

Development of New Measuring Systems Based on Symmetric Components in Electric Networks

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Introduction

Basic condition for qualitative control of electric network is to be familiar with its structure, and limitation factor is inability of a man to perceive: the structure and occurrence in the network, its size (only at 10 kV level per couple of thousands of power transformer stations), complexity and disconnection of power users, faults, ...). Therefore, systems for acquisition, transmission and processing of data got an important role in the process of electric network control. These were realized by HW/SW technology, by which the managing functions were really feasible.

Due to changes in type and number of users, the forms of system control and ways for resolving the problems that occurred at that time have also been changed. Existing solution of system for acquisition and processing are mainly at dispatcher level, while user level did not have much influence on global operation of the system. Lacks of these classic solutions are low speeds and acquisitions, which resulted in inability of registration of all changes in network structure and lower number of operations, which couldn't comprise all interesting categories. Development of electric networks and increase of tasks on dispatcher level conditioned the improvement of methods for control, elaboration and creation of automatic systems for dispatcher control. Such managing system comprise unique complex part of dispatcher level, which provides acquisition, transmission, processing and recording of information in given system state and control of planned optimal regimes.

Signal processing implies conversion of exciting signal into challenging signal in a way defined by system

on which exciting signal acts. Processing of electric signals indicates conversion of electrical exciting signal into electrical challenging signal.

Analysis of the measuring system structure in electric networks

System which performs acquisition of data is consisted of a few blocks, which is shown in Fig. 1. At the input there are measuring convertors, which large values of electric quantities from high-tension level from electric network bring to levels which are suitable for conversion into digital signals, which are convenient for further processing. Signals diskretized in such way are brought to processor inputs for digital processing of signal on which outputs are obtained responses characteristic for certain condition in which electric network is.

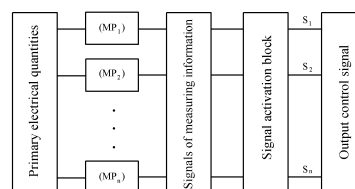


Fig. 1. Structure of a system for activation with analogue signal at input (MP measuring convertor)

Primary electric quantities in the network are mostly voltage and current. In the analysis of digital signal processing it is much simply to consider voltages as primary quantities. Primary electric quantities are obtained by reduction of voltage levels from network in domain into domain of low voltages, with preservation of all other

parameters carried by signal. In three-phase electric network for conversion of measuring information into signal three measuring convertors are used. Discrete values of primary electric quantities even in this block have already been formed symmetrical network components. Acquisition block gathers all signals that carry information on measurement frequency, delays and harmonic deformities. Block parameters for signal acquisition at their output practically have discrete real values of symmetric components (zero, inverse and direct component). One such structure is just a part of network and is of interest for analysis of failures that occur in system.

Main task of control system is to achieve desired state in plants according to acquired data on immediate state and realization according to given procedures. Therefore in modern control systems is performed separation of data acquisition functions from signal processing function, which indicates the existence of several levels of process control system.

In the less automatized power transformer stations are microprocessors with clearly determined functions and are used only for local control in power transformer station. Their main task, besides automatic fast influence on events in plant is to acquire and transmit information in central station and to receive and execute command from that station. In this case microprocessor does not perform the processing of received commands, but just examines their logical correctness.

Recognition that control and protection demand and use same information (currents, voltages, frequencies...), and similar technical requests logically lead towards attempt for finding a solution in a first step for engaged data from acquisition system to be processed and used in protection system. In such way necessary experiences would be obtained for projecting of global control system.

DSP role in electrical networks

In the digital signal processing theory signal is defined as certain physical quantity that changes in time, space or depends on some other independent variable or variables, and presents certain deliberately induced physical processes that carry desired message. Digital system can be implemented using software, where certain program specifies operations over signal, and using digital hardware implementation, where signal processing is performed by digital hardware. Hence, in the broader sense, digital system can be realized by combination of digital hardware and software, where each has separate functions. Main task in the process of digital processing is finding of algorithms that can be easily implemented and which are fast and efficient. Almost every algorithm is by nature analogue, so voltages and currents take values from continuous range.

Characteristics of operator \dot{a} of inverse voltage component

Operator \dot{a} is a complex vector, which absolute value is equal to one and shows certain angular position.

Using Euler's expressions by vector \dot{a} is possible to present all other angles in phasor diagram, and of importance are $=120^\circ \cong 2\pi/3 \rightarrow \dot{a}$ and $=240^\circ \cong 2 \cdot 2\pi/3 \rightarrow (\dot{a})^2$. Following is obtained by further procedure

$$\dot{a} \cdot \dot{a} \cdot \dot{a} = (\dot{a})^3 = e^{j2\pi} = 1, \quad (1)$$

$$1 + \dot{a} + (\dot{a})^2 = 0. \quad (2)$$

Different asymmetries are present in electric networks, which can be recognized by changes of phase positions, change of voltage and current amplitudes in the presence of different faults in electric energy transmission process. Asymmetric system can be transformed into three symmetrical systems, and as such can be used in calculations. Signal then forms symmetrical phasor system and they can be divided on symmetrical components:

$$\text{direct order } U_d = \frac{1}{3}(U_A + \dot{a} \cdot U_C + \dot{a}^2 \cdot U_B), \quad (3)$$

$$\text{inverse order } U_i = \frac{1}{3}(U_A + \dot{a}^2 \cdot U_C + \dot{a} \cdot U_B), \quad (4)$$

$$\text{zero order } U_0 = \frac{1}{3}(U_A + U_B + U_C), \quad (5)$$

where U_A , U_B and U_C are signals phase moved in vector diagram. In symmetric system phase positions are $2\pi/3$ and modules are equal.

Determination of fault parameters

Through each elementary part of the network flows one fictitious system of balanced currents, and elements of that part have certain phase impedance which can be dependable on sequence of phases in observed balanced system. For calculation of fault parameters in electric network theory of symmetric components is used. Power elements impedances in electric networks are not the same, so the following inequality is applied

$$Z_1 \neq Z_2 \neq Z_0. \quad (6)$$

Power elements that compose the three-phase network oppose to flow of direct current component by certain impedance Z_1 – (direct order impedance), impedance that oppose to inverse current flow is called, Z_2 – inverse order impedance, Z_0 – zero order impedance-opposes to zero order current flow. If analysed electric network is symmetric, then existing symmetric components are independent and can be separately resolved [7, 16]. In that case, the following expression is applied:

$$\hat{U}_1 = \hat{U}_{i1} - \hat{I}_1 \hat{Z}_1, \quad (7)$$

$$\hat{U}_2 = \hat{U}_{i2} - \hat{I}_2 \hat{Z}_2, \quad (8)$$

$$\hat{U}_0 = \hat{U}_{i0} - \hat{I}_0 \hat{Z}_0. \quad (9)$$

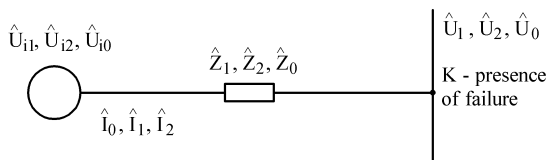


Fig. 2. System model in a presence of failure

Higher harmonics in electric networks

In electrical networks deformity of simply-periodic forms of voltage in binding post can occur, as a consequence of voltage drop on equivalent impedance, which is caused by deformed periodic current of higher intensities.

By understanding the characteristics of larger number of receivers that generate higher harmonic components of current, it can be said that in the larger number of cases the dominant harmonics are of $\nu = 3, 5, 7, 11$ and 13 order, that is, harmonic components of frequency $f = 250, 350$ and 650 Hz . Those receivers have deformed current with dominant harmonic even when supplied by pure simply-periodic (sinoidal) voltage. For the case of wave shape of quarters, amplitude of harmonic decreases with the increase of their order, according to equation

$$I_\nu = \frac{I_1}{\nu}, \quad (10)$$

where I_1 – is amplitude of basic harmonic ($f = 50 \text{ Hz}$);
 ν – harmonic order.

Decrease of amplitude of harmonic with the increase of harmonic order is different in real receivers and depends on real wave shape.

Semi-controlled bridge rectifiers also generate even harmonics, which are hard to eliminate, because of such realizations of rectifiers are used only at low powers. Luminous sources create very distinctive third harmonic (up to 20% of basic), which particularly can be dangerous for zero conductor, concerning that triply higher third harmonics flow through it than in phase conductor. So, zero conductor is loaded with effective current value of third harmonic that is equal to 75% of current of basic load harmonic, which is why it has to be appropriately dimensioned.

Input signals, such as phase voltages and currents in electric networks, are essentially periodical, and voltages and currents in the system in permanent state are pure sinusoids in the frequency of current system (50 or 60 Hz). Certain parts (transformers, converters, inverted converters and chargers) create harmonic distortion in existing signals [16]. In preventive protection, signals also tend to be pure sinusoids. Non-fundamental parts of voltage and current frequency in acquisition are nor really periodical, but are changing in time. The nature of these non-fundamental frequency signals is of great importance in derivation of protection algorithm.

Starting from the basic structure of development of hierarchical two-level system (dispatcher and user level), with the detailed analysis of digital processing of signal it is possible to considerably increase the capacity and availability of acquisition system. Two-level acquisition system implies that on the first level are executed functions

of local regulator and sensor (converter), and on the second (higher) level is executed the acquisition of data regarding the adjustability of low tension network and work regime characteristics after their implementation into the systems for control and protection. Real signals from the network contain disorders which are declared as nonlinear deformities that can be divided into three types: even and uneven nonlinear deformities and nonlinear deformities due to hysteresis.

The largest number of nonlinear deformities met in signals through communicational and acquisitioned systems is even nonlinear deformities. Nonlinear deformities can be divided into two basic groups: nonlinear harmonious deformities (when in a signal of basic frequency occurs only whole multiples of basic frequency, that is, basic signal harmonics) and nonlinear inharmonious deformities (when in receiving signal, besides basic and harmonious frequencies also exists combined, inharmonious frequencies). Uneven nonlinear frequencies are less rare case than even nonlinear deformities. In this analysis in input signals are present nonlinear harmonious deformities, where third and fifth harmonics are dominant. Dominant harmonics, except the source, also create different multiphase users, throttles, transformers etc, and their frequencies present products of basic frequency of input signal components and basically all of them present parasitic components.

If parasitic components fall into frequency range that occupies spectrum of useful basic frequency signal, then it is clear that its deformity will take place. Problem is not only that the parasitic components of one signal in the system, to a great extent, can influence on other units of the system in the area of high-tension and medium-tension distributive networks, but also because that causes their influence on variations of phase, amplitude and frequency of basic harmonics. Filters of symmetrical components are continually exposed to influence of higher harmonics, which are present in currents and voltages not only in the case of failures but also in normal regimes of electric networks. Estimation of influence of higher harmonics on filter performance is derived according to analysis of frequency characteristics. Frequency characteristics present dependences of output voltages (currents) from the frequency of input quantities that form systems of direct and inverse order.

Mathematica wolfram as development environment

Software package *Mathematica* can be used as development environment for projecting, implementation and testing of algorithms necessary for realization of communication devices and systems for acquisition and data processing. New version of software *Mathematica* was introduced in mid 2007, which enabled additional conveniences for algorithm development [13]. Some of more important characteristic are ability of generation of dynamic object, so is possible to observe graphics that change form in real time as system parameters change. Beside considerable improvement of numerical characteristics in operating rate, as well as the application of colour for marking the functions and quantities, and with rich graphic user interface, development environment

provides high conformity and simpler algorithm visualisation. With the introduction of new version of software Mathematica, application software *Schematic Solver* has also significantly improved its characteristics. Some of special functions that are used in previous version now are implemented into kernel, so the work in software *Schematic Solver* has become richer and more comfortable.

Schematic solver-software for interactive algorithm development

Complete work in the algorithm development takes place in electronic document that consists description, formulae, code, processing results and graphics and pictures for visualisation [14]. Electronic document can be formatted in free form, for example, as a conference report or paper, so with the development of algorithm simultaneously is generated all associated documentation. When the document where algorithm develops is open, *Mathematica* loads basic information and enables operation with installed functions. If it is necessary to load additional information, which are placed in previously prepared files, or as additional application, then first must be loaded additional information from applicable software. By activating the command **Needs [“Schematic Solver”]** necessary information loads. Algorithms are easiest to describe graphically, where block diagram is drawn in which every instruction can be presented by graphic element.

Symbolically defined parameters obtain numerous values only when that is necessary, for example, a signal to be drawn. In the analysis phase of algorithm performance, one or more parameters can be symbolically defines, so its value can be additionally determined, as a result of optimization. Standard projecting procedure develops in a way that system scheme is drawn by drawing programs, and is coded for algorithm by another tools. Many digital systems process signal according to drawn scheme but don't have simple analysis of scheme in frequency domain. *Schematic Solver* enables same scheme, namely, its description as a list, to be used for automatic generation of implementation code and drawing of frequency response to impulse excitation.

Analysis and results

For realization of computer measuring system higher harmonics are used for detection and analysis of failures, and in such way is monitored the system condition in real time. As input parameters, three-phase voltage system according to frequency 50 Hz forms symmetrical components. For the easier projecting of digital filter inverse component stands out and application of Z transformation implies general appearance of digital filter. One cell of digital filter must satisfy two basic demands. First is that there is no weakening of amplitude as a signal of basic frequency of third and fifth harmonic in whole pass-band, and second to perform phase shift of $2\pi/3$. According to these demands, we can conclude that digital all-pass filter must be projected. One cell of digital all-pass

filter is used for realization of measuring system algorithm, simulation and implementation itself.

Fig. 3. shows general appearance of the system for acquisition and processing of input signals from three-phase low-tension network. System was realized from the expression for inverse component and it is noticeable that in its composition has two digital filters. Both digital filters are adjusted to have phase shifts $2\pi/3$. As for inverse component phase B shifts for $2\pi/3$ and phase C for $4\pi/3$, so they are brought to anticipated inputs that perform phase shifts, which can easily be seen on the Fig. 3.

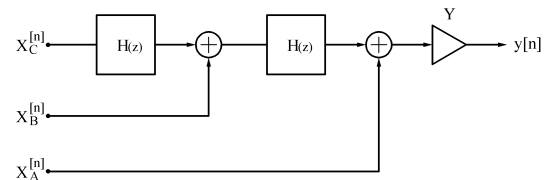


Fig. 3. General appearance of system for acquisition and signal processing

Fig. 4 presents detailed appearance of the system for acquisition and processing of input signals from three-phase low-tension network. Filter is projected according to basic given parameters and whole system is composed of three complete models: signal model, model of earth-fault regime and system model. Analysis has three approaches. First was conducted by projection of digital filter with previously defined parameters from the model of expression for inverse component, which completes system analysis. Second approach presents the signal model in which analysis was conducted with a few assumptions: in a case that there are no disturbances, that is, only basic frequency signal is present, case when third harmonic is present and case when third and fifth harmonics are present.

Third approach is analysis of acquisitioned signals in the presence of earth-faults, where K_1 , K_2 and K_3 present marked places on phases where earth-fault occurs, that is, on phases A , B and C , respectively.

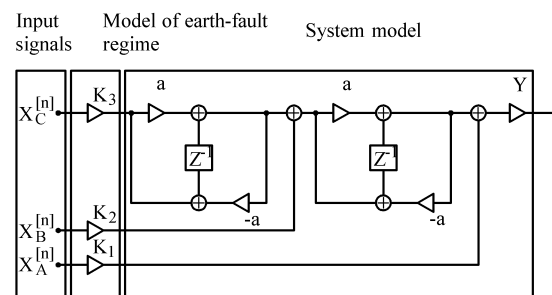


Fig. 4. Model of a system for acquisition and signal processing

Signals are computer generated in passed through simulated system for acquisition and processing and all results are presented in the following part of the paper. Analysis includes the presence of third harmonic and simulation was conducted with 400 samples with presentation of 32 samples. Coefficient of digital harmonic is $a = -0.614014$.

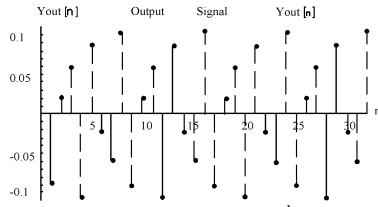


Fig. 5. Output signal in the presence of 3rd harmonic

Analysis in the presence of 3 harmonic in short circuits in measuring frequency $f_s = 400 \text{ Hz}$.

Fig. 5 presents signal response at output of the system for acquisition and processing of data from the network. Fig. itself presents that in inverse component exists only component of 3rd harmonic. On Fig. 6 are presented input signals. As that is three-phase system, besides basic frequency

$$s_A = A_0 \cos(\omega_0 t),$$

$$s_B = A_0 \cos(\omega_0 t - \frac{2\pi}{3}) \text{ and } s_C = A_0 \cos(\omega_0 t - \frac{4\pi}{3})$$

third harmonic is also present in form $s_3 = \frac{A_0}{3} \cos(3\omega_0 t)$. Fig.

7 presents spectral components of input and output signal. Figs 8, 9, 10, 11, 12 and 13 give presentation of spectral components at the output in the case of earth faults on the phases $A, B, C, A-B, A-C$ and $B-C$, respectively.

In analysis are used models of ideal short circuits, which are presented in way that values K_1, K_2 and K_3 have value 0 if short circuit has occurred, and value 1 if there is no short circuit. Also, analysis and simulation are also conducted for final impedances of short circuits, but due to limitation of the paper only numerical values are presented.

For final impedances of short circuit nominalised values of impedance are taken into account, so coefficients K_1, K_2 and K_3 take values 0.2 in the case of short circuits.

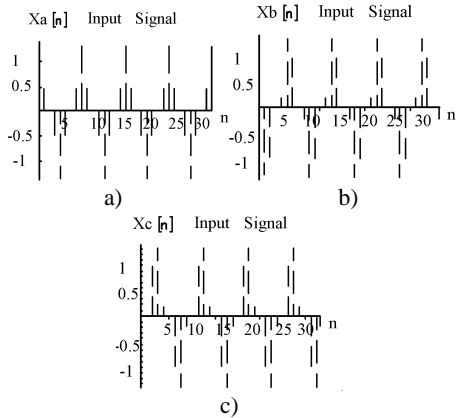


Fig. 6. Forms of input signals in the acquisition system

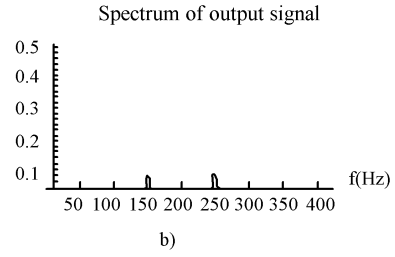
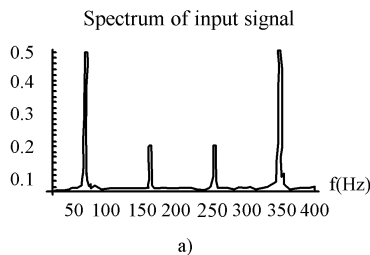


Fig. 7. Spectrum of input: a – and output signal; b – in normal regime without failures

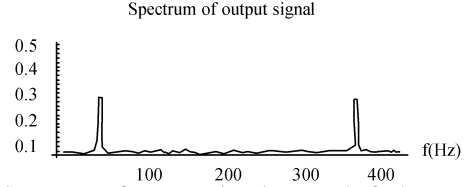


Fig. 8. Spectrum of output signal at earth fault on the phase $A \Rightarrow K_1 = 0, K_2 = 1, K_3 = 1$

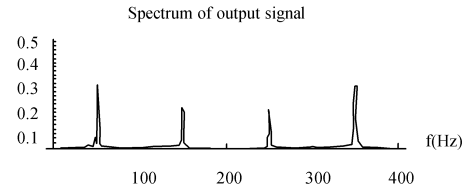


Fig. 9. Spectrum of output signal at earth fault on the phase $B \Rightarrow K_1 = 1; K_2 = 0; K_3 = 1$

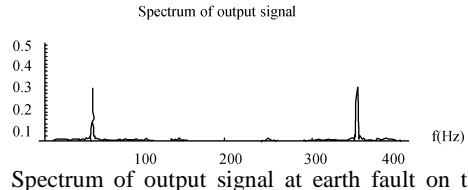


Fig. 10. Spectrum of output signal at earth fault on the phase $C \Rightarrow K_1 = 1, K_2 = 1, K_3 = 0$

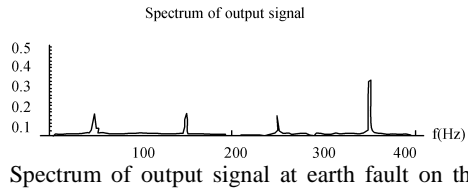


Fig. 11. Spectrum of output signal at earth fault on the phases $A-B \Rightarrow K_1 = 0, K_2 = 0, K_3 = 1$

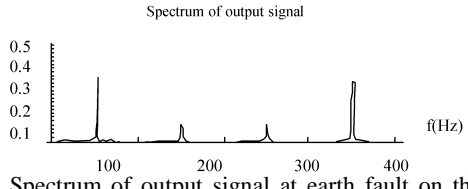


Fig. 12. Spectrum of output signal at earth fault on the phases $A-C \Rightarrow K_1 = 0, K_2 = 1, K_3 = 0$

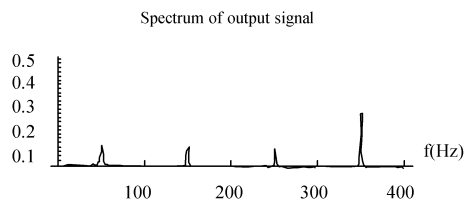


Fig. 13. Spectrum of output signal at earth fault on the phase $B-C \Rightarrow K_1 = 1, K_2 = 0, K_3 = 0$

Conclusions

Development of systems for acquisition, transmission and signal processing in electric networks includes, besides introduction, structure analysis, and conceptual solution for functional discretizer and examination of higher harmonic influences. Active filters of symmetric components as basic parts of the acquisition system structures are realized by operational amplifiers with respect to criterion of sensitivity on disturbances. For interactive algorithm development in *Mathematica Wolfram* surrounding software *SchematicSolver* has been used.

Results are arranged and presented in spectral diagrams and analysis refers to first and third harmonic. It was presented good concordance of results with respect to mathematical model.

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N. Marković, U. Jakšić, S. Bjelić, M. Vujičić. Development of New Measuring Systems Based on Symmetric Components in Electric Networks // *Electronics and Electrical Engineering*. – Kaunas: Technologija, 2010. – No. 8(104). – P. 57–62.

This paper describes real-time functions of development measuring system in distributive electric network and structure of the system for acquisition in systems for measuring, protection and control. Here are presented particularities of process and projecting of DSP processor in which base is digital filter that acquisitions, processes and transfer to SCADA all data of possible failures in the moment of their occurrence and new models that are used in the system analysis (behaviour simulations) for the purpose of adjustment of parameters. It has been shown that the third harmonic is one of the most dominant quantities, which reliably and accurate describes situation in electric network. Ill. 13, bibl. 16 (in English; abstracts in English, Russian and Lithuanian).

H. Маркович, У. Якшич, С. Бьелич, М. Вуйчиц. Разработка новых систем измерения для электрических сетей на основе симметричных компонентов // *Электроника и электротехника*. – Каунас: Технология, 2010. – № 8(104). – С. 57–62.

Описываются измерительные системы реального времени для электрических сетей. Указаны особенности проектирования датчиков для обработки цифровых сигналов. Полученные результаты обрабатываются системой SCADA. Найдено, что анализ третьей гармоники полностью и однозначно определяют состояние электрических сетей. Ил. 13, библи. 16 (на английском языке; рефераты на английском, русском и литовском яз.).

N. Marković, U. Jakšić, S. Bjelić, M. Vujičić. Naujos matavimo sistemas elektros tinkluose sudarymas taikant simetrinius komponentus // *Elektronika ir elektrotechnika*. – Kaunas: Technologija, 2010. – Nr. 8(104). – P. 57–62.

Aprašomos paskirstytuosiuose elektros tinkluose tiriamų matavimo sistemų realaus laiko funkcijos. Taip pat apibūdinama apsimokančiosios sistemos, gebančios matuoti, apsaugoti ir kontroliuoti, struktūra. Pateiktos skaitmeninių signalų apdorojimo valdiklio projektavimo proceso ypatybės. Skaitmeninių signalų apdorojimo valdiklis paremtas skaitmeninio filtro veikimo principu. Visi duomenys perduodami į SCADA. Nustatyta, kad trečioji harmonika yra vyraujanti ir patikimai ir tiksliai nusako padėtį elektros tinkluose. Il. 13, bibl. 16 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).