DATA ACQUISITION AND PROCESSING SYSTEM FOR SMART MEASUREMENT OF POWER IN HV GRIDS BY OPTOELECTRONIC MEANS

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***Abstract* – The present concerns related to the smart use of energy require changes in the way in which the electric energy consumption management should be performed, under the circumstances connected to the assurance of electric energy delivery continuity, reduction of polluting emissions, consumption metering and use of flexible tariffs.**

In this paper, an analysis of the power measuring system based on an optoelectronic system for voltage and current measurement in the high voltage networks, where the supply and data transmission to and from a high potential is exclusively achieved by fiber optic, is presented.

It is shown to what extent this measuring system with information multiplexing can be achieved, also the measurement uncertainty resulted at power measurement.

Keywords: *smart grids, smart metering, non-conventional instrument transformers, optical power data link*

1. INTRODUCTION

At present, there is an intense concern for using efficiently the natural energy resources, given that the electric energy resulting from the use of these resources is the only one able to meet the most important necessities of the contemporary world.

These concerns are conceived by EU as specialized policies for implementing the information technology in support programmes of ICT-PSP type[1].

A concrete form of materialization is represented by the Smart Grids, and related to them at a high importance level, the Smart Metering.

The Smart Grid is a power system that can incorporate millions of sensors all connected through an advanced communication and data acquisition system.

This system will provide real-time analysis by a distributed computer system that will enable predictive rather than reactive response to blink-of-the-eye disruptions [2].

Smart metering should offer modern solutions, information on the global and local energy consumption, a high and reproducible measurement accuracy, the possibility of using some flexible tariffs a.s.o., so as to allow diminishing the useless consumptions; at the same time, the smart metering should contribute essentially in taking the decisions related to the assurance of uninterrupted supply of the consumers, should offer the flexibility necessary to the energy demand management, i.e. the ability to react to requests, in case of failures in the power system inclusively.

In this paper, one appeals to the measuring means able to meet the above requirements, which are based on modern measuring systems where information transmission and supply of the voltage and current sensors at high potential is exclusively achieved by fiber optic. Thus, the use of classical instrument transformers, which have a high consumption of active materials, high weight, low safety in operation, high measurement errors especially under transient state and reduced frequency band, is avoided.

Further on, the data acquisition and processing system is analyzed for the case when, besides the usual quantities – voltage and current – the function of power measurement is integrated. The calculation algorithm is built and the measurement errors for the case when a multiplexed acquisition system is used are determined.

2. OPERATION PRINCIPLE AND STRUCTURE OF THE HIGH POTENTIAL DATA ACQUISITION SYSTEM SUPPLIED BY FIBER OPTIC

The fast development of fiber optic (FO) telecommunications which took place in the last decade made possible to supply the high potential measurement and data acquisition system modules also by fiber optic.

Are presented the operation principle of this system for supply and data acquisition by FO (see Fig. 1), generically named Optically Powered Data Link (OPDL). Here, it is supplied with electric energy a laser source whose light beam is transmitted at a high potential where a photosensitive element converts the light into electric signal, serving for supplying the electronic acquisition system which is at the same potential.

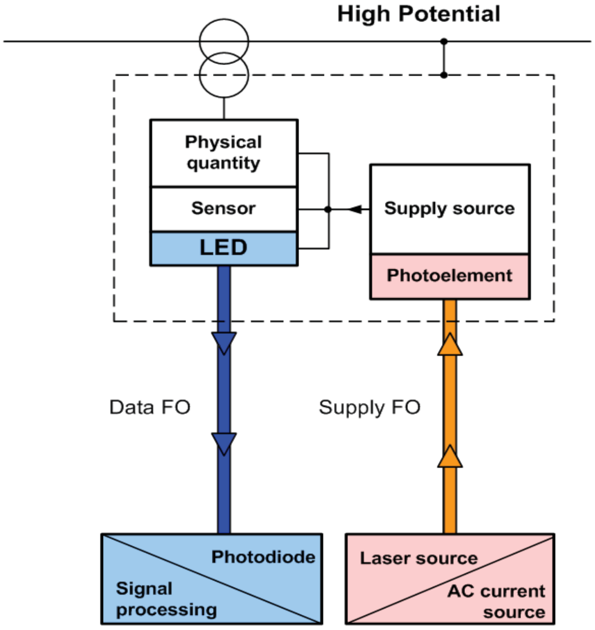


Figure 1: Operation principle of OPDL.

The signal to be measured is then converted into a digital signal and then, by an electric-optic converter, a light signal is sent by other FO to an electric-optic converter being at zero potential, where it is processed and transmitted to the control room under analog or digital form.

Undoubtedly, the level of the powers which could be conveyed by usual FO is relatively low (about 1 – 2W). 1W means, by instance, 5V and 200mA, values sufficient for the modern integrated circuits.

In general, fiber optic of standard multimode type with a core diameter of 62.5 µm is used.

The problem requiring attention in this case is the quality of optical connectors, through which the light radiation produced by a semiconductor laser is transmitted at high potential.

The power density for transmitting 1W electric power is as high as 400-500W/mm^2 of fiber optic section, value which could lead to the burning of the fiber optic in case an unsatisfactory contact interface.

Usually, such OPDL system has at least two channels for being possible to transmit by adequate sensors, the voltage and current from that node of the electric grid.

From the use of this optic system, many advantages result: reduction of the own consumption of energy, immunity to electromagnetic disturbances, indication stability and accuracy, possibility to be used both for measurement and protection.

The technical characteristics of OPDL should comply with the standards for unconventional instrument transformers (IEC 64044-7,8) and by the level of the output signals, they could be connected to the modules described by the standard 61850[3]. So, a measurement node of Smart Metering type can be easily achieved, according to the principle above presented. The block diagram of a current transformer with OPDL [4] is presented (see Fig. 2). For easiness, a hybrid system was presented, namely a measuring system which uses a conventional Rogowski sensor for current measurement.

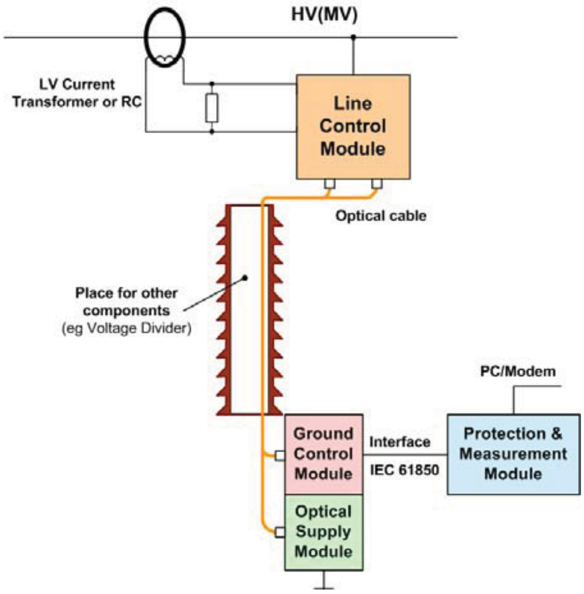


Figure 2: Unconventional current transformer with OPDL.

Usually, the Line Control Module (Remote Module) contains one more channel for data transmission to ground for the line voltage. One of the great advantages of FO transmission consists in the fact that when increasing the rated voltage of the measuring system, the total costs are influenced to a small extent by the additional cost of the insulator and of FO. The OPDL system used in the performed experiments is shown (see Fig. 3).

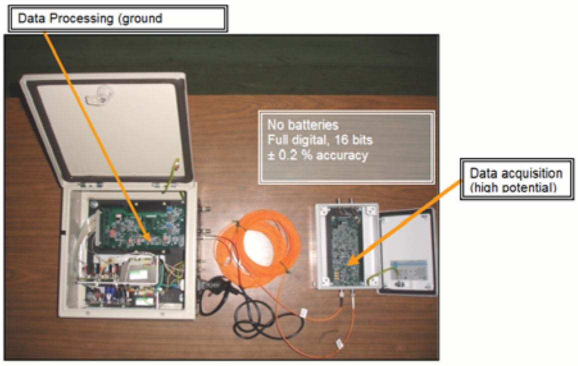


Figure 3: OPDL system during laboratory test.

3. DATA PROCESSING SYSTEM

An economical solution for processing the signals supplied by the above described optoelectronic system, with a view to calculating the power, will be presented further on. So, the solution of using an acquisition board NI USB 6229[6], which will receive on two analog input channels the signals supplied on the analog outputs by the optoelectronic system, was adopted. For software processing these signals, the programming environment LabVIEW is used. For noticing the errors introduced in this measurement chain, a signal generator AM300 from R&S Company was chosen for being used as standard. In the next paragraphs, we will describe the components of this application.

This acquisition board, although is lowcost, represents a viable option due to its performances versus its price, and by facilitating the communication on the USB of plug-and-play type, these devices are simple enough for performing rapidly the measurements and, at the same time, versatile enough, being recommended even for more complex data acquisition. Among the characteristics of this board the following could be mentioned: 32 analog inputs (16-bit, 250 kS/s); 4 analog outputs (16-bit, 833 kS/s); 48 digital I/O (32 at up to 1MHz); 32-bit counter.

3.1. LabVIEW software

The programming language used is LabVIEW, also referred to as G, is a dataflow programming language. Execution is determined by the structure of a graphical block diagram on which the programmer connects different function-nodes by drawing wires. These wires propagate variables and any node can execute as soon as all its input data become available. Since this might be the case for multiple nodes simultaneously, G is inherently capable of parallel execution. Multi-processing and multi-threading hardware is automatically exploited by the built-in scheduler, which multiplexes multiple OS threads over the nodes ready for execution. LabVIEW ties the creation of user interfaces (called front panels) into the development cycle. LabVIEW programs/subroutines are called virtual instruments (VIs). Each VI has three components: a block diagram, a front panel and, a connector panel. Controls and indicators on the front panel allow an operator to input data into or extract data from a running virtual instrument.

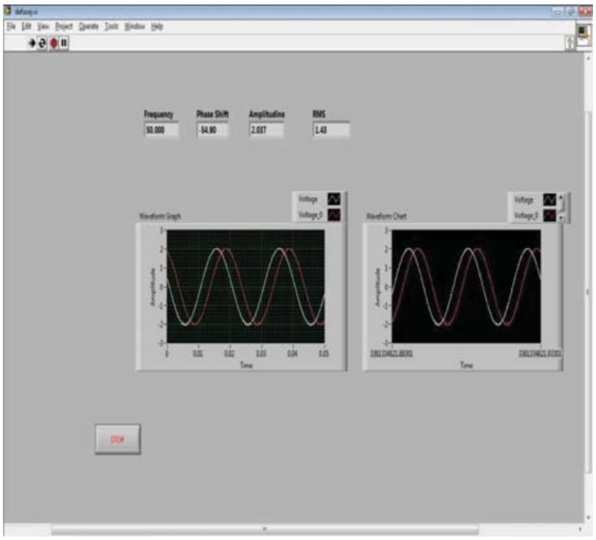
3.2. Application Program

For calculating the active and reactive power from this system, the element to be calculated which requires a special attention is the phase shift. The program which performs this is realized in LabVIEW and is composed from a front panel (see Fig. 4) and a block diagram (see Fig. 5). It can be seen that the phase shift, frequency of processed signals and RMS values are displayed. The programming environment LabVIEW offers many software instruments which implement mathematic operations and signal analyses for calculating the phase shift and, implicitly, the powers.

The Fast Fourier Transform (FFT) and the power spectrum are powerful tools for analyzing and measuring signals from plug-in data acquisition (DAQ) devices. For example, we can effectively acquire time-domain signals, measure the frequency content, and convert the results to real-world units and displays as shown on traditional benchtop spectrum and network analyzers. By using plug-in DAQ devices, we can build a lower cost measurement system and avoid the communication overhead of working with a stand-alone instrument. Plus, we have the flexibility of configuring our measurement processing. We use the following equations to compute the amplitude and phase versus frequency from the FFT:

$$Amplitude = \frac{Magnitude[FFT(X)]}{N} = \\ = \frac{\sqrt{[real[FFT(X)]]^2 + [imag[FFT(X)]]^2}}{N} \qquad (1)$$

$$Phase = Phase[FFT(X)] = \\ = arctg\left(\frac{imag[FFT(X)]}{real[FFT(X)]}\right) \qquad (2)$$



Frequency 50.000
Phase Shift -54.90
Amplitudine 2.087
RMS 1.48

Figure 4: Front panel.

The FFT of a signal represent the Fast Fourier Transform and N represent the number of acquired samples.

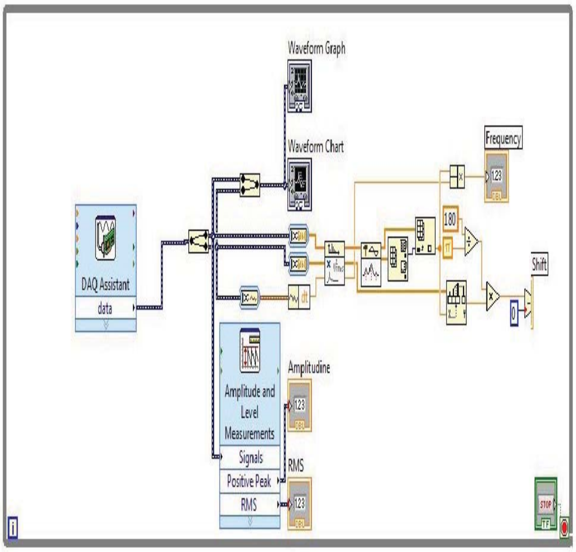
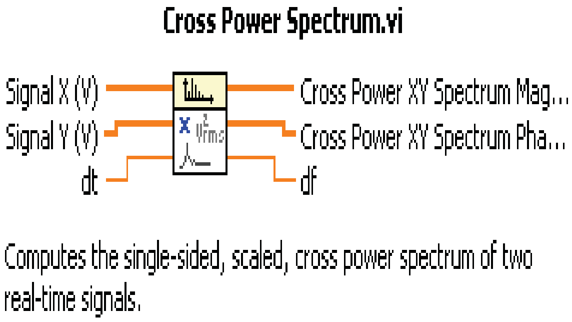


Figure 5: Block diagram.

The cross power spectrum block (see Fig. 6) calculate the cross power spectrum give by the next equation:

$$S_{AB}(f)=\frac{FFT(Y)\times FFT^{*}(X)}{N^{2}} \qquad (3)$$

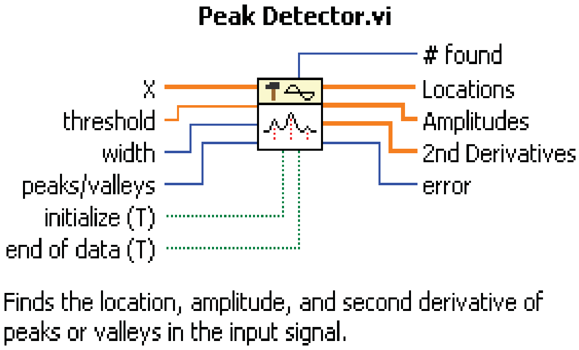


Computes the single-sided, scaled, cross power spectrum of two real-time signals.

Figure 6: Block software cross power spectrum.

Beside this block computes the single-sided, scaled, cross power spectrum of two real-time signals. The Cross Power Spectrum VI computes the single-sided cross power spectrum of Signal X and Signal Y. If Signal X and Signal Y have different lengths, the VI first pads the end of the shorter input signal with zeros to make the signals the same length.

The peak detector block (see Fig. 7) find the location, amplitude, and second derivative of peaks or valleys in the input signal.



Finds the location, amplitude, and second derivative of peaks or valleys in the input signal.

Figure 7: Block software peak detector.

This peak detector VI is based on an algorithm that fits a quadratic polynomial to sequential groups of data points. The number of data points used in the fit is specified by width. For each peak or valley, the quadratic fit is tested against the threshold. Peaks with heights lower than the threshold or valleys with troughs higher than the threshold are ignored. Peaks and valleys are detected only after the VI processes approximately width/2 data points beyond the location of the peak or valley.

The software block linearly interpolates (see Fig. 8) calculate a decimal y value from an array of numbers or points using a fractional index or x value. The connector pane displays the default data types for this polymorphic function.

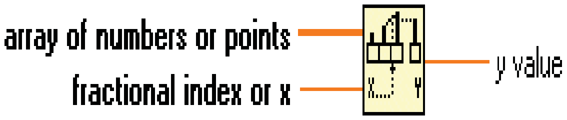


Figure 8: Block software interpolation.

The software block amplitude and level measurement (see Fig. 9) performs voltage measurements on a signal.

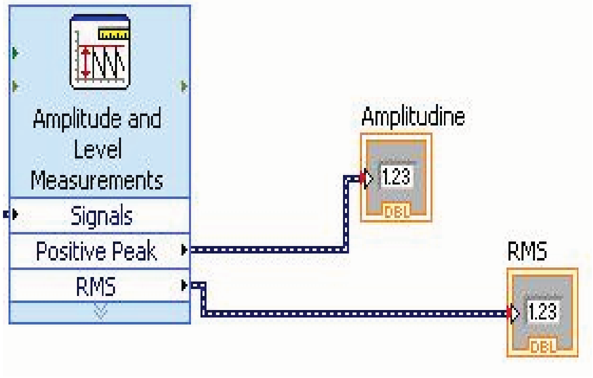


Figure 9: Block amplitude and level measurement .

This block contains the following options:
- DC—Acquires a DC measurement of Signals.
- RMS—Calculates the root mean square value of Signals.
- Apply window—Applies a low side lobe window to Signals. This option is available only when you place a checkmark in the DC or RMS checkbox. Use smoothing windows to taper the sharp transitions in the effective signal. You do not typically use windows if you can acquire an integer number of cycles of the signal or if you are analyzing noise spectra.
- Maximum peak—Measures the most positive peak in Signals.
- Minimum peak—Measures the most negative peak in Signals.
- Peak to peak—Measures the most positive peak to the most negative peak in Signals.
- Cycle average—Measures the mean level of one complete period of a periodic input signal.
- Cycle RMS—Calculates the root mean square value of one complete period of a periodic input signal.

4. EXPERIMENTAL RESULTS

This experiment aims to compare the phase shift provided by a standard equipment with the phase shift between two signals which are supplied by the output of the optoelectronic equipment and processed by the computer. The input of the OPDL optoelectronic equipment is supplied by the Rohde & Schwarz AM300 device.

4.1. Standard And Debugging Equipment

The R&S AM300[5] is a dual-channel Arbitrary /Function Waveform Generator that offers high functionality and spectral purity. With its superior characteristics, the instrument reproduces the digitally generated signals almost distortion-free - even at high output levels and frequencies. The AM300 thus meets requirements of a reference source . With a high sampling rate of up to 100 MS/s, a 256K-point waveform memory per channel and the Waveform Composer software, almost any waveform can be realized . The upper frequency limit of 35 MHz for sine signals and two channels with precise phase relation between the signals provides enough scope for our tasks.

Another equipment used for debugging is the oscilloscope Tektronix TDS2024. This oscilloscope have four Channel Digital Real-Time and the next features:
- 60 MHz, 100 MHz and 200 MHz Bandwidths;
- Sample Rates up to 2 GS/s;
- 2.5 k Points Record Length;
- Waveform and Setup Memories;
- FFT Software.

4.2. Description Of The Experiment

In general, when calculating the power, one should take into account the measurement errors of all the elements which intervene in the measurement chain: analog or digital wattmeter (δ_W), voltage transformer $(\varepsilon_U, \delta_U)$ and current transformer $(\varepsilon_I, \delta_I)$.

Under these circumstances, the relative error of power measurement can be written as [7]:

$$\delta_P \approx \delta_W + \varepsilon_U + \varepsilon_I - 0.0291 \times (\delta_U - \delta_I) \times tg\varphi \quad (4)$$

where φ is the phase shift between voltage and current.

In the studied case, due to the multiplexing of the voltage and current signals, an additional error term given by this process - noted δ_{MUX} - appears, which determines the above relation to become

$$(\delta_P)_{Total} = \delta_p + \delta_{MUX} \quad (5)$$

δ_{MUX} represents the additional phase error created by the multiplexing process which depends on the technical characteristics of the acquisition board, especially of the used sampling rate.

The performed experiments were focused on determining this error.

We have realized experiments for comparison of the phase shift between two signals provided by R&S AM300 equipment considered as phase shift standard, and the phase shift, between the same two signals after them was collected at the output of the measurement chain.

For instance, for the acquisition board NI USB 6229 with a sampling rate of 125 KS/s per channel for a reference phase shift of 55°, an absolute error of 0,1°, i.e. 0,18%, is got.

Repeating this calculus for a high number of pairs of standard phase shift value and measured phase shift value we can assert that the relative error is less 0.2% on the entire range of values between 0° and 180°.

5. CONCLUSIONS

The new generation of measuring systems at high potential developed by ICMET for Smart Metering appeals to the most advanced technology known at present, based on optical power data link.

It is presented the constructive principle of a voltage and current measuring system to which a software module for measuring the power (energy) achieved in LabVIEW was associated.

The use of a low cost acquisition board from NI in which the two signals, U and I, are multiplexed by a relatively low sampling rate, of de 125 kS/s, required a detailed verification of the phase shift error influence on the power measurement. With that end in view, as phase shift standard, a dual-channel arbitrary/Function Waveform Generator from R&S(AM 300) was used.

The got results show that such solution is satisfactory in practice, the measurement errors being of the order of 0.2% in a wide range of phase shift values.

In the near future this system will be installed in a power station for a comparison between the energy measured by a standard energy meter and the energy measured by this system. Although the solution presented for calculus of phase shift and power uses a low cost DAQ board with good results, for obtaining a acceptable measuring system is necessary to use a DAQ board with minimum a few MS/s.

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