SPECTRUM OF HIGHER HARMONICS IN THREE PHASE CIRCUIT

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INTRODUCTION

Analysis of patterns of distribution of higher harmonics in three-phase circuit has more than seventy years. The basis of it is described in the [1]. Some of the provisions of this analysis without checking survived intact to this day and established research and academic literature on the theoretical foundations of electrical engineering [2, 3, 4]. It is necessary to discuss this issue taking into consideration two factors.

First. Increasing use of devices containing nonlinear elements, determines the importance of the validity of theoretical propositions in this area.

Second. A number of known distributions of principal provisions of the harmonic spectrum in three-phase circuits.

These provisions include the claim that the three-phase circuits without neutral wire can not proceed harmonic currents, whose frequency is a multiple of three.

So the [2] categorically states: "*In the absence of a neutral conductor harmonic order is equal to three, in the current curves can not exist*". In [3] states: "*If there is no neutral wire currents in the phases do not contain harmonics of order multiple of three*". Similar erroneous assertions hold relative to other harmonics. For example, consider that 5, 11, 17th, harmonics form a symmetrical system of currents feedback, and 1, 7, the 13th - a direct phase sequence. These statements are also far from the real picture of events. It should be noted that in the literature, no experimental confirmation of these provisions.

It is important not only to correct erroneous findings and conclusions, but also to identify the cause. Despite the perfection of the method of analysis of electrical circuits, the most common methodological principles to ensure unity of approaches to their analysis, not yet fully formed.

In respect of non-linear circuits such principle is not defined. Sufficient to indicate the absence of an algorithm that uniquely identifies a set of operations and sequence of their application for calculation of simple electrical circuits with nonlinear elements. In these and other works taking idealized initial conditions under which the harmonics whose order is three, the same three phases, and other harmonics form a symmetrical three-phase forward and reverse phase sequence.

ANALYSIS OF THE HARMONIC SPECTRUM OF THREE-PHASE CIRCUIT

Spectrum of higher harmonics in three phase circuit is determined by the nature of the nonlinear elements. Difficulty of analyzing nonlinear phenomena led them to consider not the corresponding methods of analysis of linear circuits. This is reflected in the fact that the system is non-sinusoidal currents of three phases, first appears symmetrical components of direct, inverse and zero sequence, then each of them expanded in Fourier series.

The fallacy contained in the source of the findings proved the elementary experiment by measuring the spectrum of harmonic currents in three-phase circuit with nonlinear load without neutral wire. Completed theoretic research and numerous measurements of the currents in the laboratory and operating facilities 10 kV led to the following conclusions.

Source is taken and other publications starting an "artificial" mode circuit, where the currents of three phases of each harmonic form a symmetrical system of currents of different sequences, essentially impossible. Even with identical characteristics of nonlinear resistors, each of these phases, under different stresses at each point in time has a different value. Asymmetric variation of the resistances of the three phases is asymmetry of the first and higher harmonic currents.

Therefore, as the initial position adopted by the presence of unbalance current harmonics. The correct analysis of the harmonic spectrum of such a chain is as follows. Sinusoidal phase currents are represented by Fourier:

$$i_a = \sum_{\gamma} I_{a\nu} \sin(\gamma\omega t + \varphi_{a\nu});$$

$$i_b = \sum_{\gamma} I_{b\nu} \sin(\gamma\omega t + \varphi_{b\nu});$$

$$i_c = \sum_{\gamma} I_{c\nu} \sin(\gamma\omega t + \varphi_{c\nu}).$$

Each unbalanced three-phase system of currents of equal frequency decomposed known method for symmetrical components:

$$\left.\begin{matrix}\dot{I}_{a\gamma}\\ \dot{I}_{b\gamma}\\ \dot{I}_{c\gamma}\end{matrix}\right\} \Rightarrow \left\{\begin{matrix}\dot{I}_{a\gamma.0}, \dot{I}_{a\gamma.1}, \dot{I}_{a\gamma.2}\\ \dot{I}_{b\gamma.0}, \dot{I}_{b\gamma.1}, \dot{I}_{b\gamma.2}\\ \dot{I}_{c\gamma.0}, \dot{I}_{c\gamma.1}, \dot{I}_{c\gamma.2}\end{matrix}\right.$$

where $\dot{I}_{a\gamma.0}, \dot{I}_{a\gamma.1}, \dot{I}_{a\gamma.2}$ - symmetrical components, respectively, zero forward and reverse phase sequence of γ - harmonic.

In the presence of the neutral conductor on it will occur zero components of the currents of all the harmonics:

$$I_N = 3 \cdot \sqrt{\sum_{\gamma} I^2{}_{\gamma.0}}.$$

When disconnecting the neutral wire will disappear zero components of the currents $I_{\gamma.0}$ of all the harmonics.

In the phase conductors are symmetrical components of currents to flow forward and reverse sequences of all the harmonic. Similar findings relate to harmonics not multiples of three.

These harmonics do not form a symmetrical system of currents, as is stated in the sources of 1 and other and contains a variety of symmetrical components.

Below are details of the experimental studies of the harmonic spectrum of currents three-phase nonlinear circuit.

Three-phase circuit, composed of identical saturated chokes, fed a symmetric system of sinusoidal voltages. Harmonic spectrum measured harmonic analyzer C5-3 and Lovato DMK-32.

The table shows the values of phase variables and the symmetric components is zero, the forward and reverse phase sequence currents three-phase circuit with neutral wire, and without him.

All values are expressed in percentages (100% passed the current value of phase A).

These tables confirm the inaccuracy of the above and related many other provisions.

So, in 3 states that in the symmetric mode for neutral closed only harmonics of order multiple of three:

$$I_N = 3 \cdot \sqrt{I^2{}_3 + I^2{}_9 + I^2{}_{15} + ...}$$

In fact, the zero-wire current flows equal to the sum of zero components of all the harmonics:

$$I_N = 3 \cdot \sqrt{I^2{}_1 + I^2{}_3 + I^2{}_5 + I^2{}_7 + ...}$$

Similar adjustments should be made to estimate the distribution of higher harmonics when connected load in the triangle, operating currents, losses, noise level, resonance phenomena and other practical issues.

Table 1. The harmonic spectrum of saturated chokes.

Harmonic number	**Phase currents**						**Symmetrical components of currents**					
γ	$I_{a,\gamma}$,%,	$\varphi_{a,\gamma}$,^{o}	$I_{b,\gamma}$,%,	$\varphi_{b,\gamma}$,^{o}	$I_{c,\gamma}$,%,	$\varphi_{c,\gamma}$,^{o}	$I_{a,\gamma.0}$,%,	$\varphi_{a,\gamma.0}$,^{o}	$I_{b,\gamma.0}$,%,	$\varphi_{b,\gamma.0}$,^{o}	$I_{c,\gamma.0}$,%,	$\varphi_{c,\gamma.0}$,^{o}
The scheme of star-star with neutral wire												
1	100	245	82	142	85	18	8,5	225	89,5	247	8,7	17
3	38	210	34,2	158	35,8	189	34,9	192	7,7	214	6,5	306
5	10,8	136	8	245	8	16	0,58	169	0,58	169	9,6	138
7	1,68	82	1,17	315	0,94	210	0,21	61	1,22	84	0,22	102
9	0,38	21	0,26	11	0,26	0	0,27	11	0,03	64	0,04	41
11	0,58	310	0,52	62	0,58	182	0,04	41	0,08	36	0,56	309
13	0,18	220	0,22	110	0,15	315	0,01	210	0,17	214	0,03	347
The scheme of star-star without neutral wire												
1	100	250	95	130	95,3	10	0	-	96	250	1,6	256
3	2,5	190	1,25	120	1,37	120	0	-	1,3	305	1,29	302
5	18	305	17,5	72	17,5	185	0	-	0,13	290	17,7	310
7	3,7	240	3,86	135	3,65	0	0	-	3,65	245	0,34	45
9	0,46	136	0,35	278	0,24	0	0	-	0,12	115	0,33	139
11	1,03	115	1,03	225	1,1	340	0	-	0,03	230	1,05	115
13	0,08	90	0,06	340	0,08	230	0	-	0,06	100	0,01	42

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