DOI: https://doi.org/10.15407/techned2019.04.065

IMPROVING MONITORING OF PULSE DISTORTIONS OF VOLTAGE IN POWER NETWORKS

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The method for detecting and tracking pulse distortion of voltage in the power network is proposed. Its idea is the comparison of the rates of change of voltage between the power network and the sinusoidal signal. The structure of the measurement instrument for measuring the dynamic parameters of electricity is developed in this paper. References 16, figures 2, table 1.
Keywords: pulse distortion, amplitude, pulse duration, decoder

Introduction. Proper powering [3] is very important for modern electronic and electrical equipment. The reliability and proper operation of that equipment significantly depends on fast changes of voltage in the power network. These changes occur as a pulse distortion of a harmonic voltage signal. Currently there is a topical problem of collecting information about the features of dynamic properties of such pulse voltage distortions in power networks in order to reject and possibly eliminate such events.

It should be noted that the measures against the pulse distortions are much more effective at the place of their occurrence. In order to detect the source of pulse distortions, it is necessary to measure their parameters, in particular, the amplitude, with high accuracy, since the amplitude of a pulse distortion decreases with increasing the distance from its source. Therefore, in order to detect the origin of pulse distortions, it is necessary to develop the methods for measuring their amplitudes with high accuracy.

The design and improvement of instruments to measure parameters of electricity is a topical problem. There are two approaches to solve this problem. One approach is based on the analog circuits with a multi-channel conversion and integration of the tested signal [4]. The second is based on an amplitude – time conversion of the parameters of pulses [10]. The instruments which based on these approaches have a rather high measurement error of (±2...±10%), although in a wide measuring range. The other approach is based on the analog-to-digital conversion of instantaneous values of the tested signal and data processing of the array of obtained results according to the appropriate algorithm [1, 12]. This approach decreases measurement error (up to ± 0.5%). Its drawbacks are a limited measurement range and a lower probability of detection of a pulse distortion in a voltage signal. It is due to the complex and cumbersome algorithm of pulse detection. As the result such instruments ensure measurement of pulses with duration up to 20…30 μs provided that relatively powerful microcontrollers are used. Modern standards and literature recommend to measure duration of pulses within the range from 1 μs to 1 ms.

Distortions of network voltage considered in this paper have a wide range of frequencies and amplitudes of pulses. Such distortions are dangerous, e.g. for sensitive CMOS logic. They also cause a large additional error due to interferences in temperature measurements using thermocouples [13]. Thus, it is necessary to form more precisely the requirements to the network voltage, which is intended to supply electronic and measuring equipment. Therefore, we suggest a method which can ensure a lower error over a wide frequency range.

The electromagnetic interference causes many problems in electronics. However, some kind of it, namely the common mode and normal mode noise have quite well developed methods for their rejection [6,

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13]. The situation with pulse distortions is completely different, therefore it requires completely different measures to cope with.

The pulse distortion of a sinusoidal voltage signal in power networks is considered as a short pulse signal superimposed on the fundamental frequency harmonic component of power networks (Fig. 1). Let us assume that the means for limiting high-voltage pulses (suppressors, varistors, gas arresters, etc.) limit the amplitude of pulses above ±350V. The amplitude of the left hand side pulse (Fig. 1) can be substantially reduced. At the same time, the amplitude of the right hand side pulse will be limited to about 600V, that is, it will remain very large. It seems this pulse is not dangerous, because it does not exceed the limits but such a pulse induces interference that can be dangerous or unacceptable [4, 5] because of its steep fronts.

Causes of appearance of a single pulse or their series can be a switching process or an emergency situation in some parts of the power system, as well as some unpredictable processes in electricity consumers. They can be caused, for example, by radiation of an electromagnetic noise from some objects or atmospheric electrical discharges.

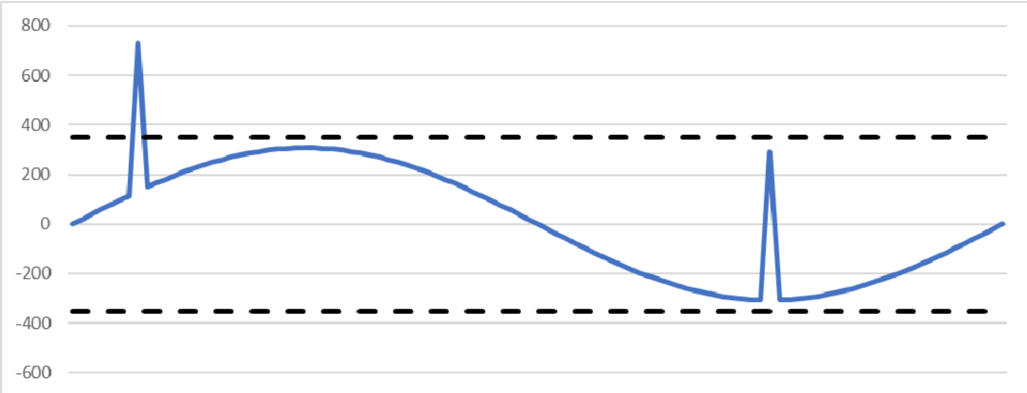

Fig. 1

According to the modern requirements and works by the leading experts in this field [5, 11] pulse distortions in electrical power networks are characterized by the following main parameters: amplitude U_{mi} and duration of a single pulse t_i or duration of the set of single or bipolar pulses $t_{i\Sigma}$ of different forms. According to [14] any voltage pulse can be presented as

$$u(t) = U_{mi} \cdot \varepsilon(t), \qquad (1)$$

where U_{mi} is the amplitude and $\varepsilon(t)$ is the standard function that describes the shape of the tested pulse. The most widely used waveforms of pulse signals are presented in Table.

Type of the waveform of pulse signal	Function $\varepsilon(t)$
Linear growth	0 for $t \le 0$; t/t_{fr} for $0 < t \le t_{fr}$; 1 for $t > t_{fr}$
Exponential	0 for $t \le 0$; $1 - e^{-\frac{t}{t_{fr}}}$ for $t > 0$
Parabolic	0 for $t \le 0$; $\frac{t^2}{t_{fr}^2}$ for $0 < t < t_{fr}$
Sinusoidal	0 for $t \le 0$; $\sin(\omega \cdot t)$ for $0 < t \le t_i$; 0 for $t > t_i$ (t_i - pulse duration)
Double exponential	0 for $t \le 0$; $1 - e^{-\frac{t}{t_{fr}}} \cdot \left(1 + \frac{t}{t_{fr}}\right)$ for $t > 0$

A distorted voltage signal $f_U(t)$ can be considered as the sum of the harmonic sinusoidal signal with the frequency of the power network and voltage pulse (1). The criterion which can be used to detect the appearance and existence of distortions was developed. It is increased rate of change of a tested signal $s_U(t)$ in comparison with the sinusoid. As it is presented in [14], using the property of the Laplace transform for the distorted signal $f_U(t)$ [9] we get the following expression after differentiation

$$f_{SU}(p) = p \cdot f_U(p) - f_U(0), \qquad (2)$$

where p is the operator, $f_U(p)$ is the Laplace transform of $f_U(t)$, and $f_U(0)$ is value of this function for $t = 0$.

Eq. (2) establishes the requirements for the unit that performs differentiation. It is necessary to separate the fundamental frequency harmonic component from the distorted signal, that is to ensure $f_U(0)=0$.

If we study the behavior of waveforms of pulses presented in Table 1, using (2) then, in the condition of ideal differentiation we get the minimum value of the standard functions

$$(\varepsilon_d(t))_{\min}=\left|\frac{\tau_{dc}}{t_{fr}}\right|, \tag{3}$$

where t_{fr} is the duration of pulse rise, τ_{dc} is time constant of the differentiation circuit.

Having combined the differentiation of the input signal with rejection of the fundamental frequency harmonic component we get the value according to (3) as a threshold $(s_U(t))_{on1}$. It means that it is necessary to compare it with an instantaneous value

$$s_U(t)\geq U_{mi}\cdot(\varepsilon_{id}(t))_{\min}=(s_U(t))_{on1}, \tag{4}$$

where $s_U(t)=\frac{df_U(t)}{dt}, \varepsilon_{id}(t)=\frac{d\varepsilon_i(t)}{dt}$, and $\varepsilon_i(t)$ is the instantaneous value of a function according (1) [16].

The exceedance $s_U(t)$ of controlled voltage over threshold is decoded as beginning of pulse distortion of the voltage signal.

Problem solution. The structure of the proposed instrument for measuring dynamic parameters of electricity is presented in Fig. 2. It consists of two main components: analog (AM) and computing (CM) modules [15].

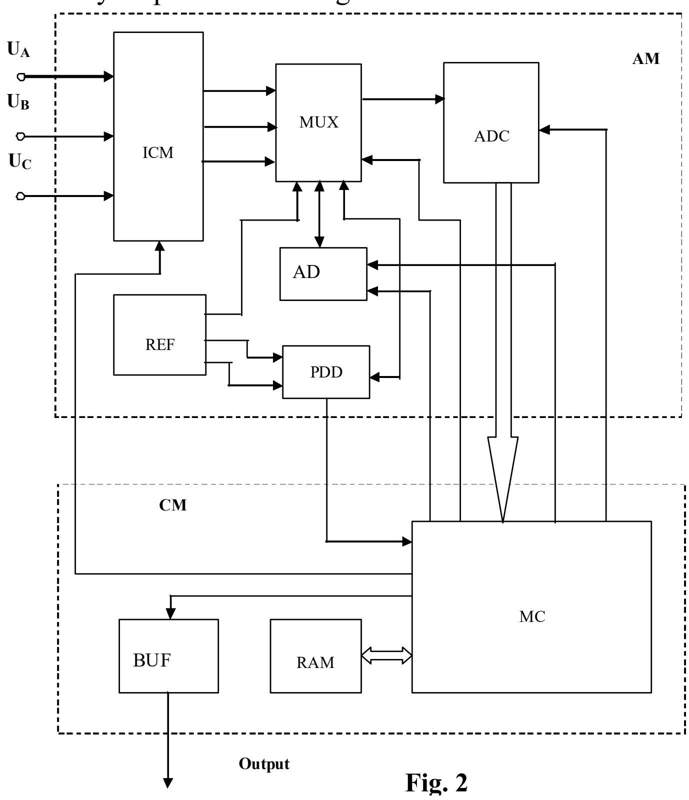

Fig. 2

AM consists of: ICM is the input conditioning module, MUX is the analog signal multiplexer, AD is the amplitude detector, PDD is the pulse distortion detector, REF is the reference voltage source, ADC is the analog to digital converter.

CM consists of: MC is the microcontroller, RAM is the random access memory and BUF is the output buffer.

The signals of the three phase power network U_A, U_B, U_C, after signal conditioning in ICM, are transmitted on the input of PDD one at a time through MUX. Its main function is detection positive and negative rises of pulse distortion and inform MC. The main component of PDD is the differentiator.

At the instant when a pulse distortion appears, (that is condition (4) fulfils), module PDD calls in MC an appropriate function to detect and measure pulse distortions in the power network.

At the same time, it is noted the place of a pulse or a set of pulses appearing in positive or negative wave of the period of harmonic voltage and is initiated a cyclic operation of ADC and turned on bipolar AD.

ADC is module with self testing [7], which sends code signal independently from appearance/disappearance of a pulse distortion. ADC provides getting arrays of codes of instantaneous values of phase voltages U_A, U_B, U_C, which are transmitted by MC directly to RAM. MC also provides searching time intervals t_{ia}, which include the value of U_{mi} for a sole or each a-th detected pulse. In addition, it is measured the duration of the pulse t_i or the set of pulses $t_{i\Sigma}$.

The specific feature of the developed instrument is the ability to obtain two arrays of codes of instantaneous values $\{u_i(k)\}$ of the pulse component of the signal $f_U(t)$ and corresponding instants

$\{t_{iU}(k)\}$ as the measurement result . The analysis of these arrays provides detection of the beginning and ending for the detected pulses $\{l_i\}$, which constitute the distortion $u_i(t)$.

MC saves beginning $(t_{ni})_{li}$ and ending $(t_{ei})_{li}$ instants for the set of detected pulses l_i. These instants are used for computing the parameters of pulse distortion such as:

– duration of all the pulses in the set

$$(t_i)_{li} = (t_{ei})_{li} - (t_{ni})_{li}, \quad (5)$$

– duration of the whole set of pulses

$$t_{i\Sigma} = \sum_{li=1}^{N_{iм}} (t_i)_{li} . \quad (6)$$

Further, the firmware of MC monitors if (4) fulfils and the instances when (4) does not fulfil, which shows the end of the first or a sole input pulse of the distorted signal $f_U(t)$. If during some time interval t_{ei} condition (5) is renew, the set of pulses is detected and each its pulse is monitored according to the algorithm presented above. It is reasonable to use as a microcontroller MC a network capable application processor with support of a set of serial interfaces with the ability of remote dynamic reprogramming via these interfaces [8].

The measurement circuit returns to the initial mode after the end of a pulse distortion. The obtained measurement results are transmitted to the output via BUF.

One of the main metrology parameters of the proposed instrument is the error due to inaccuracy of pulse distortion detection

$$\delta_{pd} = \delta_{dl} + \delta_{ni}, \quad (7)$$

which consists of the error of the differentiator of PDD – δ_{dl} and the component δ_{ni} of error of identification of inequality (4) caused by the comparator of PDD. The former of these components is determined by the deviation of a real conversion function of the differentiator of PDD from the ideal one.

The value of δ_{pd} influences accuracy of time measurement for either t_i or $t_{i\Sigma}$ and the rate of change of a distorted signal $s_U(t)$. This error also influences the accuracy of detection of distortion According to [14], the value δ_{dl} for all types of fronts of pulse signals from Table 1 does not exceed ±0.5%.

The error δ_{ni} does not exceed ±0.1% when using modern accurate voltage comparators.

The accuracy of measurement of U_{mi} is determined by the errors caused by analog saving by AD and analog to digital conversion by ADC. In general, the error estimation of the proposed instrument is close to the technique given in [2]. Modern components ensure the error of voltage measurement not worse than $\pm 0.1 ... \pm 0.2\%$ with respect to the range of change of t_i.

Conclusions. The proposed instrument is based on the analysis of the voltage waveform in electric power networks and detection of pulse distortions. The proposed instrument is based on a hardware detection of pulses and their software identification. It is also presented the structure of the proposed instrument. This detection opens the ways for rejecting the sources of pulse distortion, increasing the reliability of power systems and protecting electronic equipment.

Acknowledgment. This work was supported by Foundation of Wuhan Science and technology Bureau (2015030809020370), Doctoral Scientific Research Fund from Hubei University of Technology (No. BSQD14037), National Natural Science Foundation of China (Nos. 61602162, 61502155), Green Industry Technology Leading Project of Hubei University of Technology (No. ZZTS2016004).

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УДК 621.3

ВДОСКОНАЛЕННЯ ВИМІРЮВАЛЬНОГО КОНТРОЛЮ ІМПУЛЬСНИХ СПОТВОРЕНЬ НАПРУГИ МЕРЕЖІ

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Запропоновано спосіб виявлення та відслідкування швидких імпульсних спотворень напруги електромережі на основі аналізу швидкості часової зміни сигналу у порівнянні із синусоїдою. Синтезовано структуру засобу вимірювання динамічних параметрів електроенергії, а також проведено аналіз точності запропонованого вимірювального пристрою. Бібл. 16, рис. 2, табл. 1.

Ключові слова: імпульс, амплітуда, тривалість імпульсу, декодер.

УДК 621.3

УСОВЕРШЕНСТВОВАНИЕ ИЗМЕРИТЕЛЬНОГО КОНТРОЛЯ ИМПУЛЬСНЫХ ИСКАЖЕНИЙ НАПРЯЖЕНИЯ СЕТИ

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Предложен способ выявления и отслеживания быстрых импульсных искажений напряжения электросети на основе анализа скорости временного изменения сигнала по сравнению с синусоидой. Синтезирована структура средства измерения динамических параметров электроэнергии, а также проведен анализ точности предложенного измерительного устройства. Библ. 16, рис 2, , табл. 1.

Ключевые слова: импульс, амплитуда, длительность импульса, декодер.

Надійшла 02.03.2018
Остаточний варіант 09.04.2019