Measurement of the AC Resistance of Small Cross Section Power Cables

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ABSTRACT

The ampacity of power cables are strongly correlated with the AC resistance of the core conductors. AC resistance is the key factor that determines the Joule heat power when an alternative current is going through the cable. A small signal method for the measurement of AC resistance has been developed, measurement results of the AC resistance of some small cross section power cables agree with theoretical calculations.

KEYWORDS

Power Cable Conductors, AC Resistance, Skin Effect.

I. INTRODUCTION

It is well known that the current rating of power cables is highly related to the AC resistance. AC resistance is proportional to the Joule heat power when an alternative current is pumped into the cable. It is quite different from the DC resistance which is more clearly known both theoretically and experimentally. The DC resistance can only reflect the size and material of power cable conductors but not the inner structure, i.e. the stranding directions, the insulation of wires. There may be two different conductors that have the same DC resistance but different AC resistance.

Skin effect and proximity effect account for the difference between DC resistance and AC resistance of power cable conductors. Skin effect is the tendency for current to flow predominantly in the periphery of the conductor. And, it is generally accepted that this tendency is caused by the fluctuation of the inner magnetic field. Skin effect causes an uneven distribution of current over the conductor cross section and hence increases its effective resistance. When another current is presented near the current-carrying conductor, the current density distribution over the conductor cross section will be effected. This is the mechanism of proximity effect.

We have developed an instrument to measure the AC resistance of power cable conductors in room temperature. The results of some typical small cross section round stranded cables have been obtained and in good agree with the theoretical predictions.

II. THEORETICAL CALCULATIONS AND MEASUREMENTS OF AC RESISTANCE OF POWER CABLE CONDUCTORS

A. Theoretical Calculation of AC Resistance

Due to skin effect and proximity effect, the Joule heat power of different volume elements is not numerically equivalent. So the Joule heat of the whole conductor cannot be simply calculated by effective current square times the DC resistance. It should be calculated by the integration of the Joule heat power over the whole conductor. A lumped parameter called AC resistance was introduced to quantify the heat-producing capability. The definition is:

$$R_{AC} = \frac{P_J}{I_{rms}^2} \quad [1]$$

It seems that the AC resistance can be measured by a thermal method since the definition involves Joule heat. For example, a possible way to measure it could be to record the temperature rise of the conductor and the effective value of the current during a given time period. However, as mentioned above, the Joule heat power of different volume elements are different, temperature is not uniform in the conductor. Besides, the thermal method is not accurate enough in practice.

According to Poynting theorem, the Joule heat power of a conductor could be expressed as a function of electric field and magnetic field on the surface. And this theorem gives another equivalent expression of AC resistance:

$$Z = R_{AC} + jX = \frac{\dot{U}}{\dot{I}} \qquad R_{AC} = \mathrm{Re}\left[\frac{\dot{U}}{\dot{I}}\right] \quad [2]$$

This is the most popular expression of R_{AC}. The following Fig.1 is the sketch of a solid circular conductor.

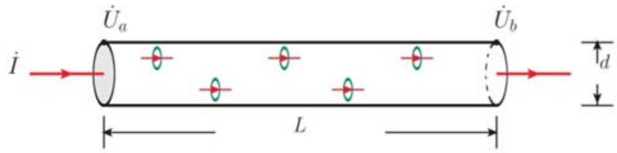

Fig.1 Current-Carrying Conductor

Point a, b are on the end face of the conductor, and i is the alternative current going through the conductor. According to Eq.2, the AC resistance of the conductor in Fig.1 is:

$$R_{AC} = \mathrm{Re}\left[\frac{\dot{U}_a - \dot{U}_b}{\dot{I}}\right] \quad [3]$$

This equation Eq.3 provides an electrical way to calculate or measure the AC resistance of the solid circular conductor. The AC resistance of circular conductors has been deeply investigated, specially by A.H.M. Arnold in references [1][2][3][4].

According to the references mentioned above, the AC resistance of a solid circular conductor can be written as:

$$R_{AC} = R_{DC}(1 + y_s + y_p) \quad [4]$$

In which, the skin effect and proximity effect are