ALFA-BETA TRANSFORMATION APPROACH FOR THE ACTIVE SHIELDING OF FLAT POWER LINE

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This paper deals with the active shielding of the magnetic field of a flat three-phase power line. The present study considers active loops with the magnetic moment opposite to the magnetic moment of the β-component currents circuit, arising in alpha-beta transformation applied to three-phase power line currents. Relationship between the size of the proposed active loops and the electric current is derived. Presented results show that such active loops allow reduction of the width of sanitary-hygienic zone under power lines, where the magnetic flux density exceeds the reference level, by 11% compared to the known active loops. References 5, table 1, figures 3.
***Keywords*:** shielding, active loop, magnetic field, alpha-beta transformation, Clarke transformation, magnetic moment.

In most cases electricity is transmitted by the overhead HV power lines. According to the modern guidelines RMS of the magnetic flux density of industrial frequency should not exceed the reference level of 0.5 µT. The width of sanitary-hygienic zone under the power line, where the magnetic flux density exceeds the reference level, may be reduced using active loops or passive loops. Shielding loops are implemented in the form of the oblong rectangles, whose longer sides are parallel to the power line wires. In active loops the electric current flow is provided by an external voltage source. The electric current flow in passive loops is caused by the phenomenon of electromagnetic induction. No external power supply usage is the advantage of the passive loops, but due to the relatively low magnetic field shielding factor their use is limited.

To have a complete active loop description, it is necessary to specify the coordinates of its forward and reverse wires, the loop current amplitude I_S and the phase φ_S. If the shielding system is composed of several superposed loops, I_S is their total current. The greatest shielding factor is achieved by the use of active loops represented in the research works by Celozzi [1] and Cruz [2]. In these papers the optimization of active loops parameters is carried out using genetic algorithm [1] and simulated annealing [2]. These optimization techniques allow to obtain the parameters of active loops that reduce magnetic field by 60-90% depending on the distance between power line wires, the size of the protected area and its distance from the power lines. Nevertheless, these shields have some disadvantages. It is difficult to implement the active loop proposed in [1], because it is assumed that current amplitudes in forward and reverse wires are several times different. After consideration of few possibilities, authors in [2] propose to place an active loop in the plane of the power line. However, the use of above stated active loop leads to asymmetrical distribution of RMS of the magnetic flux density along the ground, so that the sanitary-hygienic zone on one side of the power line is one and a half times wider than the other side. Also approaches used in [1] and [2] do not answer the question: why the shielding factor increasing is obtained, and how to modify active loop parameters with power line changes.

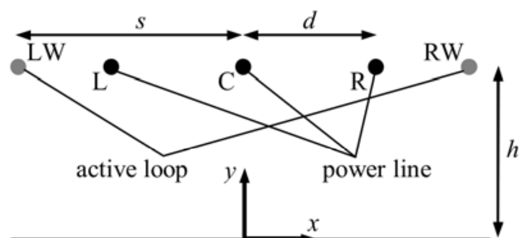

Figure 1

The aim of this research is to determine the interdependencies between the parameters of active loop and power line, which will allow to reduce the width of the sanitary-hygienic zone, where the magnetic flux density exceeds the reference level.

The flat three-phase power line is considered in this paper: I is the amplitude of power line currents, d is the interphase distance, h is the height of the power line location. In some studies, eg [3], authors take the sagging effect into account. Nevertheless, a classical model [1,2,4,5] is used in the present work, according to which, the power line and active loop wires are straight, endless and parallel to the ground (Fig. 1).

Electric current in the power line varies harmonically with the frequency of 50 Hz. Accordingly, the current frequency in active loop should be 50 Hz. Therefore, the total magnetic field is harmonic too. Since all the time-dependent quantities change harmonically, hereinafter the variables are described in terms of the complex amplitudes.

Using alpha-beta transformation (Clarke transformation) the currents of three-phase power line can be represented as a superposition of α- and β-components [5]:

$$\begin{pmatrix} \dot{I}_\alpha \\ \dot{I}_\beta \\ \dot{I}_0 \end{pmatrix} = \begin{pmatrix} 2/3 & -1/3 & -1/3 \\ 0 & 1/\sqrt{3} & -1/\sqrt{3} \\ 1/3 & 1/3 & 1/3 \end{pmatrix} \cdot \begin{pmatrix} \dot{I}_C \\ \dot{I}_L \\ \dot{I}_R \end{pmatrix},$$

where $\dot{I}_L, \dot{I}_C, \dot{I}_R$ − are complex amplitudes of currents on the left, center and right phases of the power line; $\dot{I}_\alpha, \dot{I}_\beta, \dot{I}_0$ − are corresponding currents given by the transformation.

As $\dot{I}_L = I \cdot e^{-j\frac{2\pi}{3}}$, $\dot{I}_C = I$, $\dot{I}_R = I \cdot e^{j\frac{2\pi}{3}}$, where j is a complex unit, then $\dot{I}_\alpha = I$, $\dot{I}_\beta = -jI$. For a symmetrical three-phase line $I_0 = 0$. Therefore $\dot{I}_C = \dot{I}_\alpha$, $\dot{I}_L = -(\dot{I}_\alpha - \sqrt{3}\,\dot{I}_\beta)/2$, $\dot{I}_R = -(\dot{I}_\alpha + \sqrt{3}\,\dot{I}_\beta)/2$ (Fig. 2).

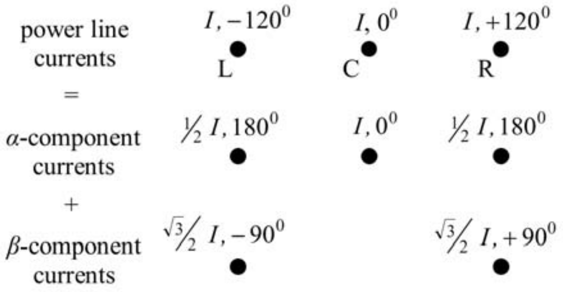

Figure 2

It was shown in [5] that the magnetic field produced by α-component currents is several times smaller than the one produced by β-component currents. Qualitatively this can be explained by the dipole model [4]. Let's consider α-component currents as a superposition of two single-phase circuits: the first circuit is formed by the "left" α-component current and a half of "central" α-component current, the second circuit is formed by a half of "central" α-component current and the "right" α-component current. The magnetic moments of these circuits are equal in magnitude and opposite in direction.

The main idea of this work is the use of an active loop to compensate the magnetic moment of β-component currents (Fig. 2). Therefore, the magnetic moment of β-component currents and active loop magnetic moment should be equal in magnitude and opposite in direction. To satisfy these conditions it is necessary to locate an active loop at a height h above the ground in the plane of the power line (Fig. 1), to set the current amplitude in active loop equal to $I_S = Id\sqrt{3}/(2s)$, where s is the half of the distance between the left wire (LW) and the right wire (RW) of the active loop, and finally to shift active loop phase φ_S on 90^0 relatively to the phase of current I_C. As a result, the current complex amplitude in the LW and RW of the active loop will be equal to $\dot{I}_{LW} = Ide^{j\frac{\pi}{2}}\sqrt{3}/(2s)$ and $\dot{I}_{RW} = Ide^{-j\frac{\pi}{2}}\sqrt{3}/(2s)$ respectively.

Hereby, the coordinates of power lines wires and active loop and respective current complex amplitudes are known. So the expression for RMS of the magnetic flux density of shielded magnetic field can be retrieved using the Biot-Savart law, the superposition principle and the method of complex amplitudes.

Power line parameters are retrieved from [2]: I=500 A, d=8.5 m, h=10 m. Active loop characteristics for different values of s and calculated values of the sanitary-hygienic zone width, where the magnetic flux density exceeds 0.5 μT, are expressed in Table. Also, there are characteristics of the Cruz's active loop [2]. Distributions of RMS of magnetic flux density B_{rms} along the ground (y=0) for the case of shield absence, using active loop # 2, active loop # 3 and Cruz's active loop are represented in Fig. 3.

In active loops, working on the proposed principle of compensation of the magnetic moment of the β-component currents, amplitude I_S and distance s are related as $I_S \cdot s = \frac{\sqrt{3}}{2} d \cdot I = \text{const}$. Increase of the distance between active loop wires allows to reduce active loop current amplitude and absorbed power simultaneously. As found in results, the decrease of active loop current by 25% leads to the increase of sanitary-hygienic zone width by 19%.

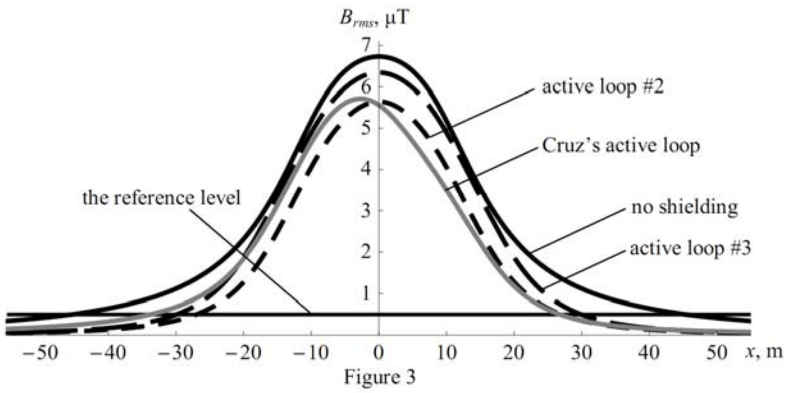

Figure 3

	s/d	I_S, A	φ_S	sanitary zone width, m
no shielding	–	–	–	90.8
active loop #1	1.5	288.7	90^0	50.3
active loop #2	1.7	254.7	90^0	53.9
active loop #3	2	216.5	90^0	59.8
active loop #4	2.5	173.2	90^0	69.3
Cruz's active loop	1.7	273	100^0	60.4

Let's compare characteristics of proposed active loops and active loops described in the literature. Since s is the same for active loop #2 and Cruz's active loop, the comparison is correct. As seen from the results, sanitary-hygienic zone width of proposed active loop is 11% lower than the one of Cruz's active loop, and power consumption of the proposed active loop is 13% lower.

Conclusions. In this paper a new approach to the design of active loops for the flat power lines is proposed. Active loops with parameters determined by this approach provide 40% reduction of the width of the sanitary-hygienic zone, where the magnetic field of the flat power line exceeds the reference level. Proposed active loops outperform known analogues by the parameters of shielding factor and the power consumption.

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ПОДХОД К АКТИВНОМУ ЭКРАНИРОВАНИЮ МАГНИТНОГО ПОЛЯ ЛИНИИ ЭЛЕКТРОПЕРЕДАЧИ НА ОСНОВЕ АЛЬФА-БЕТА ПРЕОБРАЗОВАНИЯ ЕЕ ТОКОВ

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В статье рассмотрено снижение магнитного поля трехфазной линии электропередачи с горизонтальным расположением фаз при помощи активного контурного экрана. Расположение, размеры и ток активного контурного экрана определяются таким образом, чтобы его магнитный момент был противоположен магнитному моменту контура тока β-компоненты, возникающей при альфа-бета преобразовании токов трехфазной линии электропередачи. Установлено, что такой экран позволяет уменьшить на 11% ширину санитарно-защитной зоны, в которой уровень магнитной индукции ЛЭП превышает гранично-допустимый, по сравнению с контурными экранами, известными из литературных источников. Библ. 5, табл. 1, рис. 3.

Ключевые слова: экранирование, активный контурный экран, магнитное поле, альфа-бета преобразование, преобразование Кларка, магнитный момент.

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ПІДХІД ДО АКТИВНОГО ЕКРАНУВАННЯ МАГНІТНОГО ПОЛЯ ЛІНІЇ ЕЛЕКТРОПЕРЕДАЧІ НА ОСНОВІ АЛЬФА-БЕТА ПЕРЕТВОРЕННЯ ЇЇ СТРУМІВ

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У статті розглянуто зниження магнітного поля трифазної лінії електропередачі з горизонтальним розташуванням фаз за допомогою активного контурного екрана. Розташування, розміри та струм активного контурного екрану визначаються таким чином, щоб його магнітний момент був протилежний магнітному моменту контуру струму β-компоненти, що виникає при альфа-бета перетворенні струмів трифазної лінії електропередачі. Встановлено, що такий екран дозволяє зменшити на 11 % ширину санітарно-захисної зони, в якій рівень магнітної індукції ЛЕП перевищує гранично-припустимий, в порівнянні з контурними екранами, відомими з літературних джерел. Бібл. 5, табл. 1, рис. 3.

Ключові слова: екранування, активний контурний екран, магнітне поле, альфа-бета перетворення, перетворення Кларка, магнітний момент.

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