IMPLEMENTATION OF A POWER QUALITY MONITORING SYSTEM FOR HARMONICS ASSESSMENT IN ELECTRICAL NETWORKS

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ABSTRACT

In this paper the hardware implementation of a power quality (PQ) monitoring system is presented. The constructed measuring system was installed on a medium voltage network at the Otto-von-Guericke University, Magdeburg, to record low frequency phenomena at the Point-of-Common-Coupling (PCC). The PQ-measuring and recording procedures are based on prescriptions of the EMC norms: EN 61000-4-7 and EN 61000-4-30. Thanks to these recommendations, the measured quantities can be compared with criteria from norm EN 50160, and the appropriate conclusions according to power quality at the monitored PCC can be drawn. Some chosen measurement results will be presented and shortly discussed.

INTRODUCTION

Nowadays the power system is influenced not only by disturbances connected with fundamental frequency (voltage fluctuation) but also by other phenomena like harmonics [1], [3]. The sources of disturbances should be recognized and then compensated or eliminated, which allows for bettering network reliability. In order to achieve this, the electrical quantities must be continuously monitored. This is accomplished with the *PQ*-measurement system.

Usage of such devices is expensive but currently justified because the power system is undergoing transformations due to the new decentralised structure on the one hand, and is becoming more and more non-linear due to the increasing amount of non-linear loads, on the other hand. (The system sensitivity to distortion is growing continuously).

The observed electrical quantities can be compared with the standardized values [2] and the conclusions according to quality of the energy can be drawn.

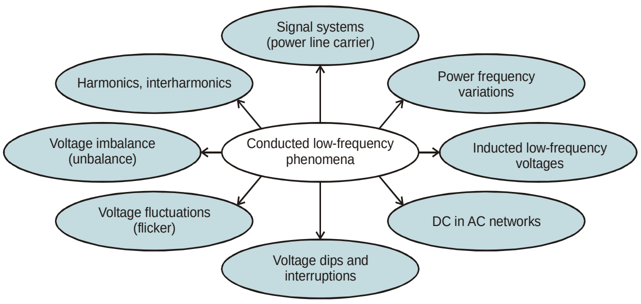

Figure 1. Classification of the low frequency conducted disturbances according to norm EN 61000-2-5 [4].

In Figure 1 the main tasks of the *PQ*- monitoring system are presented. Generally, such systems only allow for recording low frequency conducted disturbances *(LFCD)* like [4], [5]:
-harmonics and inter-harmonics
-voltage imbalances
-voltage fluctuation
-frequency fluctuation
-induced low frequency voltages (coupling effects)
-transmitted signals
-DC components
-voltage dips and fluctuations

In this paper the measurement system for recording the phenomena/electrical quantities listed above is described and some results of the measurements are presented.

PQ-MONITORING SYSTEM

In Figure 2 the layout of the implemented system is presented. Its inputs are three voltages and four currents which come from instrument transformers installed directly at the medium voltage network. The primary instrument transformers applied can transform medium voltages (10 kV network) and strong currents (up to 600 A) into significantly lower voltages and currents, respectively. Generally, these elements provide normalized values (IEC 60044-1 [6], IEC 60044-2 [7]) on their secondary side, so that the inputs conform to norm EN 61000-4-7 [8] as well: for currents the nominal range is 1 A *RMS* and for voltages 100/√3 V *RMS*. The measurement error of these converters for voltage equals 0,2 % and for current is 0,25 %. Naturally, these error conditions appear only at specific working points of the instrument transformers, which are explicitly defined in norms IEC 60044-1 [6] and IEC 60044-2 [7] for current and voltage measurement, respectively. Because of the significant input ranges of these measurement elements, it was not possible to measure their real characteristics (dependent on frequency). Therefore, it was assumed that the errors which appeared did not exceed these given values.

The data acquisition card (Figure 1) used in the measuring system can only record signals up to 5 V, so that to maintain the required signal levels the secondary instrument transformers were used. For this purpose the hall-effect current and voltage instrument transformers are applied which converter the outputs from the primary transformer into low signal levels.

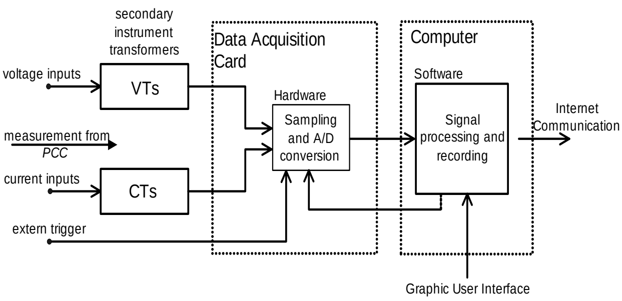

Figure 2. Layout of the power quality monitoring system.

The full measurement error consists of the errors of the primary and secondary instrument transformer and, in some cases, can exceed the recommendation given in EN 61000-4-7 [8]. In order to compensate for this measurement error, which occurred at the secondary transformer, these elements were calibrated with reference to the measurement devices with very low error.

The results of the calibration approach for the current transformer *(CT)* are given in Figure 3. This procedure was performed for a range of 1 A *RMS* value, which is assumed to be nominal. As can be observed the error lies in the range of -0,1 % to -0,2 % for a frequency range up to 2,5 kHz, and shows linear behaviour. Over 2,5 kHz the calibration curve becomes irregular and for 3 kHz exceeds even -0,25 %. From this consideration it can be assumed that in a measurement range up to 2,5 kHz [2] the error curve of the *CT* can be approximated with the help of linear functions that are separately defined for the following frequency ranges: 0 Hz - 250 Hz, 250 Hz - 2 kHz and 2 kHz - 2,5 kHz. Such calibration was performed for each converter separately. The obtained curves were implemented in the *PQ*- monitoring system to improve its measuring accuracy. Small signals (up to 5 V) from secondary instrument transformers are acquired by *A/D* data acquisition cards with 16-bit resolution. These cards have an anti-aliasing filter available that eliminates the error appearing from sampling effects. The filter adjusts the parameters automatically to sampling frequency. Moreover, the applied cards make it possible to acquire the signals simultaneously (without multiplexing), so that no shifting between measured signals appears.

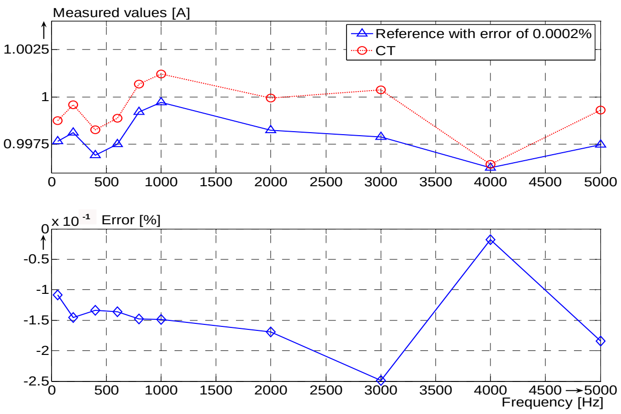

Figure 3. Calibration results of the current converter by 1A range.

For the signal acquisition a constant sampling rate was chosen that equals 10,240 kHz. This provides a certain error for harmonics calculation when system frequency differs from 50 Hz. Due to this fact the measured values are re-sampled in order to minimize the error. Next, the digital signals are processed according to the recommendations of the standards [8], [9]. A special software program was developed with the goal of achieving the above given tasks, namely: error compensating, signal processing and recording.

The implemented system enabled the recording of the significant group of disturbances given in Table 1. The improved algorithm of the *FFT* was used for calculating the harmonics. Due to fact that the calculation window equals ten periods (recommendation of the norm [8]), the frequencies that appeared are recorded with a resolution of about 5 Hz, which depends on the actual system frequency.

phenomenon/quantity	observation time	measuring/ recording interval
harmonics and inter-harmonics	min. 1 day with 3s-recording	10 periods/ 3s, 10min, 2h
over-voltages	min. 1 week with 10min-recording	10 periods/ 10min
under-voltages sustained interruptions	min. 1 week with 10min-recording	10 periods/ 10min
frequency variations	min. 1 week	half of period/ 10s
voltage imbalances	min. 1 week with 10min-recording	10 periods/ 10min, 2h
short interruptions	min. 1 year	$U_{rms(1/2)}$<0.1 p.u/ half of period
sags (dips)	min. 1 year	0.1<$U_{rms(1/2)}$<0.9 p.u/ half of period
swells	min. 1 year	1.1<$U_{rms(1/2)}$<1.8 p.u/ half of period
cos φ/ power factor	-	10 periods/ 3s, 10min, 2h
power active/reactive	-	10 periods/ 3s, 10min, 2h

Table 1. The common recorded phenomena/quantities by the *PQ*-Monitoring system according to the valid standards [8], [9].

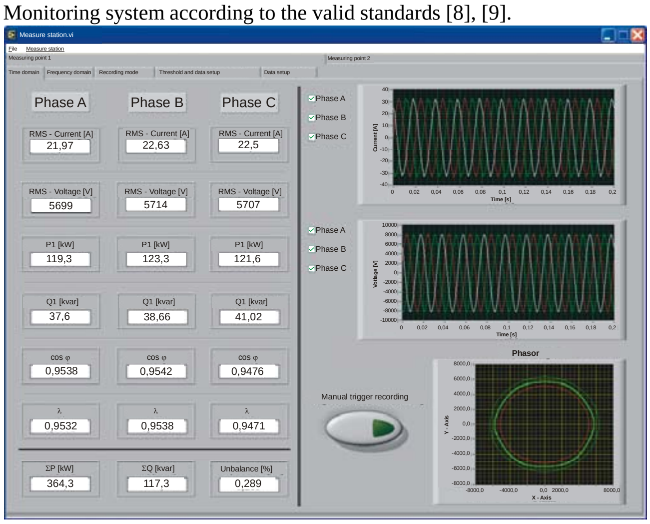

Figure 4. Graphics User Interface of the developed Power Quality Monitoring Systems (Front panel) – important quantities in time domain.

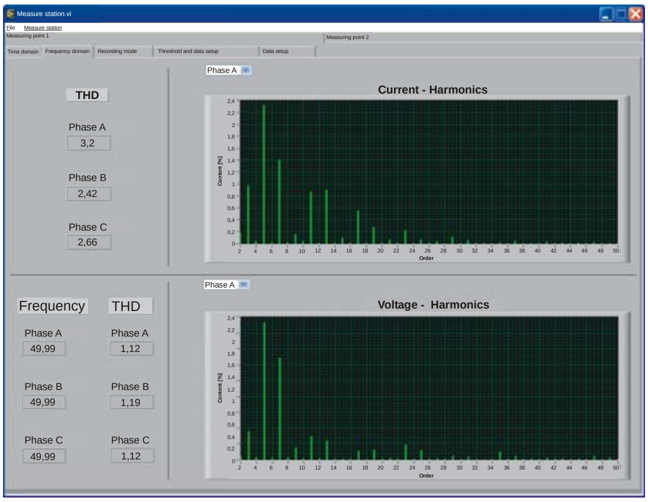

Figure 5. Graphics User Interface of the developed Power Quality Monitoring System (Front panel) – important quantities in frequency domain in percentage values.

In order to simplify the analysis of harmonic and inter-harmonic influence on the system, these frequencies are automatically divided (according to recommendation [8]) into the following groups: harmonic groups, inter-harmonic groups, harmonic subgroups and inter-harmonic subgroups. In Figures 4 and 5 the front panel of the developed software is presented. It gives graphical information about electrical quantities in the network in time domain (Figure 4) and in frequency domain (Figure 5). Moreover, the software allows for changing the recording modes according to the recommendations of the valid norms. It is possible to carry out synchronized measurements (integrated trigger function) that allow for analysis network behaviour at special time points.

Further, to maintain flexibility in data transmission internet communication can be used. This makes it possible to analyze the data without visiting the system.

STATIONARY DISTURBANCE RECORDING

In this section the results obtained from the constructed monitoring system is presented and discussed. In Figure 6, the most important harmonics in the voltage are presented for an entire week in 10 min intervals (see Table 1). These harmonics are the 3rd, 5th, 7th, 11th, and 13th. For other harmonics it was observed that content lies under 0,5 %, which conforms to the norm EN 50160 [2], as well. As proposed in this norm, the 3rd and 7th harmonic should not exceed 5 %, the 5th: 6 %, 11th: 3,5 % and 13th: 3 %. These requirements are fulfilled for each harmonic in the entire observation time. Moreover, the so called *THD* lies under 8 % which corresponds to the EN 50160 guidelines [2]. These results confirm the recommendation according to the quality of the energy with regards to harmonics.

In Figure 7 the harmonic current is shown. The data come from a one week-long measurement period, averaged in 10 min intervals. As can be noted, the harmonic current for the 5th harmonic injected to the network sometimes

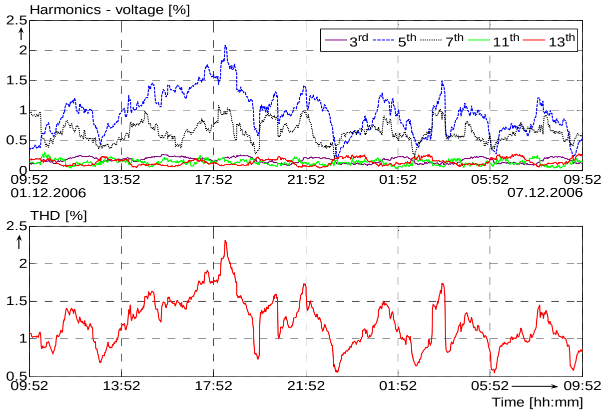

Figure 6. Harmonic profiles and *THD*-factor of the voltage measured during one week.

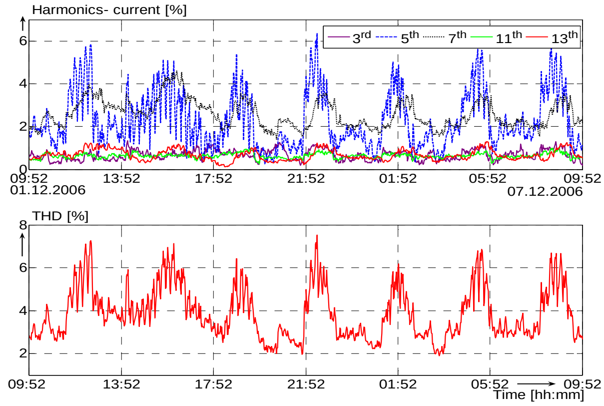

Figure 7. Harmonic profiles and *THD*-factor of the current measured during one week.

exceeds 6 %. The second significant harmonic in this network is the 7th. They both exhibit a similar daily profile character, namely: at night their contents grow and during the day they diminish. Moreover, one can observe that the current profiles are closely connected with time especially at weekdays, when almost the same power demand takes place during the day and at night. The generated harmonics do not present the critical values (*THD* lies under 8 %; for current there is not any concrete normalized limits), and any correlation showing the influence of the drawn current on the external supply system is recognized.

IMPROPER SYSTEM OPERATION - RECORDING

The implemented system also allows for recording non-stationary occurrences in the network (for example, dynamic magnitude changes). This type of recording takes place with the same frequency as the sampling rate. The applied data acquisition cards are not able to dynamically sample frequency changes. The momentary recording is initiated when the given limits are exceeded. These limits can be established by the operator of the measuring system. There is one factor (the so called phasor) which is used to record momentary disturbances. The phasor consists of two parts, V_Y and V_X, which are connected with the X and Y axes respectively, and are projected values of the phase voltages. The expression for phasor calculation is given by the following formula:

$$V_x(t) = \frac{\sqrt{3}}{2} V_B(t) - \frac{\sqrt{3}}{2} V_C(t) \quad , \qquad (1)$$

$$V_y(t) = V_A(t) - \frac{1}{2} V_B(t) - \frac{1}{2} V_C(t)$$

where V_A, V_B, V_C are the phase voltages. Ideally, the Vx and Vy quantities projected on the x,y - coordinate system cross a circle with a specific radius. If the radius of this circle exceeds the given range the momentary recording is initiated. An example is given in Figures 8 and 9. In the first time phase one can observe that the network voltage has a normalized value (save operating area) then, due to network disturbance the sag (improper system operation area) appears that continues for more than 0,5 period (the phasor crosses many circles). More detailed results from this recording are given in Figure 9. It can be noted that voltage sag causes the oscillation of the current drawn from the network, especially for phase *A*. Additionally, it can be observed that voltage goes down by about 25 %, which can be considered a strong disturbance. The given method based on the phasor assessment allows for recording not only disturbances connected with fundamental frequency but also different disturbances connected with harmonic magnitude growth, low frequency transient, and voltage imbalances. The captured disturbances can be classified according to the propositions given in [10].

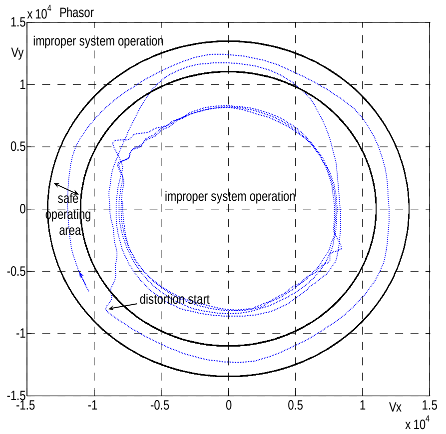

Figure 8. Captured phasor during disturbance.

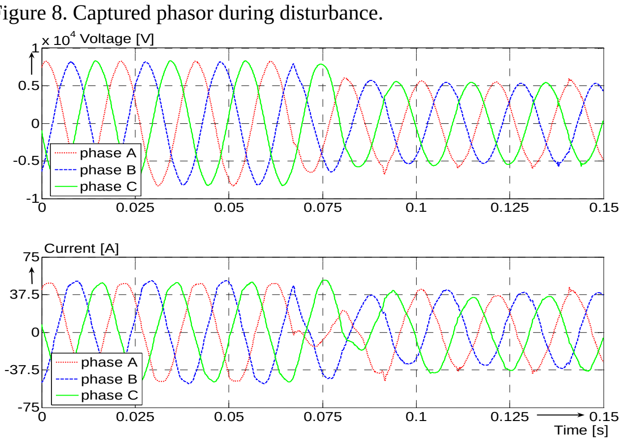

Figure 9. The recorded voltages and currents during sags.

CONCLUSION

In this paper a method for implementing a power quality monitoring system was presented. Use of the data acquisition card made it possible to achieve accuracy levels quite close to standard recommendations according to the power quality measurement. Although the implemented system can be not considered a class *A* device in terms of the recommendation [8], it can be used to test the quality of the energy. The results present valuable information about electrical quantities at the *PCC* and can be used to detect disturbances.

The measurement results show that the present power quality at the *PCC* is very good. More detailed conclusions can be drawn after long time measurements are conducted.

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