Realisation and Approbation of Conditionally Constant Coefficients Method for Loss Counter Measuring Tools

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Abstract. To date, electrical power in a form of higher-order current harmonics and voltage are reported to be worsening substantially in power lines of industrial and non-commercial consumers. This fact relates to the change of power consumer types to use different household and industrial power receivers. Higher-order harmonic current components cause extra losses in transformers. As a consequence, electrical power delivery is less efficient and losses increase. Therefore, it is necessary to measure harmonic components of current and voltage in distribution networks. The paper presents a measuring tool of loss counter developed on the base of constant coefficients method. Performance and relative accuracy were studied experimentally using a variable-speed drive with the results reported in the paper. The developed measuring tool meets the standards of admitted relative accuracy and is applicable to implement conditionally constant coefficients method in order to calculate excessive losses to be caused by non-sinusoidal loads in transformers of distribution networks.

1. Introduction

Nowadays, electrical power consumption has been facing certain changes caused by a variety of domestic and industrial electrical receivers to use DC voltage generated via rectifying AC voltage and its leveling in a tank filter [1]. The equipment above creates non-linear electrical loads for the power supply system and consumes non-sinusoidal electrical current. As a result, distortions are registered in supplying networks; furthermore, distorting voltage affects other machines to receive electrical power from one source [2]. It is said that electrical receivers are deteriorating electrical power much worse these days. Considerable quality degradation in power supplying lines of commercial and non-commercial consumers has been registered recently [3, 4]. The quality of electrical power in distribution networks is decaying in the most developed economies, since a smaller number of electrical receivers with linear volt-amper parameters are left [5].

The supply of power is impossible without transformers, which transport it efficiently over distances and distribute among consumers. Being an important part in the energy system, transformers are found throughout all levels of voltage and considered to relate a network with consumers [6]. Higher-order harmonic components of electrical current cause extra losses in windings of transformers and excessive losses on vortex currents in a magnetic circuit. This fact has a negative effect on efficiency of power supply and cuts an estimated service life of electrical equipment and electrical networks due to accelerated heat and electrical aging of insulation [7]. Therefore, the rational use of power and reduction of losses in distribution networks with non-sinusoidal loads are challenging research and engineering issues in power engineering today [8].

Nowadays, operation modes of electrical power systems and networks appear to be characterized as special modes with non-sinusoidal and asymmetric loads, the introduction of which is dominated by new manufacturing technologies and domestic needs, so it is necessary to investigate how the non-sinusoidal load influences efficient power losses in power three-phase double-wound transformers [9, 10].

The study [11] researches the role of non-sinusoidal load parameters for losses of efficient power in power three-phase double-wound transformers using methods of constant coefficients. This paper suggests an algorithm to estimate losses of full transformer capacity applying the method of constant
coefficients instead of a conventional method involving circuit equivalents of each harmonic. The algorithm above requires data on harmonic components of current and voltage in a network of 0.4 kV supplying power to consumers from transformers in a transformer station of a distribution network.

Harmonic components of current and voltage in distribution networks are to be measured with the purpose to determine the quality of electrical power. Today, a number of ready-to-apply approaches are available to analyze the quality of electrical power, e.g. quality analyzers: MI 2892, Fluke 437, version II, CI 8335 etc. The quality analyzers of electrical power above possess a variety of measuring functions, but they are expensive.

To sum up, it is necessary to develop a loss counter measuring tool based on conditionally constant coefficients in order to estimate extra losses caused by non-sinusoidal loads in transformers of distribution networks. The measuring tool of a loss counter is proposed to be constructed of available components, possess all required measuring functions and an acceptable cost price.

2. Materials and Methods
Basic parameters to be measured and estimated by a loss counter measuring tool are in line with characteristics of available quality analyzers of electrical power and listed in Table 1.

Table 1. – Basic parameters to be measured

| Parameter, measurement unit                                           | Measuring range | Limit of acceptable relative error, \( \delta \) (%) |
|----------------------------------------------------------------------|-----------------|--------------------------------------------------|
| True RMS of AC voltage in phases L1, L2, L3, V                        | 100 – 400       | ± 0.5                                           |
| True RMS of current force in phases L1, L2, L3, A                    | 0 – 5           | ± 1.5                                           |
| True RMS of current force in a neutral conductor circuit, A          | 0 – 100         | ± 1.5                                           |
| Amplitude of harmonic components of AC voltage in phases L1, L2, L3, B| 1st to 50th     | ± 3 to ± 15                                     |
| Amplitude of current force harmonic components in phases L1, L2, L3, A| 1st to 50th     | ± 3 to ± 15                                     |
| Effective power measured in one phase, W                             | 0 – 2000        | ± 3                                             |
| Power coefficient                                                     | 0 – 1           | ± 3.5                                           |

Figure 1 shows a functional diagram of a loss counter measuring tool.
Further we outline the operation cycle of the loss counter measuring tool according to the functional diagram (Fig. 1), taking as an example one channel of current and voltage measurement in phase L1 (other current and voltage measuring channels in phases L2 and L3 are identical). The voltage signal in phase L1 comes to the resistance voltage divider 1, where it is decreased to the required level and transported further to a galvanic insulation amplifier 1. Power is supplied to the amplifier from an insulated DC/DC transformer 1. A signal, proportional to voltage to be measured in phase L1 is transported to input 1 of a synchro-analogue-to-digital converter (ADC). A signal of current in phase L1 is converted into a range 0 to 5 A by a current transformer, being changed further into a voltage signal ranging 0 to 1 V by a current clamp 1. A signal proportional to current to be measured in phase L1 comes to input 2 of the same ADC. Furthermore, there is an additional current clamp 4 to measure current in a neutral conductor circuit in a range 0 to 100 A.

To start the measuring process, Arduino DUE synchronizes time in real time module according to GPS signals. Time synchronization is carried out every 1.5 min. This way, measurements are synchronized when using several measuring tools of loss counters.
Fig. 1. – Functional diagram of a loss counter measuring tool

As module Arduino DUE gets the signal of interruption or even-not-even minute voltage numbers (proportional to voltage to be measured and current in phases \( L_1, L_2 \) and \( L_3 \), as well as to current in a neutral conductor circuit) are recorded in a synchronal way according to interface SPI and ADC. Measuring lasts 0.2 s, i.e. 10 periods with a frequency of 50 Hz, each 0.02 s. The total number of points in one of seven ADC channels is 1000 (or 7000 in all channels) over the whole measuring period, or 100 points in 0.02 s (as stated in Kotelnikov theorem for a frequency of 50 Hz). Arduino DUE recalculates measured signals into instant values of current and voltage in the circuit according to ADC resolution, transformation coefficients of a current clamp and voltage divider. Further a true RMS of AC voltage current and current force in phases \( L_1, L_2, L_3 \) is calculated, as well as a current force in neutral conductor circuit, efficient and full power, and a coefficient of power. Afterwards, discrete Fourier transformations are carried out to the 50th harmonic component of current and voltage [12]. All calculations and transformations done, the values are registered in a document «dd.mm.yyyy.csv» on SD card, providing time and date of record (time and date are taken as in a real time clock), and coordinates (longitude and latitude) according to GPS signals. Then the data similar to those saved on an SD card are transferred by Arduino DUE, using a USB bus to the PC or a pocket Raspberry-based PC. Simultaneously the data are UART-transferred by an interface to a wireless connection module LoRa for remote monitoring. After an even (or non-even minute) according to the real time clock, the cycle of measurement, calculation and transformation is repeated.
As module Arduino DUE gets the signal of interruption or even-not-even minute voltage numbers (proportional to voltage to be measured and current in phases L1, L2 and L3, as well as to current in a neutral conductor circuit) are recorded according to interface SPI and ADC. Measuring lasts 0.2 s, i.e. 10 periods with a frequency of 50 Hz, each 0.02 s. The total number of points in one of seven ADC channels is 1000 (or 7000 in all channels) over the whole measuring period, or 100 points in 0.02 s (as stated in Kotelnikov theorem for a frequency of 50 Hz). Arduino DUE recalculates measured signals into instant values of current and voltage in the circuit according to ADC resolution, transformation coefficients of a current clamp and voltage divider. Further a true RMS of AC voltage current and current force in phases L1, L2, L3 is calculated, as well as a current force in neutral conductor circuit, efficient and full power, and a coefficient of power. Further discrete Fourier transformations are carried out to the 50th harmonic component of current and voltage [12]. All calculations and transformations done, the values are registered in a document «dd.mm.yyyy.csv» on SD card, providing time and date of record (time and date are taken as in a real time clock), and coordinates (longitude and latitude) according to GPS signals. Then the data similar to those saved on an SD card are transferred by Arduino DUE, using a USB bus to the PC or a pocket PC on the base of Raspberry. Simultaneously the data are UART-transferred by an interface to a wireless connection module LoRa for remote monitoring. After an even (or non-even minute) according to the real time clock, the cycle of measurement, calculation and transformation is repeated.

The developed measuring tool of the loss counter is supplied from 220 V network through a power supply unit and uninterruptible power supply unit. A voltage of power is 5 V, current ranges to 2.5 A.

3. Results and Discussion

Experiments to determine performance and relative accuracy of the developed loss counter measuring tool were carried out with the help of a variable-speed drive VLT 6000 manufactured by Danfoss. The quality analyzer of electric power made by METREL (MI2792) was used as a sample device.

The following conclusions were made according to the results of measurements. A maximal absolute measurement error in phase L1 for voltage doesn’t exceed 0.5 V, for current force – 0.0195 A, efficient power – 3 W, power coefficient – 0.02, therefore, relative accuracy is below 0.36 % for voltage; 1.36 % for current; 2.5 % for efficient power, and 3.33 % - power coefficient.

A maximal absolute measurement error in phase L2 for voltage doesn’t exceed 1.1 V, for current force – 0.0215 A, efficient power – 8.4 W, power coefficient – 0.02, therefore, relative accuracy is below 0.79 %; for voltage; 1.49 % for current; 3.0 % for efficient power, and 3.33 % - power coefficient.

A maximal absolute measurement error in phase L3 for voltage doesn’t exceed 0.3 V, for current force – 0.0202 A, efficient power – 3.4 W, power coefficient – 0.02, therefore, relative accuracy is below 0.22 % for voltage; 1.5 % for current; 2.96 % for efficient power, and 3.33 % - power coefficient.

As the level of even harmonic components was quite low when measuring, the results are omitted. The data on non-even measurements of current force harmonic components (n) 1 to 25 in phases L1, L2 and L3 are given in Figures 2, 3 and 4 (harmonic components after 25 is quite low and is not shown).

Fig. 2. – Measuring diagram of current harmonics 1 to 25 in phase L1
As seen in the measurements above, maximal relative accuracy of measured harmonic components of current force in phase $L_1$ is below 13.61%, in phase $L_2$ – 13.87%, in phase $L_3$ – 14.56%.

4. Conclusion

The developed loss counter measuring tool determines parameters listed in Table 1 according to specified relative accuracy and can be used to implement the developed method of conditionally constant coefficients of excessive losses caused by non-sinusoidal loads in transformers of distribution networks.

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