Experimental and Theoretical Study of Effects in Power Distribution Net

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Abstract. *Magnetic field is responsible for many disturbing effects in the power distribution nets. Its calculation is complicated by the skin-effect and eddy currents. A formula was derived for the current density distribution in conductor of rectangular cross section. In order to verify it, the magnetic field was measured. Preliminary experiments confirmed the formula qualitatively. For better verification the experimental accuracy should be improved, which is realizable by relatively simple means.*

Keywords: AC Magnetic Field, Skin-effect, Low Magnetic Field Measurement, Eddy Currents

1. Introduction

Strong currents flow in distribution points that can lead to high forces between conductors, especially when transition effects take a place. In order to estimate the forces, magnetic field produced by the conductors must be known. It can be calculated from currents in conductors, but the calculation must be verified experimentally, at lest in the initial stage.

Because of high currents, distribution points use conductors of large cross section. Due to the skin effect, the current density is not uniform in them even at low technical frequencies. In this simple case the current distribution in analytical form can be derived and calculated simply. Unfortunately, the solution is in unusual complex symbolic form. Its understanding is more difficult and its improper use can lead to serious errors. Therefore, the experimental verification of results is necessary. Since the current density inside conductor cannot be measured, its theroretical distribution should be verified by excited magnetic field. It is the second, theoretical, reason for the magnetic field precise measurement.

2. Subject and Methods

We consider a massive conductor of rectangular cross section of dimensions 2a and 2b in plane XY and current in the direction of Z axis. The following formula was derived for current density[1] $\hat{i}(x,y)$ simply supposing constant current density i_o on the conductor surface [1]

$$\hat{i}(x,y)=i_o\left[-\frac{\cosh(\hat{\delta}x)\cosh(\hat{\delta}y)}{\cosh(\hat{\delta}a)\cosh(\hat{\delta}b)}+\frac{\cosh(\hat{\delta}x)}{2\cosh(\hat{\delta}a)}+\frac{\cosh(\hat{\delta}y)}{2\cosh(\hat{\delta}b)}\right]. \quad (1)$$

The attenuation coefficient $\hat{\delta}$ is given by the formula

$$\hat{\delta}=(1+\mathrm{j})\sqrt{\frac{\omega\mu\gamma}{2}}, \quad (2)$$

where

- $\omega = 2\pi f$ is angular frequency and f is frequency,
- μ is absolute permeability of the conductor material,
- γ is electrical conductivity of the conductor.

[1] Complex numbers are denoted by a hat above symbol. Imaginary unit symbol is j.

Three massive conductors, modeling the key part of distribution net, are fed by the three phase system. Apparatus used for the complete study is in Fig. 1 together with its block scheme. The skin-effect is studied by changing the frequency in the range from 15 Hz to 1.2 kHz. The current in conductor varies from about 1500 A to about 250 A. The vector of AC magnetic flux density is measured along a selected line (over the conductors) by a 3D Hall probe. The probe position is controlled by a computer and all the waveforms are stored in its memory.

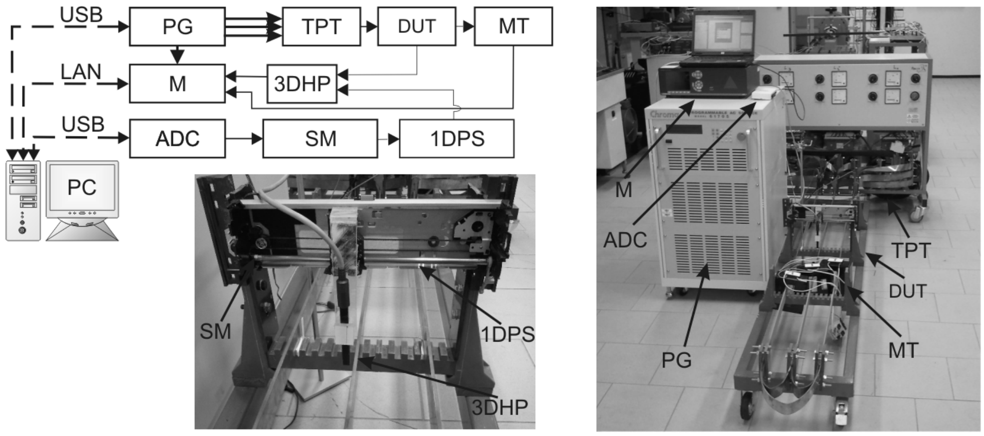
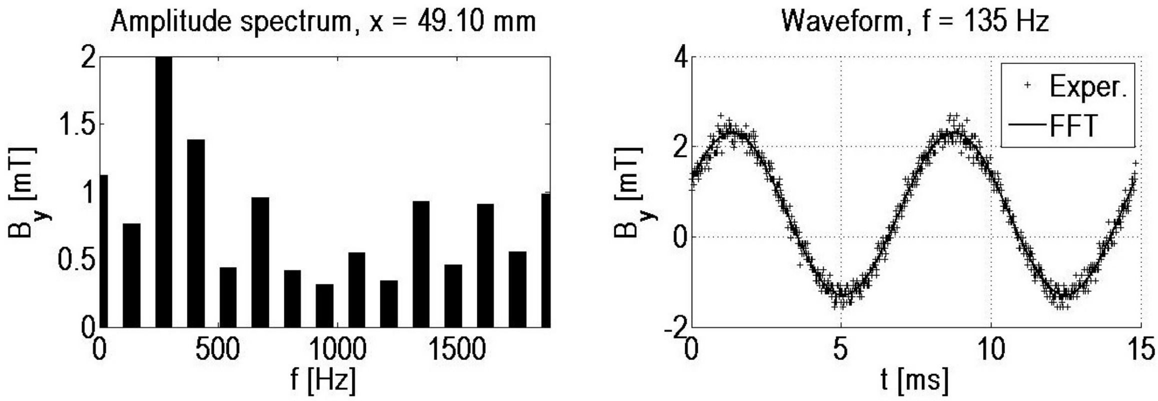


Fig. 1. Apparatus for complete power net study. Legend: PG – Power generator Chroma 61704, M – General purpose meter Norma 5000, ADC – Analogue to digital converter NiDaq, TPT – Three-phase transformer, 3DHP – 3D Hall probe, SM – Step motor, DUT – Massive conductors, MT – Measuring transformers, 1DPS – 1D positioning system, PC – Personal computer.

Preliminary experiments in three phase system revealed that the effect of eddy currents is dominant at all frequencies. In order to study the skin-effect, one phase system was used. Only the central conductor was fed and the current flows back by outside conductors.

Irrespective of high currents in conductors the magnetic flux density generated by them is low and noise is present. There are several methods of noise reduction. As the best one the method of FFT (Fast Fourier Transform) was found. Its application is in Fig. 2. Several waveforms were extracted from the probe output and their spectrum was computed by the FFT, see Fig. 2a. Then the actual waveform was reconstructed from the dominant harmonics (and DC component). Both the waveform and experimental points are in Fig. 2b.



a) b)

Fig. 2. Waveform reconstruction. a) FFT spectrum of 2 selected periods. The DC component and the second harmonics are 50 times higher in reality. b) Measured points and waveform reconstructed from both the DC component and the second harmonics.

This approach was applied to all the probe positions. Since the eddy currents are proportional to the current (and magnetic flux density) derivative, the time moment for calculations was selected at the maximum of reconstructed waveform. Then eddy currents are in principle avoided.

The magnetic field, as a check of skin-effect, was calculated numerically for both the constant current density and the varying current density according to formula (1) in MATLAB. The speed of calculation is relatively fast, since an analytical formula exists for a straight thin conductor, which is presented in literature [2], for instance. Then the numeric integration is performed only in the conductor cross section.

3. Results

Only preliminary experimental results dealing with the magnetic field measurement by apparatus described in part 2 are presented here. Both the component of magnetic flux density was measured above the conductors and close to them according to Fig. 3. The first realized probe movement, using printing system from old printers, was limited to about 210 mm.

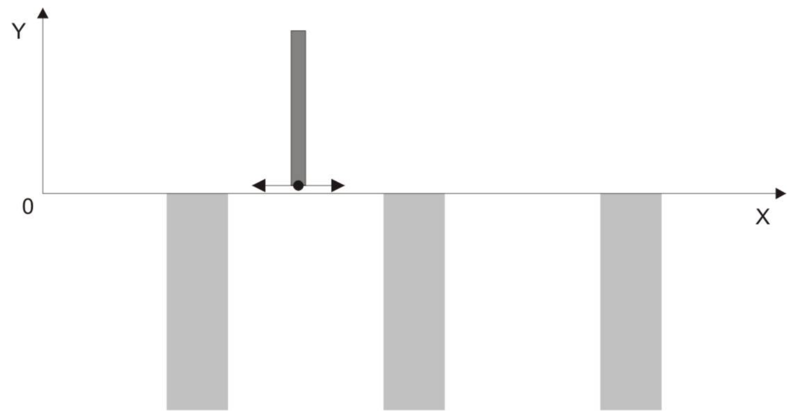
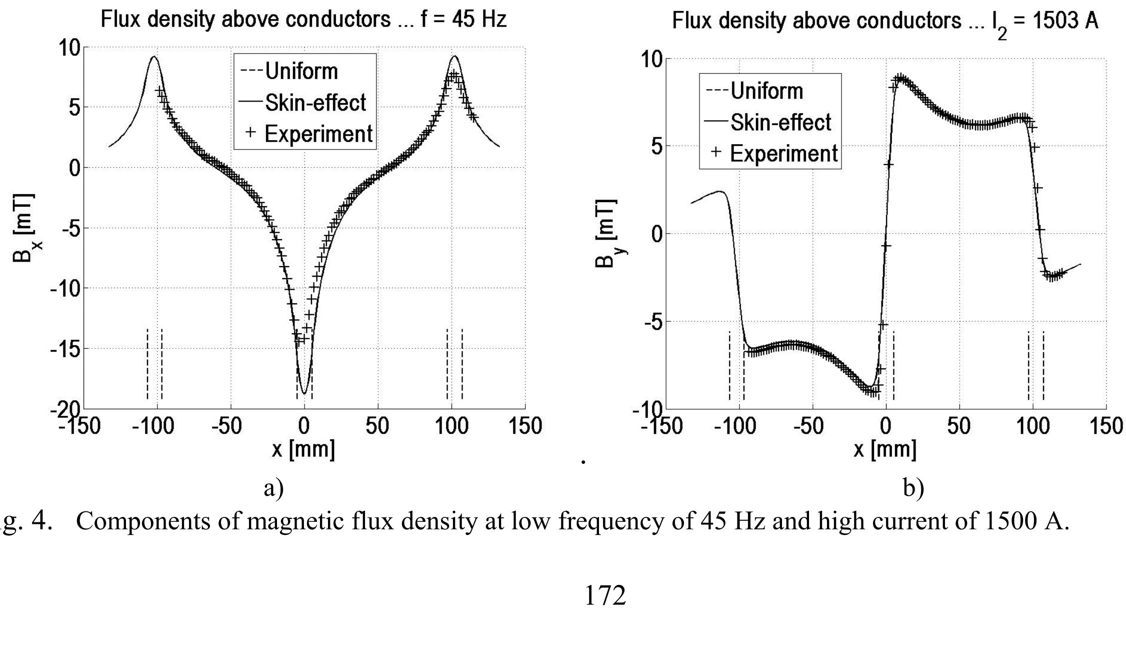


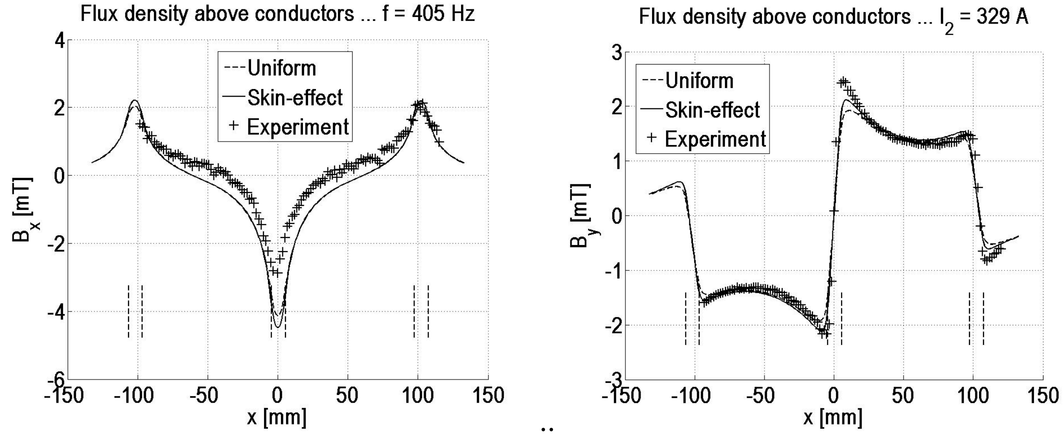
Fig. 3. Probe movement above the conductors (cross section) and coordinate system.

At low frequency of 45 Hz both the magnetic flux density components are in Fig. 4. The skin-effect does not take a place practically and the agreement between theory and experiment is good. If the frequency increases about 10 times, the skin-effect is evident for B_y component, as it is shown in Fig. 5b. In both the figures, the preliminary experiment is limited to the measurement in area near the central conductor.



a) b)

Fig. 4. Components of magnetic flux density at low frequency of 45 Hz and high current of 1500 A.



a) b)

Fig. 5. Components of magnetic flux density for higher frequency of 405 Hz and decreased current of 330 A.

In the case of higher frequency the current decreases about 5 times, the magnetic field is lower and measurement errors are visible, especially for the *x* component. The serious current decrease is a feature of commercial instrument.

4. Discussion

We have shown that the skin-effect can be studied by relatively simple means – measurement of magnetic field near the massive conductors. At low frequency a good agreement between theory and experiment was found. Systematic error for the *x* component in Fig. 4a is due to the incorrect probe calibration, probably.

At about 10 times higher frequency the skin-effect takes a place theoretically. The difference is not high, however, and its maximum is at conductor edges. Experiment confirms qualitatively the skin-effect for the B_y component in Fig. 5b. The experimental points are not symmetrical however. As for the *x* component, the errors are too high, to allow any judging.

Main problem for quantitative verification of skin-effect formula (1) is in the low magnetic field that is difficult to measure precisely. The current cannot be increased by given source. The solution is to increase the probe sensitivity and accuracy. As it is shown in Ref. [3] the improvement is practically realizable and the skin-effect formula verification can be made.

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