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초 정밀 10A Shunt 개발을 위한 위상각 해석

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Analysis of the Phase Angle for High Precision 10 A Calculable Shunt

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Abstract - The phase angle which is mainly depend on time constant τ of the calculable 10 A and 0.1 Ω ac/dc resistor has been analysed. The low values of resistors are usually inductive and time constant τ very large compare to high values of resistors. The numerical analysis has been shown that the time constant τ becomes zero when introduce the compensation capacitance geometrically to the resistive coil with proper dimension. As a result a very low phase angle can be achieved within the realizable dimensions.

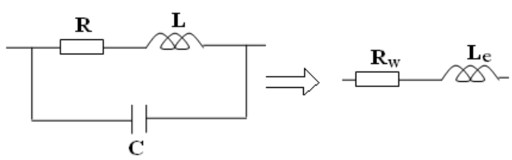
1. INTRODUCTION

Current shunts are commonly used in ac power measurements in order to measure current very precisely. However when current is converted into ac voltage a phase shift occurs between current and voltage influence of quadrature component which is cause by inductance and capacitance of the shunt resistance. This phase angle difference between current and voltage causes of an error in ac power measurement. Recently, in ac power measurement field the special attention has been given to calculable ac/dc resistors and publications on theoretical and experimental analysis about the shunt resistors have been published.[1,2] However most of the reports gave more attention to the real part of the total impedance and presented ac/dc difference of the shunt. But imaginary part mainly depend on time constant τ of the ac resistance is given more contribution to the phase angle difference between current and voltage. Therefore analyzing time constant τ of the calculable shunt resistor is given clear idea of the phase angle. Moreover determining time constant very precisely, the realization of the standard of shunt resistor is possible. In this paper the phase angle of the calculable 10 A low ohm bifilar shunt resistor has been analyzed.

2. Theory

2.1 LCR Circuit Analysis

The standards representation of a resistor can be considered as a series circuit consisting of a resistance R and an inductive L, across self capacitance C and equivalent circuit as shown in Figure 1.



<Fig 1> Standard representation of the resistor and its equivalent circuit

Where
R_w is the inphase resistance or amplitude of the equivalent impedance at the frequency ω rad/s and
L_e is the imaginary or series reactance part of the equivalent impedance.

The impedance Z of such arrangement can be written as

$$Z = \frac{R + j\omega[L(1-\omega^2 CL) - CR^2}{(1-\omega^2 CL)^2 + \omega^2 C^2 R^2} \quad (1)$$

Now in a resistor both L and C are small so that the we can make a approximation the effective resistance and reactance of the shunt are

$$R_\omega = \frac{R}{(1-\omega^2 CL)^2 + \omega^2 C^2 R^2} \approx R[1+\omega^2 C(2L - CR^2) \quad (2)$$

$$L_e = \frac{\omega[L(1-\omega^2 CL) - CR^2}{(1-\omega^2 CL)^2 + \omega^2 C^2 R^2} \approx \omega(L - CR^2) \quad (3)$$

and the Phase displacement (Φ) between the voltage and current is

$$\Phi = Tan^{-1}\frac{\omega(L - CR^2)}{R} \approx \omega(\frac{L}{R} - CR) \quad (4)$$

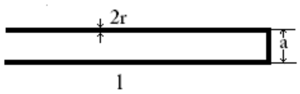
and time constant τ

$$\tau = \frac{L}{R} - CR \quad (5)$$

The equation (4) shows that the phase angle mainly depend on the time constant for fixed angular frequency ω while equation (5) reveals that the time constant τ be determined by dc resistance values of shunt and its residual capacitance and inductance. Futhermore equation (5) shows that low value resistors have larger time constant relatively higher value resistors. To design 10 A current shunt the value of resistor should be less than 1 Ω to reduce power consumption of the resistor. In this study we are planning to design 0.1 Ω bifilar coil resistor and maintain low power consumption rate. Therefore the time constant of the coil is comparatively lager and it is need to be reduced. The phase angle Φ of the calculable ac/dc resistors that will be used as standard is preferable to be frequency independent which means the resistor having the time constant nearly zero need to be constructed. Therefore a numerical analysis has been carried out to find the conditions where the time constant is close to zero introducing geometrical solution within the realizable dimension. From equation (5) we can derive that the time constant is zero when L = CR^2 . To find the condition the residual inductance and capacitance of parallel wires have to be calculated.

2.2 Residual Inductance and Capacitance

Fig. 2 shows that the simple arrangement of bifilar resistive coil which has induction and capacitance uniformly distributed along the length.



<Fig 2> Simple bifilar arrangement

For a such type of double wire having unit permeability, radius **r**, length l cm and distance apart a, the inductance is given by

$$L = 4l\left(\ln\frac{a}{r} + \frac{1}{4} - \frac{a}{l}\right) \times 10^{-9} \ henry \qquad (6)$$

and the total capacitance between the wires is

$$C_1 = \left(\frac{l}{3.6 ln\frac{a}{r}}\right) \times 10^{-12} farad \qquad (7)$$

and the dc resistance of the wire can be written as

$$R = \rho\frac{(2l+a)}{\Pi r^2} \quad ohm \qquad (8)$$

For double wire residual capacitance C = C_1 / 3 and therefore the time constant τ becomes

$$\tau = \frac{L}{R} - \frac{C_1 R}{3} \quad second \qquad (9)$$

Equations (6) to (9) show that the time constant of the resistive coil can be calculated using dimension of the wire arrangement and resistivity of the material used.

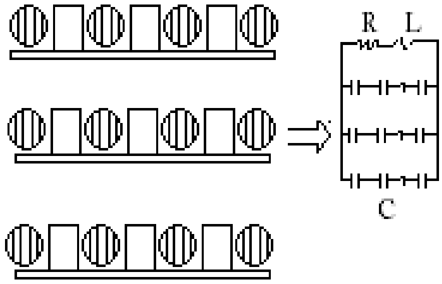
3. Numerical Simulation and Results

The resistivity value of the Manganin $4.4\text{x}10^{-7}$ has been taken for the calculation. The diameter (2r) of the wire is considered as 3mm to minimize the heat when 10 A pass through the shunt resister and 1.6 m is required to design 0.1 Ω resistive coil using Manganin wire which has very low temperature co-efficient. The following values were calculated using above mention equations. .

Residual Induction L = 6.5 x 10^{-7} H, for (a = 10mm)
Residual Capacitance = $1\text{x}10^{-11}$ F
Amplitude of the ac Resistance R_w = R (1+1.4x 10^{-7}) at ω = 10^4
Imaginary part of the impedance $L_e \approx \omega L$ =6.5 x 10^{-5} at ω= 10^2
Time constant $\tau \approx \frac{L}{R}$ = 6.5 x 10^{-7} rad/s

The above results revealed that the residual inductance is grater than the residual capacitance and the capacitance is negligible. Furthermore, the results shows that the ac/dc ratio error is very small the value of angular frequency is up to 10^4. In fact the phase angle is very large even at low frequency (ω= 10^2) since the time constant is very large for low value of resistors as shown in the results. The time constant does not becomes zero since the CR^2 is always very small when the coil resistance is less than 10 Ω. However it shows that time constant can be zero when the resistor value is more than 100 Ω and scientific literature provides examples for such type of analysis[3].

In this calculation it can be predicted that the time constant becomes zero when we introduce three parallel compensate capacitors with the value of 65μF to the resistance coil. Each value of capacitors can be obtained using ten series capacitors between two wires as shown in Figure 3.



<Fig 3> Arrangement of the resistance coil

Teflon or pyrex can be used to make support to the coil and this support edges provide capacitance effect to the coil. In this simulation dielectric value of Teflon is used. The calculated cross area of the capacitors is 3.081 mm^2. The time constant becomes zero in this model within 1x 10^{-10} s and the phase angle difference is less than 10ppm at ω =10^4.

Conclusion

The numerical simulation shows that the phase angle of ac/dc calculable resistors can be realized using electrical and geometrical properties. Furthermore this study is very useful to design high precision 10 A current shunts in ac power measurements.

Reference

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