Investigation of the Electromagnetic Field of the Power Cable in a Steel Sleeve

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***Abstract*— When 0.4 kV cable run entries into buildings and transformer substations are performed in steel sleeve, that is a steel tube built into concrete foundation. At this work the two-dimensional modeling of the electromagnetic field created by the cable during the current flow was carried out in ANSYS Multyphysics, and also the influence of this field on the steel sleeve was investigated. Investigation of the possible heating of the tube in the presence of higher harmonics in the current spectrum is was of interest. Also the Diagrams of temperature distribution in the system "cable- tube" are presented in this paper.**

Keywords*— *cable in steel sleeve; temperature distribution; electromagnetic field; modeling in ANSYS Multyphysic; higher harmonic components

I. Description of the Type of Cable

For modeling in the ANSYS Multyphysics package, a cable of the ABBG 1x120 type was chosen. It is consists of the following parts [1]:

- Aluminum conductor.
- Core insulation: polyvinylchloride (PVC) plastic I-40-13A.
- Sheath: PVC O-40 plastic.

The working temperature of heating of aluminum cores is 70 ° C, and the operating temperature in the area should be ± 50 °C. Cables of this type are used for power supply in networks of the voltage of up to 1000 V and a current load is not more than 252 A. Typically, AVVG (vinyl-insulated flexible aluminum power cable in vinyl sheathing) cable is used three-phase four- or five-core with core stranding along the core for the supply of houses, outbuildings, etc. Electromagnetic fields created by currents flowing in phase conductors compensate each other, so the cable itself does not warm up to unacceptable high temperatures.

AVVG cable is not recommended for cable run in the ground without using of polyethylene pipes (HDPE pipes), and it is also forbidden the laying this type of cable in steel pipes due to the lack of an armor layer. However, to remove the cable from the transformer substations 10 / 0,4 kV in the wall or foundation, make a hole placing the steel sleeve (pipe length), that protect cable from damage.

The overheating of the insulation and the pipe does not arise during operation without overload when laying three-, four-, and five-core cable. However, permissible temperature can be increased when laying single-core cable that is phase conductor or neutral conductor.

If there is a three-phase symmetrical load, in neutral conductor the current does not flow, however, measurements made in practice have shown that if there are non-linear consumers in the network, it may appear in the neutral. This is due to the presence of nonlinear load that generates harmonic components, which are higher than the first order. Harmonics multiples of three are added together in the neutral conductor, that can cause unacceptable overheating and destruction.

During the research, the worst case was assumed for modeling. Amplitudes of the harmonic components multiple of three in each phase reach 30% of the fundamental harmonic amplitude, thus if one of the harmonics is multiples of three, a phase current of frequencies 150 Hz (3rd harmonic), 450 Hz (9th harmonic) or 750 Hz (15th harmonic) flows in network.

An alternating magnetic field is created around the cable. Magnetic flux penetrates the pipe; as a result, current is induced in it. The depth of current penetration into the pipe depends on the current frequency, so it changes due presence of harmonics and the power losses also changes in the pipe wall.

The paper presents the results of a study of the dependences of the power losses released in the pipe and core on the frequency of the current, the dependence of the power losses on the thickness of the pipe wall and its diameter, and also thermal and electromagnetic fields. For simulation of the heating process in ANSYS Multyphysic a time corresponding to 12 hours of continuous current flowing was chosen. An average value of current is 250 A.

II. The Results of Research

A. Electromagnetic and thermal fields

At the first step of the simulation, the electromagnetic problem was solved. The result obtained is a distribution of the electromagnetic field depending on two different frequencies. (Fig. 1, 2).

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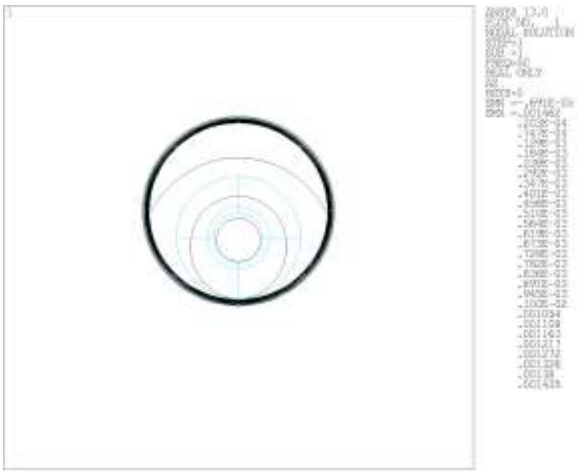

Fig. 1. Electromagnetic field. Frequency 50 Hz

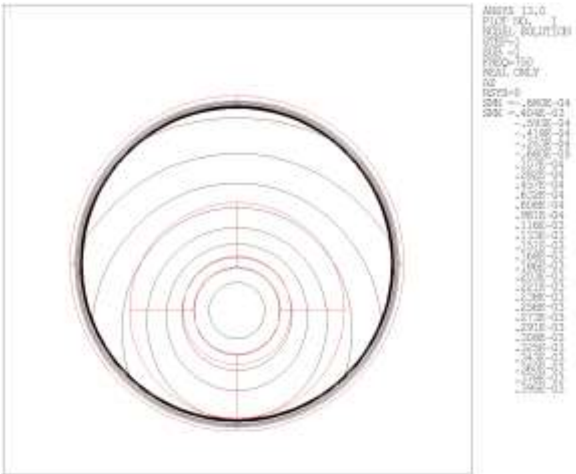

Fig. 2. Electromagnetic field. Frequency 750 Hz

As shown on Fig. 1 and 2, at frequency increasing, the concentration of the field force lines around the wire increases too. It can lead to more heating of the pipe. As the pipe is made of ferromagnetic material, the lines of the field are concentrated inside it, and the asymmetry of the field pattern along the vertical is due to the cable is arranged closer to the bottom of the pipe.

At the second step, the thermal problem was solved. The results of solution are obtained temperature distribution patterns throughout the "cable-pipe" system for frequencies of 50 Hz, 150 Hz and 450 Hz (Fig. 3, 4, 5).

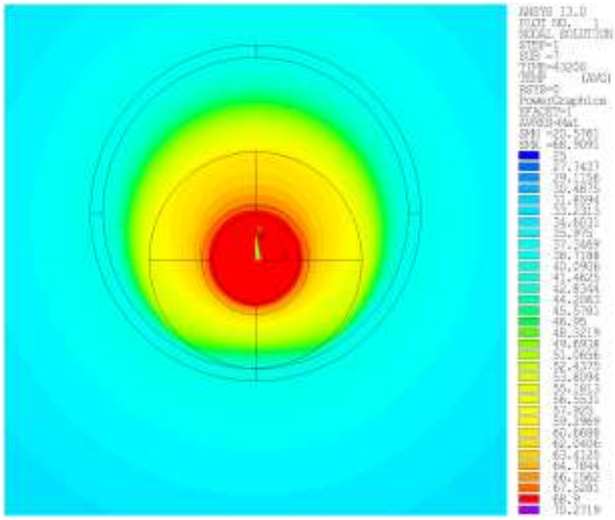

Fig. 3. Thermal field. Frequency 50 Hz

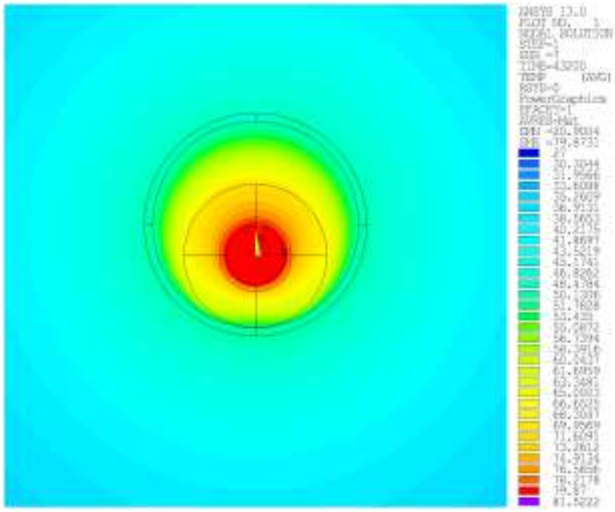

Fig. 4. Thermal field. Frequency 150 Hz

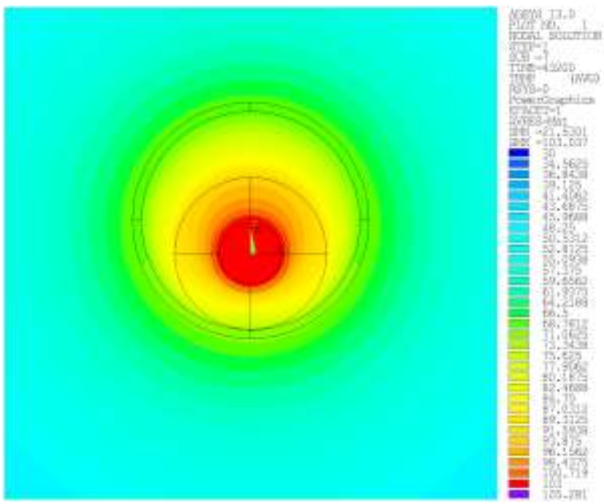

Fig. 5. Thermal field. Frequency 450 Hz

From the above figures it may be infers that at a frequency of 150 Hz, the core temperature rises above 70 degrees, it can be the fire risk. At the place of contact between the pipe and the cable heat exchange takes place between them, it leads to a temperature equalization.

B. Dependence of power losses on different parameters

During the work, the values of the power losses in the pipe were analyzed. They are caused by the currents flowing through pipe, induced by alternating magnetic field of the cable. Thermal energy is produced in the layer of penetration depth according to the Joule-Lenz law.

The graphs of the dependence of the power generated in the pipe and in the core, on the frequency of the current flowing in the cable are shown in Fig. 6 and 7. In Fig. 8, 9 graphs present the dependence of the power losses in the pipe on its diameter and wall thickness, respectively.

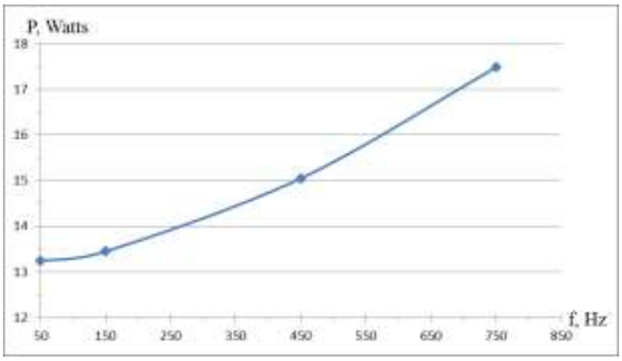

Fig. 6. The dependanece of power losses in core on frequency

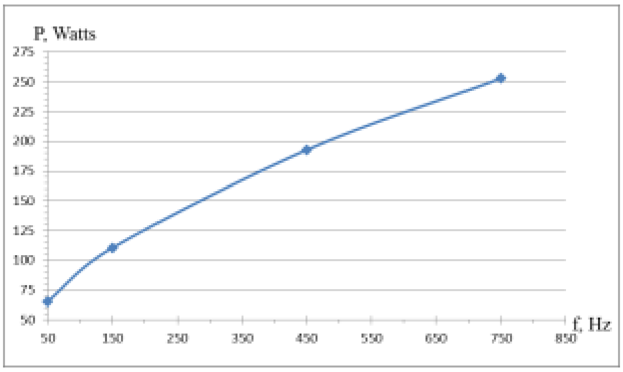

Fig. 7. The dependanece of power losses in pipe on frequency

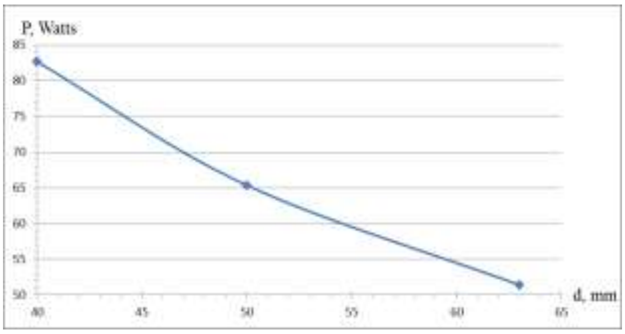

Fig. 8. The dependanece of power losses in pipe on diameter

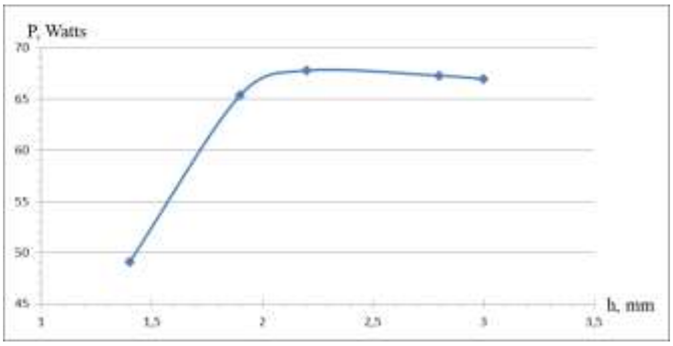

Fig. 9. The dependanece of power losses in pipe on wall thickness

From Fig. 6 and 7 it follows that as the frequency of the current increases, power losses increase too. It is due to a decreasing penetration depth and wavelength. While the length of the electromagnetic wave is longer than the thickness of the pipe wall, the heating will be stronger due to the reflection of the electromagnetic wave from the inner pipe wall.

However, in Fig. 9, an peak can be seen depending on the wall thickness, because it becomes longer than the wavelength, and so reflection does not take place, and the wave decays exponentially in the wall thickness, so the power released in the pipe decreases.

According to Fig. 8 with increasing diameter of the pipe, the power losses in it decrease, because the field penetrating the pipe wall weakens, and, consequently, the strength of the induced current decreases.

III. Conclusions of the Achieved Results

The dependences presented in the work, as well as the temperature distribution, allow make a number of conclusions on the use of single-core cables of the AVVG type.

Outlet of cables of this type separately in the pipe is possible for a phase conductor through the wall of the transformer substation if the frequency of the current is 50 Hz, and the diameter and thickness of the pipe are optimally chosen.

However, if we assume that the neutral conductor will pass separately in the pipe, troubles can occure with overheating of the core and the surrounding volume when the higher harmonic components pass through the neutral cable. In order to avoid overheating of the insulation and the surrounding volume, it is necessary to make a pipe with a larger diameter.

Thus, definite rules for laying cables must be taken into account. The neutral cable is not to be laid separately from the phase conductors, and the cable supplied to the houses is applied either four-core (3 phases and neutral) or five-core (3 phases, neutral and ground) [3].

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