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A POWER QUALITY INSTRUMENT FOR HARMONICS INTERHARMONICS AND AMPLITUDE DISTURBANCES MEASUREMENTS

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Abstract − In the last years the increased interest about power quality, forced international working groups to define new standards for testing and measurement techniques. In this paper a pc-based power quality instrument is proposed, according to IEC 61000-4-7 and standard IEC 61000-4-30. It is a low-cost and easily reconfigurable instrument able to measure harmonics, interharmonics and amplitude disturbances and supply unbalance. The complete instrumentation has been tested using standard test procedures in order to verify its accuracy limits.

Keywords: IEC 61000-4-30, power quality measurements.

1. INTRODUCTION

In recent years the liberalization of energy markets and the perspective of specific contracts between customers and users, in which the energy price can depend on power quality, require measurement instruments able to monitor current and voltage characteristics and easily re-configurable in order to be accorded to the evolution of standards.

Moreover current and voltage distortion due to semiconductor devises and the improvement of the disturbances limits in power systems require accurate procedures to obtain satisfactory power network monitoring.

Actually, the only in force international complete standard about power quality measurement methods is the [1], published on February 2003. For the measurement of some specific power quality parameters (i.e. flicker, harmonics, interharmonics) [1] refers to other in standard in order to completely define the measurement methods and the interpretation of analysis results for all power quality parameters.

The aim of these documents is to describe measurement procedure, used in order to obtain reliable, repeatable and comparable results in any measurement environment.

In order to assure reliability, repeatability and comparability of obtained measurement results in harmonic and interharmonic content analysis, the standard [2] fixes hard limit for the synchronization system, in order to limit leakage error produced by sampling conditions. A common problem is that a lot of synchronization techniques are not able to respect the accuracy limits stated by [2] in particular pollution conditions of under test power system.

The main problems in projecting a complete power quality monitoring system are to assure accuracy limits given by standards also in presence of high pollution level on tested power system, to perform online monitoring and to allow an easily re-configuration.

Instruments actually available on market are able to perform some power quality parameters and are usually quite expensive. Often, they are not reconfigurable by the user (according to standards development or specific needs) and test procedures used to perform instruments accuracy are often not reported on manufacturer specification. This can causes wrong definition of instrument performances characteristics and accuracy evaluation especially when several contemporary influence quantities occur. Moreover, they often calculate power quality parameters not referring to the in force standards.

Starting from these considerations in this paper a new PC-based instrument is presented able to develop a complete power quality analysis of polyphase systems in real time, according to [1] and [2].

From the control panel of the developed instrument, user can easily define by himself different detection thresholds, measurement procedures and event buffering conditions according to specific requirements (i.e. standards evolution, customer/supplier agreement, specific sensibility to some power quality parameter); in addiction, the developed pc-based instrument is easily to up date in order to be accorded to the standards evolution.

In the first section instrument fundamentals are described while in the second section accuracy tests and specifications are presented.

2. POWER QUALITY MONITORING INSTRUMENT

The developed instrument characteristics deal with the standards IEC 61000-4-30 and IEC 61000-4-7 for harmonic and interharmonic measurements.

In particular, the instrument is able to detect:

- Power frequency;
- Supply voltage amplitude;
- Supply voltage dips and swells;
- Voltage interruptions;
- Harmonic and interharmonic voltages;
- Supply unbalance;

· Mains signalling on supply voltage.

In the following, a complete description of the different instrument blocks is reported, according to the block diagram reported in Fig.1. The instrument consists of two sections:

- the synchronizing systems to define the sampling frequency;
- the measurement section.

2.1. Synchronizer

The IEC 61000-4-30 refers to [2] for harmonic and interharmonic measurement for power quality measurement and limitedly to the class A instrument (high accuracy ones).

The main problem in analysing these kinds of real signal is that their spectral content depends both on supply condition and on load status; this means that the signals are usually non-stationary also in the observation window (the sampled window of signal in the time domain).

This particular signal condition cause spectral errors in the digital analysis performed by means of time to frequency transformation algorithms [4, 5].

The main error is the leakage one, that produces in the resulting spectrum the spreading of a single spectral component energy into different adjacent frequency bins.

In order to assure reliability, repeatability and comparability of obtained measurement results also when non stationary components are present in the analysed signal, the standard [2] suggest the transformation algorithm to be used (Discrete Fourier Transform), fixes hard limit for the synchronization system (in order to limit leakage error produced by sampling conditions) and introduce the concept of grouping (the rms of different closed spectral lines is evaluated in order to limit leakage error influence on the measurement results).

About the second requirement (synchronization), a common problem is that a lot of PLL or several kinds of different synchronizing systems (zero crossing, FFT analysis, interpolated frequency analysis) are not able to respect accuracy limits stated by [2] in particular distortion conditions of sampled signal.

In [3] Authors presented a synchronizing system able to respect standard limits. In the same paper, it has been shown that the developed system, based on Chirp Z-Transform, is able to assure its accuracy also in presence of high distortion level in sampled signal due to interharmonics near to the fundamental component (usual pollution condition in power systems). This synchronizer has been implemented in the developed power quality monitoring system.

It applies the CZT analysis to the sampled observation window (10/12 cycles sliding buffer), calculates the frequency of the fundamental component and the corresponding sampling frequency. This value is used to control in real time the sampling board to sample the successive observation window.

Moreover, the synchronizing system automatically checks the respect of the accuracy limit fixed by [2] in order to select the windowing function to be applied to the observation window before harmonic and interharmonic measurement.

In order to allow an optimisation of evaluation time and the easy reconfiguration, different measurement blocks have been arranged as follows:

- Power frequency;
- Supply voltage dips, swells and interruptions;
- Supply voltage amplitude;
- Supply unbalance;
- Harmonic and interharmonic voltages;
- Mains signalling on supply voltage

Moreover all measurement blocks are interconnected in order to avoid counting a single event more than once in different parameters, as expressly prescribed by [1].

The basic measurement interval for each parameter magnitude is 10/12 cycles of the signal fundamental component, evaluated by means of synchronizing system. Usually, supply voltage characteristics vary during monitoring, and, consequently, all power quality parameters oscillate.

In order to assure a time-smoothed survey of these parameters, instrument provides, according to [1], a post processing applied to the all measured parameters, evaluated over 10/12 cycles interval.

Three different aggregation time interval are defined:

- fifteen 10/12-cycles intervals respectively for 50/60Hz systems;
- 10min interval (referred to an absolute time clock);
- 2h interval (referred to an absolute time clock).

The aggregation is performed by calculating the square root of the mean of the squared values of different parameters. The instrument absolute time clock is synchronized every 10 min with an external reference value.

2.2. Power frequency

Power frequency is evaluated by the instrument each 10s. Each measurement interval begins on the absolute 10s time clock, calculated with accuracy better than ±10ms.

Of course, measurement is produced on a reference power system phase. The integral cycles are counted by means of a zero crossing detector. If no dip, swell or interruption occur during the 10s interval, the obtained power frequency is used as reference value for the calculation of the $U_{rms(1/2)}$. The same value has been used to evaluate power frequency disturbances, comparing the obtained result with the nominal value f_n. According to [6], two different thresholds are considered: ±1% of f_n and +4%/-6% of f_n.

Power frequency events are recorded (duration, percent difference by nominal value) and classified according to different thresholds.

2.3. Dips, swells and interruptions

As basic measurement for the amplitude disturbances has been used the $U_{rms(1/2)}$, evaluated on each measurement channel. This parameter corresponds to the r.m.s. voltage measured over 1 cycle (commencing at a fundamental zero crossing) and refreshed each half-cycle.

The synchronizer sets the appropriate sampling frequency in order to acquire signal points. According to the evaluated power frequency (mean value evaluated over 10s by means of zero crossings) measurement block calculates half-cycles duration (i.e. number of sampled points) and evaluates the $U_{rms(1/2)}$s.

Each evaluated $U_{rms(1/2)}$ is compared with the thresholds set by the user (i.e. the default values are that ones reported in [6]) in order to detect dips, swells or interruptions.

It is possible to set different thresholds as percentage of the nominal supply voltage value.

Dip starts when the $U_{rms(1/2)}$ voltage of one or more channels is below the threshold and ends when it is equal or above the threshold plus the hysteresis voltage (a value that has been introduced in order to avoid counting multiple events when the magnitude of the parameter oscillates about the threshold level).

Similarly, swells starts when the $U_{rms(1/2)}$ voltage of one or more channels is above the threshold and ends when it is equal or below the threshold minus hysteresis voltage.

In [6], swells are not considered, for these reason, Authors have set a default threshold value equal to 10% of the nominal value.

IEV 161-08-20 define an interruption as a getting down voltage below the 1% of the nominal value. This value, reported also in [6], has been chosen as default threshold level. Anyhow, considering that power system black out usually occurs for a higher voltage level and that transducers accuracy difficultly allows correct measurement around a 1% level of nominal voltage, user can easily sets a different threshold detection limit according to real user sensibility and to measurement transducers accuracy (manufacturer specification or test results).

For each event, instrument records the absolute time clock corresponding to the start, the duration (by using the power frequency value) and the event maximum amplitude.

Interruptions are classified basing on duration (longer or shorter than 3min that corresponds to the usual maximum power system switch re-closing time).

In addition, for dips, swells and interruptions the total duration and the number of monitored events are reported.

Moreover, considering that dips, swells or interruptions influence other power quality parameter measurements (i.e. frequency domain analysis), in order to avoid counting a single event more than once in different parameters, instrument “flags” these other measurement values.

Flagged values are stored and also included in the aggregation process (time smoothing). Also the smoothed values are flagged and stored.

Many power quality parameters can show variations between weekday and weekends. For these reason, a reference assessment period has been considered.

In order to avoid statistical errors in the assessment periods, flagged smoothed values are recorded but not taken into account for the power quality survey.

Depending on user settings, the measurement system can record the voltage signal, when a dip, a swell or an interruption occur, in order to allow off line analysis and validations.

2.4.Magnitude of the supply voltage

Also in this parameter, the basic measurement is the $U_{rms(1/2)}$.

The rms values are evaluated over an absolute time clock interval of 10min resynchronised at every 10min.

The U_{rms} evaluated over 10min is compared to nominal value. Events are separately recorded (starting time, duration and amplitude) referring to two different thresholds: U_n ±10% of and U_n +10% / -15% [6].

The user can easily set alternative thresholds, according to customer/supplier agreement or other particular requirements.

Disturbances evaluation is performed over each supply power system phase.

2.5.Unbalance

Voltage unbalance is intrinsically a polyphase characteristic. A voltage unbalance occurs when the rms values of the phase voltages or the angles between them are not equal.

This parameter is evaluated by means of symmetrical components. Both negative and zero sequence components are evaluated and taken into account to detect power quality level.

Symmetrical components are evaluated over low pass filtered 10/12 cycles signal intervals. The obtained results are smoothed over 10min.

Negative sequence component is compared to the limit fixed by [6] (0 / 2% of the positive phase sequence component). No limit is given about zero sequence component, considering that this parameter usually does not produce main interferences of appliance connected to the power system. Anyhow, its value is reported in the visualization instrument panel.

2.6.Harmonics and interharmonics [7]

According to the definitions given by [1], harmonic and interharmonic content can be evaluated by means of the procedure defined in [2].

Synchronization system checks the sampling process in order to establish in which cases, procedure accuracy is not respected. In these cases, algorithm has to apply windowing (by means of Hanning function), in order to reduce leakage error, before proceeding Fast Fourier Transform (FFT) analysis.

Strictly speaking, harmonic measurements can be performed only on a stationary signal, considered that fluctuating signals (signals varying with time) cannot be described correctly by their harmonics only. However, also if power signals (current or voltage) can be never considered as stationary, it is often useful obtaining their distortion analysis. For this reason, and in order to obtain results that are intercomparable, a simplified approach has been applied.

The output c components of the FFT are grouped according to the specifications reported in [2] to evaluate harmonic and interharmonic subgroup.

The distortion evaluation is performed over 10/12 signal cycles.

The FFT lines are grouped evaluating the rms value: all spectral lines resulting from FFT analysis are considered, separately grouped to evaluate signal harmonic and interharmonic content.

The effects of fluctuations of harmonic components, that cause 'sidebands' close to the harmonics, are partially reduced by excluding from interharmonic groups the bins immediately adjacent to the harmonic frequencies.

The interharmonic components i = 1 and 9 (50 Hz systems) or 11 (60 Hz systems) directly adjacent to a harmonic are grouped to form a harmonic subgroup according to (1), whereas the remaining interharmonic components (i = 2 to 8 or 10) form the centred interharmonic subgroup according to (2,3).

Fig. 2 gives a clear idea of different bins, grouped to form harmonic and interharmonic subgroups.

Harmonic subgroups for 50 and 60 Hz systems can be expressed as:

$$\boldsymbol{C}^2_{\boldsymbol{n}_{sg}} = \sum_{\boldsymbol{i}=-1}^{+1} \boldsymbol{c}^2_{\boldsymbol{n}\cdot f_0+\frac{\boldsymbol{i}}{\boldsymbol{T}_w}} \quad . \qquad (1)$$

Interharmonic subgroups for 50 Hz systems:

$$C^2_{(n+0.5)_{sg}} = \sum_{i=+2}^{+8} c^2_{n\cdot f_0+\frac{i}{T_w}} \quad , \quad (2)$$

and for 60 Hz ones:

$$C^2_{(n+0.5)_{sg}} = \sum_{i=+2}^{+10} c^2_{n\cdot f_0+\frac{i}{T_w}} \quad . \quad (3)$$

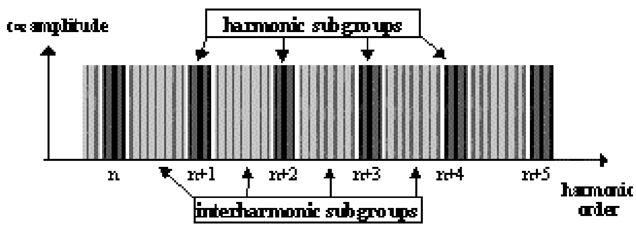

Fig. 2. Illustration of harmonic and interharmonic subgroups (here represented for a 50Hz system).

In order to perform a complete distortion analysis, the developed instrument evaluates total harmonic distortion factors according to [2] and [6].

The following distortion factors are evaluated:

§ Total Harmonic Distortion (THD)

THD is evaluated as the rms value of the harmonics to the rms value of the fundamental; it can be evaluated by using (4) for both 50 and 60 Hz systems.

$$\boldsymbol{THD} = \sqrt{\sum_{\boldsymbol{n}=2}^{40} \left(\frac{\boldsymbol{c}_{\boldsymbol{n}\cdot f_0}}{\boldsymbol{c}_{f_0}} \right)^2} \quad . \quad (4)$$

§ Sub Group Total Harmonic Distortion (THDS)

THDS is evaluated as the THDG but referring to the harmonic subgroups. The implemented formula is reported for 50 and for 60 Hz systems in (5).

$$\boldsymbol{THDS} = \sqrt{\sum_{\boldsymbol{n}=2}^{40} \left(\frac{\boldsymbol{C}_{\boldsymbol{n}_{sg}}}{\boldsymbol{C}_{1_{sg}}} \right)^2} \quad . \quad (5)$$

User can easily monitorate distortion level from visualization panel and set different thresholds detection for each harmonic and interharmonic or for THDs.

Threshold levels given by [6] are considered as default values.

2.7.Mains signalling

This particular parameter is evaluated considering that in some countries, the public distribution systems may be used for the transmission of signals. This can cause mutual influence of neighbouring signalling installations and conducted disturbances problems to the customer.

The implemented method can be used to verify the level of the signal voltage for a known carrier frequency.

Measurement is based over the rms value of the nearest 10/12 cycle rms interharmonic bins.

User can select in the visualization panel the carrier frequency to be verified, the power system phase to be analysed and the length of the observation period.

Default detection threshold are given by [6] depending on carrier frequency.

Anyhow, user can set different arbitrary detection thresholds.

3. INSTRUMENT CHARACTERIZATION: SIMULATION TESTS

The instrument has been developed by means of Labview. With the aim to perform its characterization several tests have been carried out by means of simulated signals with known harmonic, interharmonic, noise and amplitude disturbances. Influence quantities level has been set according to ranges defined by standards recommendations given by [1,2]. In the simulation, A/D conversion errors, considering a 12-bit resolution, have been taken into account.

Tests have shown that instrument is able to respect accuracy limits given by [1,2] for class A performance: in particular the following accuracy have been verified referring to U_{nom} (nominal value):

- power frequency:
  - ±6mHz;
- dips, swells:
  - duration: 1 cycle (half a cycle for the commencement) ;
  - magnitude: ±0,20% U_{nom};
- interruptions (below 1% of U_{nom}):
  - duration: 1 cycle (half a cycle for the commencement);
- magnitude:
  - ±0,20% U_{nom};
- unbalance (zero and negative sequences):
  - ±0,10%;
- harmonics and interharmonics:
  - ±0,12%U_m for $U_m \geq 1\%U_{nom}$
    ±0,019%U_{nom} for $U_m < 1\%U_{nom}$

(under non synchronous sampling conditions:
$\pm 1{,}00\%U_m$ for $U_m \geq 1\%U_{nom}$
$\pm 0{,}028\%U_{nom}$ for $U_{m<}1\%U_{nom}$)

- main signalling:
    - $\pm 0{,}12\%U_m$ for $U_m \geq 1\%U_{nom}$
    $\pm 0{,}019\%U_{nom}$ for $U_m < 1\%U_{nom}$;

4. CONCLUSIONS

In this paper, a new polyphase pc-based and low-cost instrument for power quality evaluation in supply systems is presented. The developed system deals with all in force standards about power quality measurement methods and harmonic and interharmonic analysis.

Default values for threshold detection limits have been set according to voltage characteristics given by [6].

Synchronization has been performed by means of a Chirp Z Transform based synchronizer that deals with standard limits also in presence of interharmonic distortion.

Instrument control and visualization panel allows to give a complete automatic monitoring of supply power quality.

All power quality parameters are evaluated and averaged according to requirements given by [1-2]; moreover, their values are recorded when they overcome respective thresholds. The signal waveform can be buffered, when any event occurs, allowing a post-processing analysis. From the control and visualization panel it is easily possible to set the instrument both for 50 and for 60 Hz systems without any additional variation of its algorithm. Moreover it can be easily controlled and set specific requirements according to customer/supplier agreement or system sensibility.

The instrument has been characterized according to the procedures defined by standards [1,2] to evaluate its accuracy class.

The result is that proposed and developed instrument respect class A accuracy limits and then it can be used, according to [1-2] where precise measurements are necessary, such as for contractual application, verifying compliance with standards, resolving disputes, etc..

The developed software measurement system can be easily implemented on any PC-microprocessor coupled with a low cost data acquisition board. It can be easily re-configured according to standards evolution.

Simulation tests suggest that computation time is lower than observation window (10-12 fundamental cycles) and this allows to obtain a complete on-line distortion survey of power systems and equipments connected thereto with low memory requirement.

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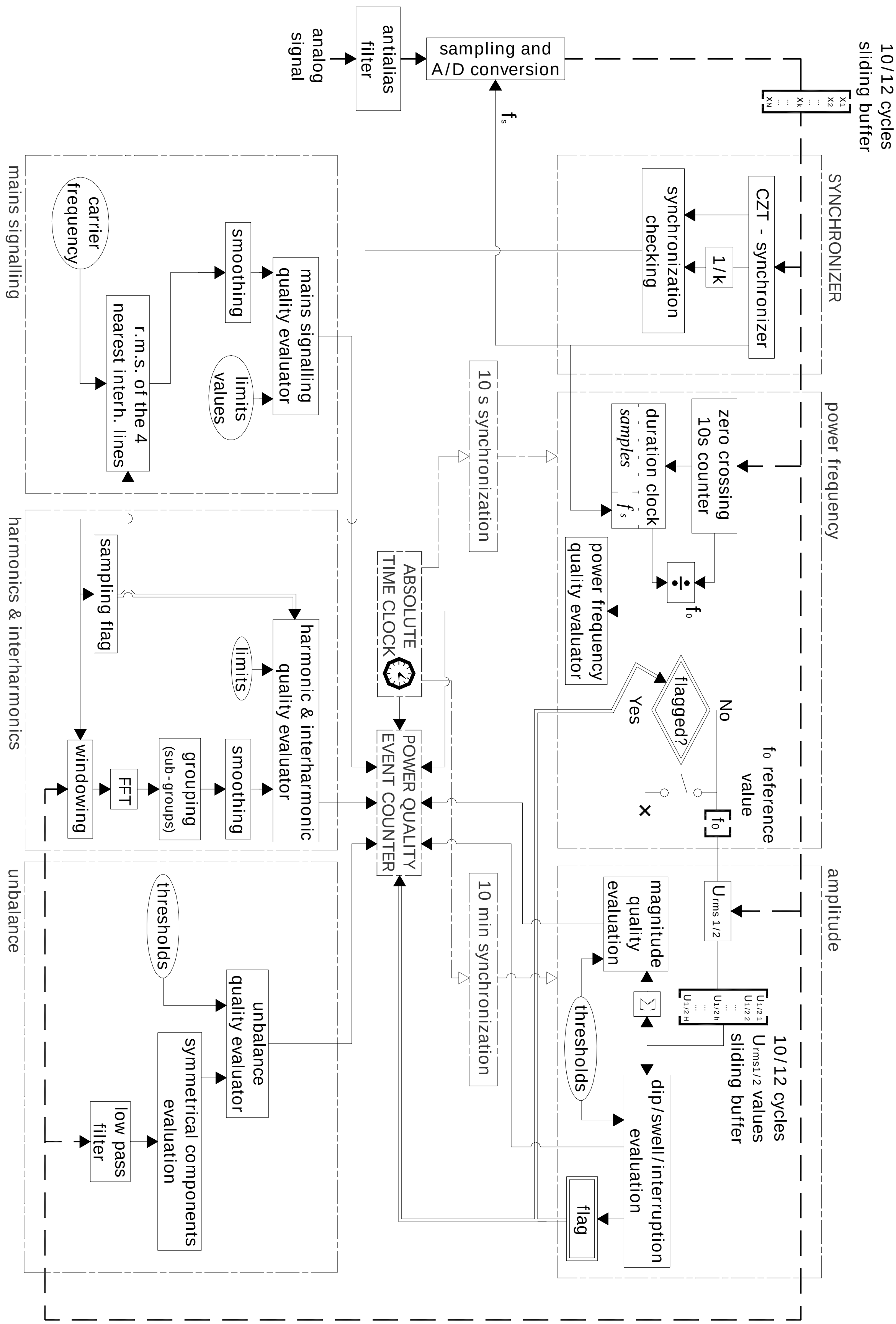

Fig. 1. Instrument block diagram.