When dealing with two or more nearby conductors, the ac magnetic field generated by each conductor induces eddy currents in the others, thus influencing the current density distribution in the nearby conductors. It can be understood as an inductive coupling among the nearby conductors. This is the proximity effect, which is more pronounced at high frequencies and small axial spacing between conductors, thus becoming prominent when dealing with very close conductors. Therefore, in each conductor there are self-induced eddy currents (skin effect) and eddy currents induced by the nearby conductors (proximity effect) [13]. The proximity effect alters the current density distribution within the conductor, thus increasing in some regions of the conductors while diminishing in other regions. It increases the effective ac resistance since the current is confined in a reduced area of the conductor, thus raising power losses when compared to those in isolated conductors. The proximity effect has great impact on all kind of windings in electrical machines such as transformers, electrical motors and generators among others and it is of especial importance in switch-mode power supplies [17].

The mathematical description of the proximity effect is more complex than that of the skin effect and an exact solution is only attainable in a very few geometries. However, when considering two parallel nearby conductors a qualitative description is possible. According to Lenz's law, the magnetic field generated by the alternating current in each conductor induces eddy currents in the other, as shown in Fig. 4. According to Ampere's law, the magnitude of the induced eddy currents decreases when increasing the spacing between the conductors. As shown in Fig. 4, when two parallel solid conductors carry currents of the same polarity, the current density decreases in the conductors' sides facing each other while increasing in the sides farthest away from both conductors. Contrarily, when the currents have opposite polarity, the current density increases in the adjacent conductors' sides, but it decreases in the remote conductors' sides. This effect is also important in insulated cables operated at power frequency since they can be placed very close together [18].

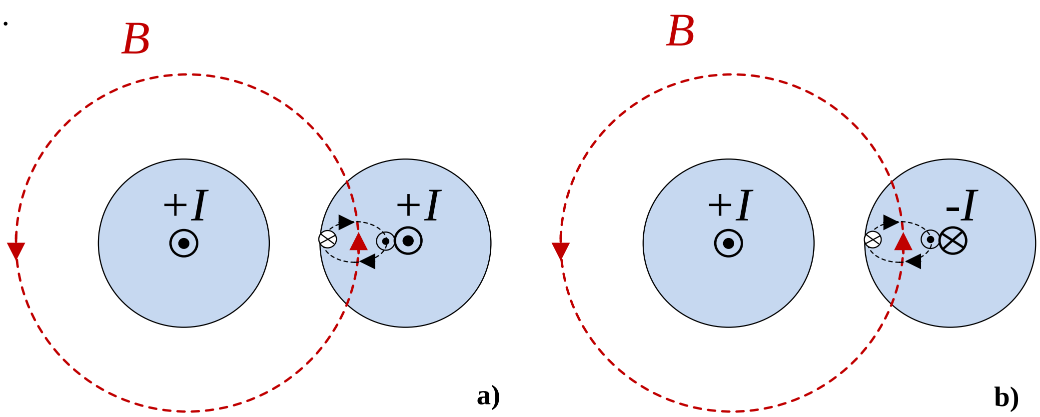


**Fig.4.** Proximity effect between two parallel solid round conductors. For simplicity only the effect of the left conductor on the right one is shown. a) Conductors with same polarity. b) Conductors with opposite polarity. The currents are in black color whereas the magnetic field density is in red color.

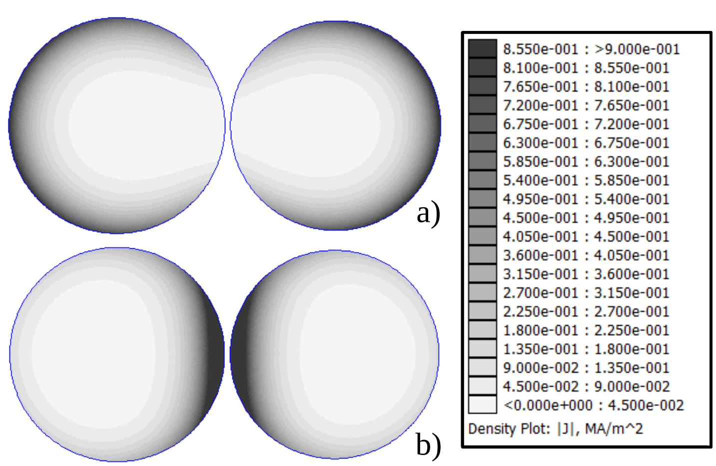


**Fig. 5.** Skin and proximity effects at 5 kHz in two AWG-0000 (11.68 mm diameter) solid round conductor of copper spaced 0.3 mm carrying 10 A each. Current density plot obtained by means of FEM simulations. a) Same polarity, +10A and +10A. b) Opposite polarity, +10A and -10A.

Fig. 5 shows the combined effects of the skin and proximity effects in two parallel AWG-0000 (11.68 mm diameter) solid round conductors of copper, spaced 0.3 mm and carrying 10 A each, when carrying currents with the same and opposite polarities.

The mathematical theory to solve this type of problems has been mainly based on the integral equation approach [19-24]. However, the solution of these equations usually offers challenging mathematical difficulties, thus the solution of a particular skin or proximity effect problem often involves applying an approximate numerical procedure based on an iterative solution of a set of algebraic equations. Exact solutions only exist for a few geometries including isolated straight round [3,4,25] and tubular conductors [26].