffer from both filtering behaviour due to their dynamics and nonlinear effects produced by the iron core. As a result, conventional calibration with a sinusoidal input and frequency response measurement are not appropriate for assessing their error contribution in the measurement of distorted signals.

The increasing number of non-linear loads and decentralized renewable generation systems have also significantly increased the power grids' complexity and instability, making substations operate under demanding conditions. Therefore, digital substations are spreading more and more to ensure stability and safety under these new complex conditions. A digital substation is an electrical substation where operations are managed between distributed intelligent electronic devices interconnected and synchronized with each other. For this reason, the first generation of analogue sensors used in power grid substations are going to be replaced with newer digital output sensors. However, a trade-off solution is currently taking place, and it consists of coupling conventional ITs with stand-alone merging units which are deviceplementing the digitalization and time synchronization.

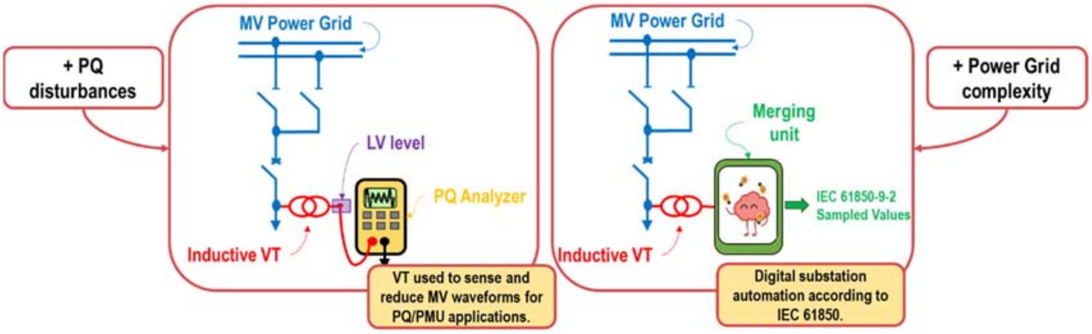

Figure 1: Graphical representation of research context and motivation.

In this scenario, from the metrological standpoint, new measurement systems and procedures must be investigated and developed for the traceable characterization of both analog and digital ITs under distorted conditions representative of the actual ones. These characterization tests require quite complex and expensive generation and measurement systems. For this reason, it is also necessary to study and develop simplified but accurate test procedures that can be easily implemented using instrumentations already available in IT industrial laboratories.

This thesis presents the design, development and characterization of a measurement setup for the calibration of MV VTs in presence of PQ phenomenon and combinations of PQ phenomena. Starting from a deep analysis of state of the art, the thesis describes possible procedures, test waveforms and performance indices to quantify the error contribution of VTs used upstream of a PQ instrument.

The measurement setup is shown in Figure 2 and it is engineered to be modular and flexible. It can be used to characterize different types of voltage sensors, including those with digital output (IEC 61850-9-2 compliant).

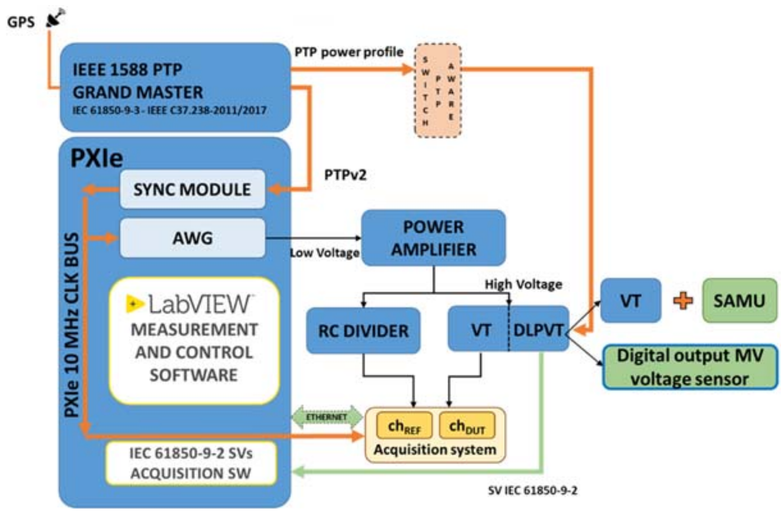

Figure 2: Block scheme of the reference system for MV VT and LPVT calibration.

As regard the measurement of the VT ratio error, the system allows characterization with relative expanded uncertainty (level of confidence 95%) equal to 70 µV/V at power frequency and 185 µV/V from 100 Hz to 9 kHz and from 5 kV to 20 kV. In the same frequency range, the relative expanded uncertainties associated with the phase error are 70 µrad and 320 µrad.

An extensive set of test waveforms has been implemented for testing voltage sensors in presence of several PQ events and combinations of phenomena. In particular, it can be used for the generation of phenomena synthesized by the users or recorded data from measurement campaigns.

As first applications, commercial inductive VTs, LPVTs and inductive VT coupled with commercial SAMU have been characterized under harmonics, amplitude and phase modulations, frequency ramps, voltage dips and a combination of harmonics and subharmonics.

From these characterization tests, one of the most significant result is related to the harmonics measurement in presence of subharmonics (see Figure 3). It has been found that the presence of subharmonics leads the inductive VT harmonics ratio and phase errors to increase up to 20 % and 30mrad, respectively.

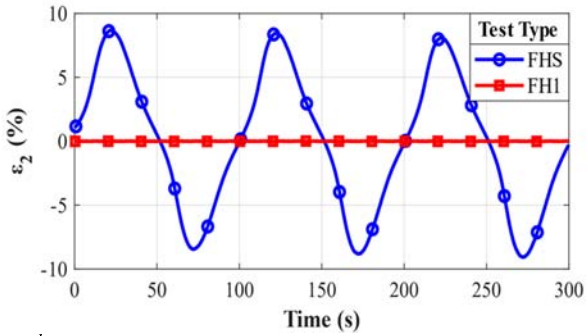

Figure 3: Ratio errors at 2nd harmonic with (circle marked) and without (square marker) subharmonic component at 0.01 Hz and 0.1 %

The thesis presents two different validated simplified techniques (E-SINDICOMP and SINDICOMP-LV) that can be performed in common industrial laboratories for assessing the frequency accuracy of inductive VTs. The E-SINDICOMP technique provides a method for the only approximation of VT ratio error response whereas SINDICOMP-LV allows to build the VT frequency response in terms of both amplitude and phase.

The two simplified procedures for the measurement of the frequency response of the VTs at MV have been applied for the frequency characterization of different VTs and validated by comparison with results obtained at MV by the INRIM reference set up (Figure 2). Both the simplified procedures allow reaching an accuracy improvement with respect to the use of a conventional LV SFS technique up to one order of magnitude for the ratio error.

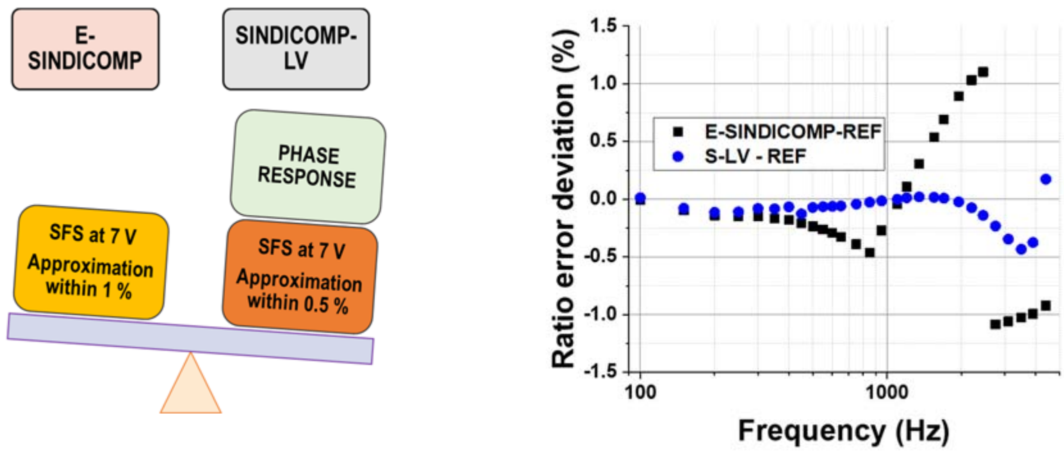

Figure 4: Simplified Techniques for inductive VT frequency characterization: overview and comparison