REDUNDANCY AND SYNCHRONIZATION IMPROVEMENT FOR PREVAILING PHASE ANGLE ESTIMATION AND FLICKER SOURCE LOCATION

Sergio SANTOS
ZIV Automation – Spain
sergio.santos@zivautomation.com

Maja PIKULA
ZIV Automation – Spain
maja.pikula@zivautomation.com

Asier LLANO
ZIV Automation – Spain
asier.llano@zivautomation.com

Aitor AMEZUA
ZIV Automation – Spain
aitor.amezua@zivautomation.com

ABSTRACT

The deployment of renewable energy sources increases fluctuating power infeed of harmonics, flicker and unbalance caused by inverters and non-linear loads. The complexity of the power structure requires the measurement of voltage and current not only from the classical point of connection between customer and supplier. Time-varying harmonics require statistical post processing and depends on the observation of different voltage and currents. This paper proposes a model that provides redundancy of the measurement aggregated harmonic phasors not only at the Point of Common Connection, but in all the distribution feeders, with joint synchronous devices. This can be get with no additional expenditures than the required for the regular Low Voltage (LV) distribution monitoring.

INTRODUCTION

In the past years different methods have been developed to quantify and evaluate the summation of harmonic currents based on grid measurements. Investigations on power direction methods and their validity has shown that there is no substantial certainty of the results. Recent studies claim that the assessment of prevailing phase angle as the best suitable methodology to identify the prevailing direction of the total harmonic current of LV networks. [1]. The main use of this measurement infrastructure is to resolve the disputes over responsibility for harmonic distortion. The effects of this redundancy, based on the Power Quality State Estimation (PQSE), will reinforce the conclusions of the emission assessment and will provide information on the calibration errors and the impedance model of each feeder.

This document is divided into two parts, the first section provides an overview of the limitations of existing methods for the assessment and estimation of power harmonics, flicker, and unbalance, as well as their synchronization and accuracy requirements. The basis of this study can be found in papers [1], [2] and [3].

The prevailing harmonic phasor is composed by a prevailing magnitude and a prevailing phase angle.
This prevailing phase angle represents the central tendency of the harmonic resulting from the phasor sum of the harmonic phasors in the aggregation interval.
The prevailing phase angle can be reported only if the harmonic phase angles have a low variation in a given time interval without any wide variation in the complex plane.

The second section discusses the technical capabilities of the low Voltage feeder supervision in order to provide the required synchronization and the benefits of the redundancy in the measurement between the different LV distribution feeders. For the current transducers, the phase shift response through the bandwidth of analysis must be compensated. This paper provides a study for the digital compensation of this effect when using current transformers for continuous measurement.

TECHNICAL LIMITATIONS

The results of the investigations that have been carried out indicate a way to improve the instrumentation.
There are several difficulties to address:

1. Voltage harmonics measurement inaccuracy
2. Current harmonics measurement inaccuracy
3. Synchronism deviation of the different measurements
4. Misalignment of the aggregation interval
5. Limited number of measurement channels

In the case of voltage measurement, the most used transducers are resistive voltage dividers that have a high linearity for the entire depth of scale and depth in frequency. Current measurement sensors present a specific impulse response problem, which will be addressed in a dedicated section, additionally, the electronics, amplifiers and analog to digital converters (ADCs) provide a specific bandwidth.

The characteristics of the analog to digital conversion and the necessary filtering in the signal conditioning stages must be compensated by the test characteristics described in IEC 61000-4-30 standard, now reinforced by the test group described in IEC 62586-2, which is designed to minimize the differences between instruments.

The impact of synchronism

When applying the method of the prevailing phase angle, the higher the harmonic index, the greater the effect of the differences in synchronism. It affects the diversity index calculation. In the detailed study [4], it is considered that for a sync difference of 1 second per day, which is required by the norm 61000-4-30 it would be unacceptable for harmonics from order 17. From these levels, GPS synchronization is recommended. However, considering the recommendations of group C4.24 of CIRED [12], which details the appearance of supraharmonics as one of the relevant magnitudes to follow, it should be considered that high harmonics will not be able to be followed with adequate tracking if no accurate synchronism is achieved.

Impact of CT bandpass

Typically, the current measurement is made using current transformers or Rogowski coils. For both cases, the pass band has an unaligned behavior, which can also vary significantly between models and between units. For high currents, the use of shunt resistors, that could provide a more linear bandpass, cause power consumption and undesired heat problems.

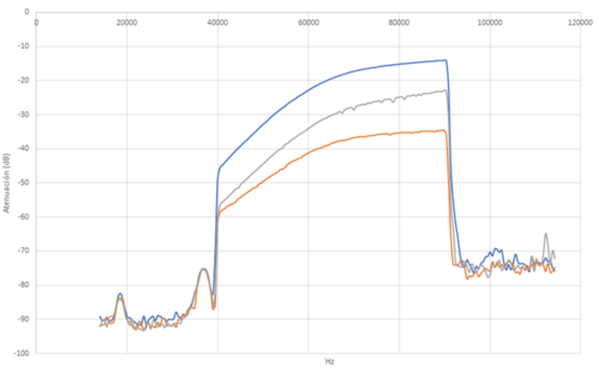

Fig.1. Study of Frequency response for different Current Transformers in the range of 40 to 90 kHz (supraharmonics)

SOLUTION DESCRIPTION

The LV supervision solution with LV controller and the supervision feeder units, supervise all the low voltage parameters in the distribution secondary substation. It is a system intended for measuring the main parameters (V, I, P, Q) on each of feeders of MV/LV substation.
The LV controller is a master device responsible for collecting, storing in the database and sending to a Head End System the needed information from LV supervision feeder units slaves. The LV controller is connected to LV feeder supervisor devices by 115200 bps RS485 bus, using HDLC as protocol and DLMS/COSEM protocol in application level.
The LV feeder supervisor provides information on instantaneous measurements per phase and registers load profiles, on each feeder. The registers load profiles allow to know all information about energy registration, average and maximum values for feeder.
Besides the measurement function, the system provides general alarms for feeder, being able to detect blown fuse, over-current and overload. Consequently, the constant LV feeder monitoring allows to detect power outages and power disturbances that may cause an impact on customers.

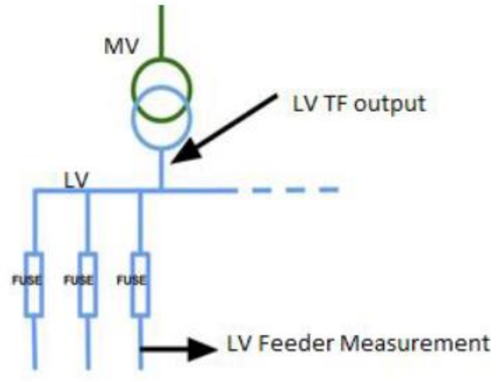

Fig.2. Detailed schematic of LV Distribution measurement location

The LV controller and feeder measurement devices provide valuable information such as Power Quality measurement according to IEC 62586-2, earth fault detection and feeder overcurrent detection algorithm which gives an updated LV network topology back to the network operator.

It is necessary to emphasize that this system enables access to all LV supervision feeder units installed in secondary substation and acquire voltage and current measurements synchronously. Harmonics, Power Unbalance, flicker, and frequency drift, can be measured and timestamped within a shared time base.

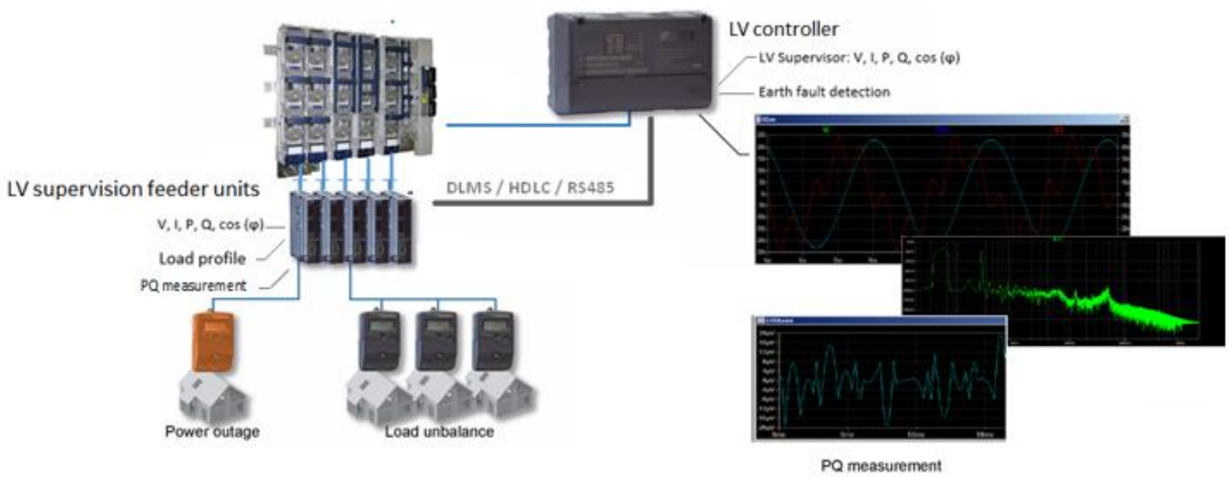

Fig.3 Overview of a LV supervision solution with supervision feeder units

Proposed synchronism solution

The time shift between the internal clocks of the instruments can be set below 1s without the use of a GPS. A simple serial connection can get this synchronization. Furthermore, an adequate character oriented protocol and microcontroller can identify the exact beginning and termination of a single cycle to get time-critical synchronized phasor measurement with enough accuracy.

In addition to this, a Digital Tanlock phased locked loop [13] algorithm ensures that the sampling is adjusted to the fundamental frequency by means of a highly noise-immune system, which eliminates the effects of the internal clock calibration differences of each device.

The proposed solution uses a synchronous phasor measurement on the current on every feeder to ensure the determination of the direction of the emissions at a given point. A single PQ event, (harmonic distortion, flicker, etc.) measured with redundancy over the voltage, and with the instant evaluation of the effects on the current on every distribution feeder, is tracked and stored with an adaptatively time interval. From a global point of view, the system results in a single instrument with a triggered sample rate for every signal for all the low voltage distribution network.

For the measurement of networks where there is a wired communication system, the level of synchronism that can be achieved, however, can be sufficiently close to that of the GPS, considering that what is relevant is not the accuracy in absolute time, rather, the difference in relative time of all the instruments involved is the minimum.

Proposed CT phase compensation solution

Current measurements are acquired by current transformers with a band and phase response modelized for all the bandwidth of measurement for the range of 2.5 kHz for the study of harmonics, and up to 100 kHz for the study of supraharmonics. In the case of low order harmonics, the model corrects the phase error of the transformer. The filter corresponds from 40Hz to 2500Hz with a precision better than 0.1% to the ideal filter for a transformer whose phase error is *arctan(K/ω)*. A genetic algorithm provides the IIR filter coefficients that corrects the signal based on the theoretical response of transformers and the information of phase delay for 50 Hz obtained during the system calibration process. This compensation is not used for very low frequency phenomena such as flicker direction estimation.

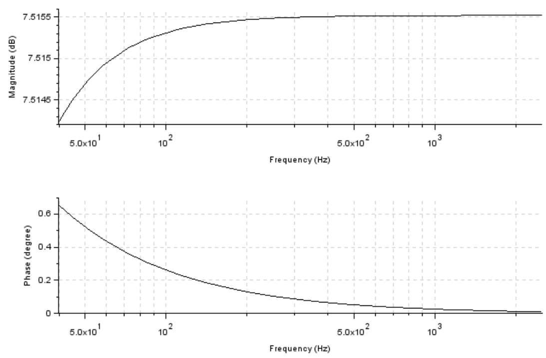

Fig 4. Phase compensation model result for 0.5 degree in 50Hz

Proposed configurable integration period

With every sensor with instant communication in a master slave network, it could be possible to adapt all the measurement points with the same aggregation. This setting could be adjusted dynamically based on the aggregated information, and could be communicated almost instantly to every meter. The aggregation algorithm would track and follow the best period, considering the order of the harmonics and their non-stationary behavior. There is a lack of definition on methods to aggregate the harmonic phase angles in frequency and in time.

FURTHER RESEARCH

The proposed solution provides several means of improvement for the observation and assessment of harmonic emissions in Distribution Networks, both for high and low frequencies. This multipoint study of a single point of distribution feeders provides an accessible approach, that comes to fill the lack of information of simple single-point systems, or the methods described on the CIGRE/CIRED C4.109 approach. Due to the limited number of analog measurement inputs in PQ meters, some of the inputs were used to simultaneously measure the same phase in different feeders rather than all the three phases of the same feeder. If penalties or rewards are to be considered, the aggregated data can be reduced by choosing the right discrimination of the calculation method and the window of integration. For flicker source, direction and propagation, as has been studied in [6] and [7], redundant measurement with equal and synchronized to a fraction of second, could be also very useful.

CONCLUSION

Low voltage monitoring is gaining momentum across all DSOs. Even those that have not deployed a MV automation system yet are planning to roll out LV monitoring systems. No need to say that LV SCADA or analogue OT systems must be implemented and adopted to be able to get out the most from these deployments. Some regulators are also considering the possibility to require PQ measurements in LV switchboards, using certified measurement devices to provide a means to solve legal disputes regarding the quality of the supply and its consequences in customers' premises and processes.
Providing tools to determine the source of disturbances, based on certified and independent measurements, will help in clarifying the responsibilities of each party in case of disturbances affecting the consumers either economically or wellness.
The implementation of the what is proposed in this paper in equipment ready to be installed in secondary substations, on the LV side of the distribution transformers is the next step towards a commercial solution for PQ measurement as a tool to assist decision makers rather than a plain measurement as data recording device. Experimentation in real environments is also required in order to develop a robust solution from both hardware and firmware points of view.

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