Measurement System of New Electric Energy Quality Factors of Power Converters

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Keywords:
Power converters, Devices, Measurements, Modeling, Power quality, Software for measurements

Abstract

A Personal Computer (PC) complex is developed for measurement of the quality of electric energy in the correlation with international and Russia standards. The system works on IBM compatible PCs under operation system WINDOWS 98. The complex computes a set of new quality factors of electric energy and therefore requires a high amount of computation power. The interface component is realized on basis of a micro-controller data acquisition and computation unit in a extremely cost-effective form. This interface measures line signals and transfers the preliminary results into a PC for storage and post-processing. For a fast system operation check and a rapid prototype realization, the development environment with a high-priced DSP system (dSpace®) which is programmable by means of MathLab® is a choice. If a special calibrated system is required commercial industry standard PCs can be used with integrated difference amplifiers with settable or programmable gain and e.g. NI® A/D cards for data acquisition in universal measurement applications.

Hardware and software complex

A very cost-effective hardware-software complex for the computation of quality factors of electric energy (QFE) of industrial mains has been developed. The final realization hardware is composed of an autonomous measuring microprocessor/micro-controller complex (MMC), realized on the basis of the micro-controller DSP56002FC66 (Motorola). The MMC accomplishes monitoring and preliminary handling of acquired data about the state of an industrial mains and the user-side load of electric energy. The MMC can work independently from a PC, accumulating data into the power-independent integrated RAM, and – when connected to a PC, it periodically transmits data to the PC through a serial interface RS-232. The measuring inputs can handle up to six (three voltages and three currents) sine wave signals with amplitudes up to 5 V(peak). The MMC is in a separate case, is equipped with input and output terminals, and also a digital display with a simple keyboard for setting the modes of operations and for indicating the operating condition of the measuring complex.

The software of the complex is composed of two parts: the micro-controller's program, and program in PC recalculating the data from the micro-controller. Such a choice is made because of the necessity of measuring QFE in real time. That procedure establishes the hard requirements on speed. The Russian standard of quality of the electric power (GOST 13109), as well as international standards (IEC 61000-3-2-95 and other), require a continuous measurement of QFE and the accumulation of these values for computing an average for defined intervals of time.

The system calculates 11 QFE in correspondence with the standard. From these, 6 factors are calculated in the micro-controller:

- deviation of voltage;
- factor of n harmonic component;
- total harmonics distortion;
- factors of non-symmetry;
- deviation of frequency,

After calculating an average for a defined interval, the values described before are transmitted to the PC. The root-mean-square values of a curve of voltage, calculated for each half of a period for calculating two "slow" QFE – doze of flicker and oscillations of voltage are transmitted to the computer, too.

The PC program accumulates data during measurements from 10 min to 7 days. From the results of measurements the investigation protocol of the quality of electrical energy is formed.

New electric energy quality factors of power converters.

The complex measures not only factors of quality of electric power available in the today's standards but adds additional factors. The necessity of including these new factors into the national Russian Federation GOST standard was proved repeatedly [1]. Since the effective value component of the current in receivers (load side) of electrical energy transfer supplied by non-sinusoidal line voltage is determined through integral factors of harmonics q-order about of a line. These factors can be easily derived from investigating a circuit with a reactor (inductance) ($\overline{\mathrm{K}}_{\mathrm{h}}^{(\mathrm{q})}$) respectively a circuit with a capacitor ($\hat{\mathrm{K}}_{\mathrm{h}}^{(\mathrm{q})}$) fed by harmonics and are defined as follows:

$$\overline{K}_h^{(q)} = \sqrt{\sum_{k=2}^{40} \left(\frac{U_{(k)}}{k^q U_{(1)}} \right)^2} \qquad \hat{K}_h^{(q)} = \sqrt{\sum_{k=2}^{40} \left(k^q \frac{U_{(k)}}{U_{(1)}} \right)^2} \tag{1}$$

For the majority of the simplified mathematical models of customers for electric energy (load side) which can be substituted by a circuit of the first order, setting q=1 is adequate.

The integral factors of harmonics q-order about a current entering a customer are measured similarly. This allows to define an inverse influence of a nonlinear customer to the distortion of the form of voltage of a line, with a simplified mathematical model of a line by inductance. rather measurements A differential factor of harmonics of the current can be defined:

$$\hat{K}_{h.c.} = \sqrt{\sum_{k=2}^{40} \left(k \frac{I_{(k)}}{I_{(1)}} \right)^2} \ . \tag{2}$$

Individual shares of customers and mains in the change of quality of a voltage.

It can be derived that an expression for relative values of own U_C^* and mutual U_B^* of individual shares of branches in a resulting change of quality of voltage at a point of common coupling (PCC), equal as a one.

$$1=\frac{1}{U_a^2}\cdot\frac{1}{T}\int_0^T e_a^2dt+\frac{1}{U_a^2}\cdot\frac{L^2}{T}\int_0^T\left(\frac{di_{1a}}{dt}\right)^2dt+\frac{1}{U_a^2}\cdot\frac{L^2}{T}\int_0^T\left(\frac{di_{2a}}{dt}\right)^2dt+\frac{2L^2}{U_a^2}\cdot\frac{1}{T}\int_0^T\frac{di_{1a}}{dt}\cdot\frac{di_{2a}}{dt}dt-$$

$$-\frac{2L}{U_a^2}\cdot\frac{1}{T}\int_0^T e_a\cdot\frac{d(i_{1a}+i_{2a})}{dt}dt=U_C^*(e_a)+U_C^*(i_{1a})+U_C^*(i_{2a})+U_?^*(i_{1a},i_{2a})++U_?^*(e_a,(i_{1a}+i_{2a})),\qquad(3)$$

If the abnormal voltage *Ua* is the voltage of higher harmonics, the total harmonic factor (own and mutual) is obtained. If the abnormal voltage is the voltage of a reverse sequence you get the factor of reverse sequence. If the abnormal voltage is the zero-sequence voltage of an asymmetrical three-phase system, the factor of a zero-sequence is obtained. In this way the factors are determined in Russian Federation national standard GOST 13109-97.

The method of defining individual shares of loads and mains in the change of quality of the mains voltage is checked using a mathematical model of network with two rectifiers and linear load with the help of the program MatLab. Practically a full coincidence with the theory. has been found.

For a functional check of the algorithm, the functional diagram (fig. 1) for the calculation of a set of own factors (U_C) and mutual factors ($U_?$) of influence of currents of customers to the common distortion of voltage was developed for the case of three customers, hooked up to one network.

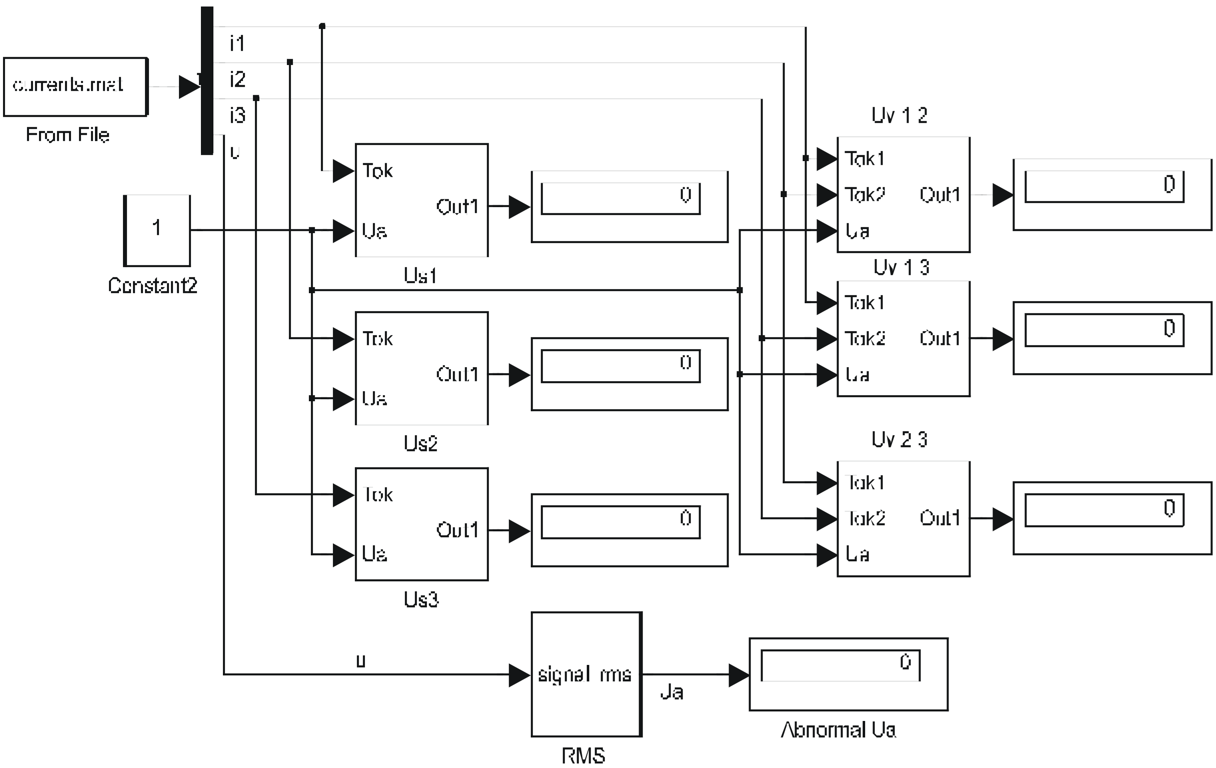

Figure 1: MatLab block diagram for a functional check for three customers on a line.

Factors according to [1] are calculated using the following formulas:

$$U_C\left(i_{a(k)}\right)=\frac{L^2}{T}\int_0^T\left(\frac{di_{a(k)}}{dt}\right)^2 dt \qquad U_?\left(i_{a(l)},i_{a(m)}\right)=2\frac{L^2}{T}\int_0^T\frac{di_{a(l)}}{dt}\frac{di_{a(m)}}{dt}dt \tag{4}$$

The factors are connected to an effective value of abnormal component of a mains voltage Ua by the following formula:

$$U_a^2=\sum_{k=1}^{k}\frac{L^2}{T}\int_0^T\left(\frac{di_{a(k)}}{dt}\right)^2 dt+2\sum_{\substack{l,m\\ l\neq m}}^{n}\frac{L^2}{T}\int_0^T\frac{di_{a(l)}}{dt}\frac{i_{a(m)}}{dt}dt \tag{5}$$

The value of Ua is determined on the basis of instantaneous values of a curve of a mains voltage.

For calculation of own and mutual interference factors, the instantaneous amplitudes of abnormal component of currents of customers are used. They models explained previously represent the scheme of a network with three customers.

The model for investigating the operating ability of the algorithm for an estimation of distortions of the shape of a mains voltage from non-sinusoidal currents of customers consists of three customers: a controlled rectifier, an uncontrolled rectifier and an active load, hooked up to one three-phase network. The check of algorithm was done as follows. First, a calculation for a set of own and mutual interference factors was started. These values allowed to predict values of a harmonic content at switching-off any of the customers. Then the switching-off of each of customers was carried out on the model, the harmonic content of a mains voltage was calculated by means of simulation. Table 1 displays the results of matching of the predicted harmonic contents with the calculated ones obtained by MatLab simulation.

Table 1.

	switched-off load		
	Active	uncontrolled rectifier	controlled rectifier
THD factor derived by modeling	0,0289	0,0258	0,0150
Predicted THD	0,0283	0,0257	0,0149

The results show conformity between the expected value of a harmonic content and the value of a harmonic content obtained by simulation of the scheme.

The model for investigating the operating ability of the algorithm for an estimation of an asymmetry of voltage consists of three active-reactive asymmetrical loads, hooked up to one three-phase grid. The calculation results of the contributions of an asymmetry of separate customers coincide with the outcomes of the MatLab simulation.

At a main window of the program (fig.2) there is an information about quality factors of the electric power on each of three phases, and also common factors for a three-phase system: factors of zero and inverse sequence, deviation of frequency. Also other modes of operations of the program are available for a more convenient representation of results of measurements for the user.

The algorithms of definition of the contributions of separate off-standard customers in common distortion of quality of electrical energy are used also in education [3,.4].

Figure 2: Hardware of the complex and PC screen shot for micro-controller DSP56002FC66 – based system

Rapid prototyping development system

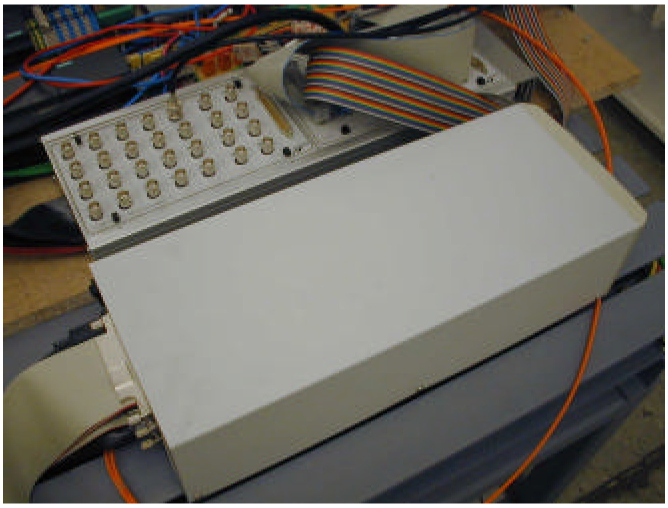

Figure 3: Rapid prototype developing system dSpace®

The demanding application requires a high amount of developing time if the software for the digital signal processor has to be written in assembler, and developing the hardware environment also takes a lot of time. In order to obtain a very fast result about the operational capability and performance, a high-priced development system can be used (dSpace ®, fig. 3).This allows for setting up the program using MatLab. The simulation program – when it runs finally - is taken as the basis of an automatic DSP code generation, the code can be downloaded onto the dSpace ® hardware (fig. 3) and is capable of running immediately. However, this is no solution for the final version due to cost reasons.

Commercial PC based realization

The realization using the micro-controller DSP56002FC66 system and a self-constructed hardware input connection is extremely cost-effective but for high-standard commercial applications a calibrated system becomes necessary. This can be realized using a commercial portable PC (fig. 4). This PC integrates up to 16 channels of difference amplifiers at the back side (fig. 5).

Figure 4: Commercial PC for measurements (front side) with included A/D card

Figure 5: Commercial PC for measurements (rear side) with difference amplifier and signal inputs

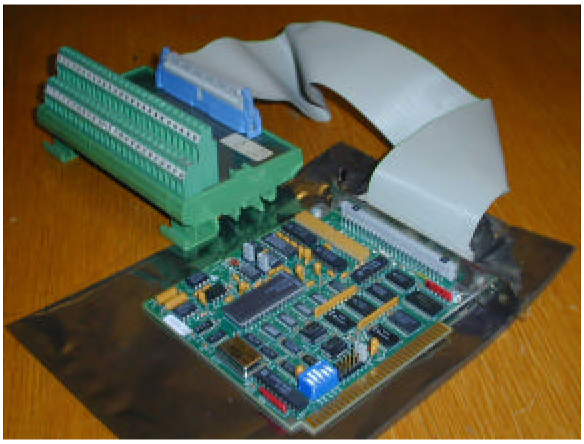

Fig. 6: Analog-to-digital conversion card (here: ISA-bus version) with standard connection terminal

The analog-to-digital conversion is accomplished by means of a National Instruments ® card (fig. 6) which is inserted into the PC. The data acquisition rate per channel can even be e.g. 10 000 samples per second, in total there are 16 analog channels which are scanned in multiplex mode. Both the difference amplifiers with settable amplification factors as well as the A/D card can be calibrated. The standard software to be used for such a system is LabVIEW® and allows a graphical programming using function blocks. The graphically developed software is transferred into an executable file running on standard IBM compatible PCs. This system is less expensive than the dSpace ® development system but still rather expensive. If the composition from calibrated commercial components is not necessary the formerly mentioned micro-controller DSP56002FC66 system with an PC is the optimal realization.

Conclusion

1. The complex measures a set of new electrical energy quality factors. They allow more adequately to determine losses of electrical energy and to find the individual shares of loads and mains in change of the quality of the mains voltage, alongside with the set of standard factors of quality of electrical energy.
2. The theory of new quality factors and the methods of their measurement are embedded in an educational course "Fundamentals of a power electronics".

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