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FEATURES OF ENSURING ELECTROMAGNETIC COMPATIBILITY OF UNINTERRUPTIBLE POWER SYSTEMS

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An overview of the main structures of uninterruptible power systems is provided. The impact on internal-system and external-system electromagnetic compatibility of these devices is determined. Contemporary standards and requirements for ensuring electromagnetic compatibility of uninterruptible power systems are analyzed. Features of the structures of uninterrupted power systems such as online, offline and line interactive by the conductive path of propagation of interference are given. The main advantages of eco uninterrupted power supply are summarized. A generalized approach is proposed for the application of radiofrequency interference filters depending on the electromagnetic environment and features of uninterruptible power systems. Refined limitations on the possibilities of adjusting the basic and influence parasitic parameters of the filter links by symmetric and asymmetric propagation of conductive disturbances. The possibility of using remote control of the effectiveness of means of reducing conductive disturbances was assessed. The expediency of localization of control parameters of smart radiofrequency interference filters with the use of artificial intelligence is determined. References 10, figures 6, tables 2.
Keywords: AC mains, electromagnetic compatibility, emission, radiofrequency interference, radiofrequency interference filter, uninterruptible power system.

The problem of high-quality and reliable power supply led to the emergence and widespread use of uninterruptible power systems (UPS). In contemporary conditions, the use of electronic devices connected to mains for various purposes may be limited in consequence interruption or deterioration of the quality of energy supply. This necessitated the development of various structures and algorithms for generating alternating voltage to achieve reliable operation of such devices. Additional requirements, for example, switching time from the mains to the UPS, device operating time, dimensions, weight, etc. lead to an even greater variety of designed UPSs. Contemporary trends in this field can be defined as the transition to switch mode semiconductor converter structures at frequencies from tens kilohertz to tens megahertz. It is the switch mode of operation that causes the formation of electromagnetic interference. This led to the introduction of relevant international standards that regulate requirements for radiated and conductive interference from uninterruptible power systems [1]. Therefore, it is advisable to analyze the main structures of these systems, to determine the possible effects of the operating modes of the system components on intra- and extra-system electromagnetic compatibility (EMC), compare the requirements of standards for them and determine recommendations for application. For a more detailed analysis, we will limit the consideration of the application to single-phase alternating current networks.

According to the principle of operation, modern UPS should be divided into three main types, as shown in Fig. 1. Usually these types are: Off-line (see Fig. 1, *a*), On-line (see Fig. 1, *b*), Line-interactive (see Fig. 1, *c*) [2, 3]. The abbreviations indicate in this figure respectively: RFI – radiofrequency interference, AC/DC – converter (rectifier or battery charger), DC/AC – converter (inverter), transfer switch or static bypass switch.

Usually, in DC/AC converter (inverter)) for all structures of UPS an RFI-filter is also used. Further improvement led to the appearance of such a type of UPS as “green-line” or “eco” UPS (see Fig. 2), which ensured reduction of active power losses during conversion and limitation of consumed reactive power [4]. The abbreviations indicate in this figure respectively: RFI is the radiofrequency interference, PFC is the power factor corrector [5], UPS is the uninterruptable power system (any type). These properties of such

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UPS are also summarized as line conditioned [6]. Covering the functions of the first two blocks of the structure in one according to various schemes is called an active power filter [7].

An important aspect of the electromagnetic compatibility of the UPS is the level of conductive interference that the UPS generates in the AC mains of general purpose and in the circuits of consumers connected to the UPS. The presence in the structures of UPS, PFC, and active filters of such nodes as semiconductor converters with transistors and thyristors that switch at high frequencies leads to the appearance of high-frequency disturbances.

The switch mode operation of power unit is a source of disturbances, which at high levels are interference – both: mains & loads [5]. The switch mode forms a sequence of pulses, which is a source of unintended electromagnetic interference that propagates in the environment and conductive circuits. This creates a danger in the sense of not ensuring electromagnetic compatibility. Therefore, it is necessary to determine the electromagnetic environment during the operation of the UPS and international standards limit the level of these disturbances for UPS offered to consumers.

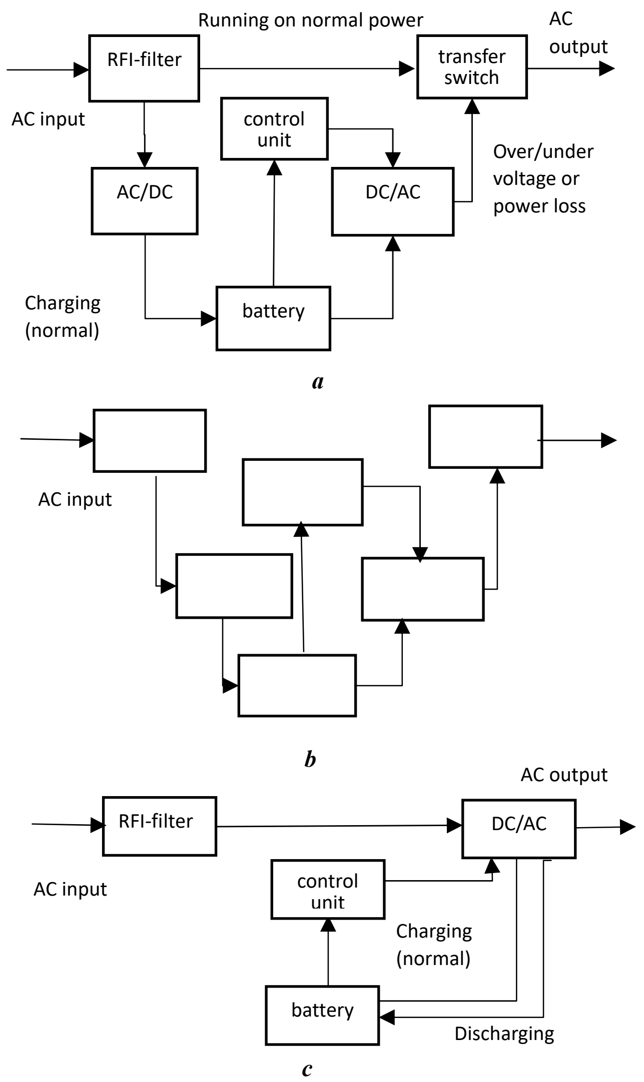


Fig. 1

The international standard [1] regulates the main aspects of electromagnetic compatibility of UPS. The standard also specifies the classification of UPS by categories of electromagnetic environment (EME).

In order to ensure compliance with standards for the level of conductive interference both for input and output AC voltage, for the UPS design process is necessary consider various means to limit the level of interference in the regulated frequency. The most effective in terms of price/quality ratio is the use of passive RFI filters. The so-called first electromagnetic environment covers residential, commercial and low-energy enterprises connected without intermediate transformers to the low-voltage AC mains. The second electromagnetic environment covers all commercial facilities, low-energy enterprises and industrial areas, except those belonging to the first electromagnetic environment, such as a building or part of it that is powered by a special transformer or generator.

UPS categories are also in these standard [1] defined. UPS of Category *C*1 is intended for use without any restrictions in the first electromagnetic environment. Such UPS are also suitable for use in residential premises. UPS of Category *C*2 is intended for use without any restrictions in the second electromagnetic environment. Such UPS can also be used in the first electromagnetic environment under certain conditions. Category *C*3 is a UPS with an output current of more than 16 A, intended for use in a second electromagnetic environment with certain restrictions. Category *C*4 is a UPS that cannot be assigned to any of categories *C*1, *C*2 or *C*3 and is intended for use in an electromagnetic environment subject to special requirements. It should be noted that these UPS categories do not limit the types of equipment used in them, but mainly refer to the power of the primary AC mains. Standardized levels of conductive disturbances at the AC input ports for rated output current up to 100 A are shown in Table 1.

Table 1			
Frequency Range, MHz	**Limits, dB (µV), Quasipeak value**		
	Category C1 UPS	**Category C2 UPS**	**Category C3 UPS**
0,15-0.5	66 to 56[a]	79	100
0,5-5	56	73	86
5-30	60		90 to 73[a]
[a] The limits decrease linearly with the logarithm of the frequency.			

Table 2			
Frequency Range, MHz	**Limits, dB (µV), Quasipeak value**		
	Category C1 UPS	**Category C2 UPS**	**Category C3 UPS**
0,15-0.5	84 to 74 [a]	97 to 87 [a]	110 to 100 [a]
0,5-5	74	87	100
5-30			
[a] The limits decrease linearly with the logarithm of the frequency.			

Standardized levels of conductive disturbances at the AC output ports for rated output current up to 100 A are shown in Table 2.

In the situation, if these levels are not agreed with the levels determined for a specific type of product, then it is necessary to ensure the electromagnetic compatibility of a specific category of UPS by appropriate measures. For example, “Limits for information technology equipment [8] and industrial, scientific and medical equipment [9] are show in Fig. 3 [8].

The given comparisons of these limits require appropriate coordination for the application of specific groups and classes of equipment. The general conclusion regarding the requirements for UPS conductive disturbances is as follows – higher levels are allowed at the AC output than at the AC input. Therefore, the electromagnetic compatibility guarantee at the AC output port needs more careful treatment to avoid redundancy and unnecessary costs for additional EMC protection facilities.

One of the two ways of propagation of electromagnetic disturbances from UPS is the conductive medium: power and signal cables, chassis, grounding wires, etc. The specified environment provides a conductive path of propagation, and, accordingly, conductive disturbances are spread through it: symmetrical (between forward and reverse conductors – in different directions (differential mode)) and asymmetric (between those conductors and ground- in one direction – (common mode)).

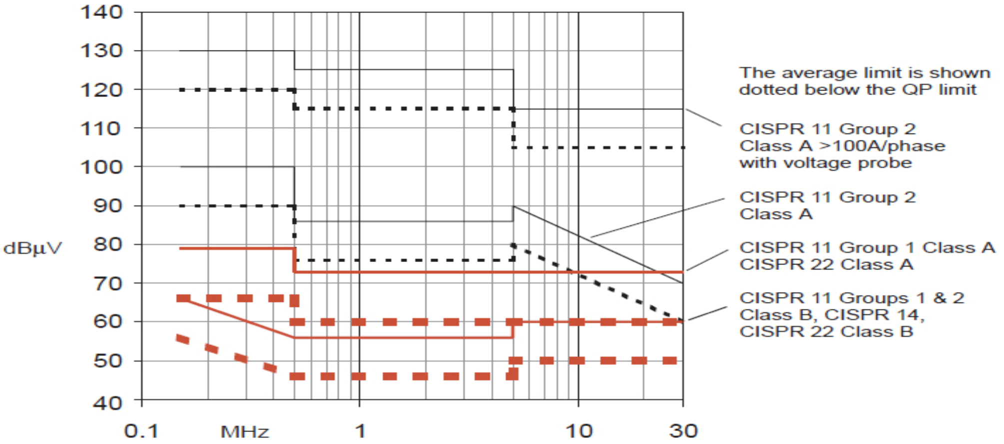


Fig. 3

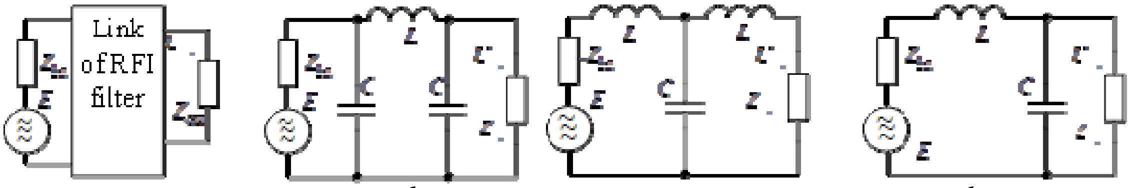
The RFI-filter is designed to perform the following functions:

– reduction of interference voltage in the electrical network to an acceptable level (according to norms, standards – national and international) – such a filter is called “a AC input RFI-filter”;

– prevention of the penetration of electromagnetic disturbances from the power grid to the load circuit such a filter is called a "AC output RFI-filter”.

The requirements for the attenuation of the output RFI-filter AC and the input RFI filter AC in the upper band of the protected frequency range (above 1 MHz) cannot be implemented by a single link of passive components according to the "*U*", "*T*" or "*L*" lines (see Fig. 4, *b*, c, *d*, respectively) due to the influence of parasitic parameters on the frequency properties of chokes and capacitors.

To calculate of effectiveness any RFI-filter, the following must be known: the level of interference created by the device – the interference generator, the total internal resistance of the interference source Z_{in}, the permissible level at the interference receptor, the total resistance of the interference receptor Z_{out}. The two parameters are regulated, and the other two can be calculated or measured.

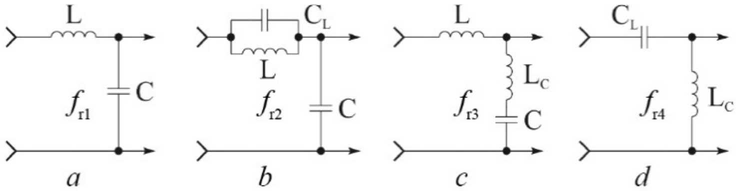


a *b* *c* *d*

Fig. 4

The next important feature of the RFI-filter is that, due to the provision of attenuation in a wide frequency band, it is necessary to take into account the influence of the parasitic parameters of the components: chokes is the parasitic capacitance C_L and capacitors is the parasitic inductance L_C.

On the basis of publications, handbooks, company catalogs and experience in the development of RFI-filters, it can be argued that the most effective is the *L*-shaped *LC* link shown in Fig. 5.



a *b* *c* *d*

Fig. 5

Each link can be characterized by resonance frequencies f_r at which the filter has minimum or maximum meaning attenuation. Depending on the relationship between the values of parameters L, C_L, C, L_C, the frequency values f_{r1} and f_{r2} can be interchanged on the frequency axis. The generalized attenuation characteristic for the *LC* link is shown in Fig. 6.

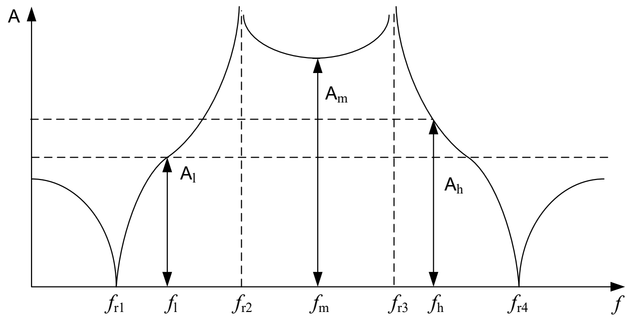


Fig. 6

The figure also shows the value of attenuation for the lower frequency of the frequency band $f_l - A_l$; the high $f_h - A_h$, and the middle $f_m - A_m$. The formula for the attenuation coefficient in these frequency band assuming zero source impedance and infinity receiver impedance is

– for lower band

$$A = \left| \frac{X_L - X_C}{X_C} \right| = \omega^2 LC - 1 = \left(\frac{f}{f_{p1}} \right)^2 - 1 \approx \left(\frac{f}{f_{p1}} \right)^2, \qquad (1)$$

– for middle band

$$A = \frac{\sqrt{L / C_L}}{\sqrt{L / C}} \cdot \frac{\xi_1 (1 - \xi_1)^{-1}}{\left(\xi_2^2 - 1 \right) \xi_2^{-1}} = \frac{f_{p2} f_{p3} f_{p4}}{f_{p1} f^2 \left[\left(f_{p2} / f \right)^2 - 1 \right] \left[1 - \left(f_{p3} / f \right)^2 \right]}, \qquad (2)$$

where $\xi_1 = \frac{f}{f_{p2}}$, $\xi_2 = \frac{f}{f_{p3}}$,

– for high band

$$A = \frac{(\omega C_L)^{-1} - \omega L_C}{\omega L_C} = \left(\frac{f_{p4}}{f} \right)^2 - 1. \qquad (3)$$

Thus, according to equation (1) in the first section of the amplitude-frequency characteristic of the RFI-filter, the attenuation increases, in the second section according to equation (2) it has a local minimum, and in the third section according to equation (3) it decreases.

Reconciliation of the EMC requirements of the UPS, taking into account the real EME, is possible under the conditions of the use of AC input RFI-filter structures with parameters controlled by the wireless channel [10]. It is expedient to use such filters in UPS structures according to Fig. 1, *b-c*. For the UPS structure in Fig. 1, *a*, we suggest modifying this structure by combining in one node an adapted RFI filter and a transfer switch controlled by artificial intelligence, which provides more flexibility in setting the RFI-filter parameters to the current EME.

Therefore, taking into account the peculiarities of EMC in different environments, it is advisable for offline UPS to use RFI-filters with controlled frequency properties of the elements based on the use of artificial intelligence algorithms that monitor changes in the electromagnetic environment of electricity consumers connected to the UPS.

For UPS of the online and line-interactive type, it is advisable to provide a wireless channel for real-time monitoring and remote adjustment of RFI-filter parameter.

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ОСОБЛИВОСТІ ЗАБЕЗПЕЧЕННЯ ЕЛЕКТРОМАГНІТНОЇ СУМІСНОСТІ ДЖЕРЕЛ БЕЗПЕРЕБІЙНОГО ЖИВЛЕННЯ

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Описано особливості основних структур джерел безперебійного живлення. Визначено вплив на внутрішньосистемну та зовнішньосистемну електромагнітну сумісність засобів послаблення у цих системах безперебійного живлення з розподілом на основні типи щодо кондуктивних збурень. Проаналізовано сучасні стандарти та вимоги щодо досягнення електромагнітної сумісності джерел безперебійного живлення за кондуктивним шляхом поширення завад. Наведено особливості структур джерел безперебійного живлення типу онлайн, офлайн та лайн-інтерактив. Узагальнено основні переваги екологічних джерел безперебійного живлення. Запропоновано узагальнений підхід для застосування протизавадних фільтрів в залежності від електромагнітного середовища та особливостей джерел безперебійного живлення. Уточнені обмеження на можливості регулювання основних та паразитних параметрів ланок фільтрів за симетричним та несиметричним шляхом поширення кондуктивних завад. Оцінено можливість застосування віддаленого керування ефективністю засобів зменшення кондуктивних збурень. Визначено доцільність локалізації керування параметрами смарт протизавадних фільтрів з використанням штучного інтелекту. Бібл. 10, рис. 6, табл. 2.

Ключові слова: емісія, джерело безперебійного живлення, електромережа змінного струму, електромагнітна сумісність, протизавдний фільтр, радіочастотні завади.

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