A simple and reliable DC large current lossless sampling circuit

Lyu Chengxiang
School of Computer Science and Technology, Shandong University of Technology, Zibo, Shandong, 255000, China.
Lyu Chengxiang e-mail: lgdzsb@sdut.edu.cn

Abstract: This article introduces a method of sampling and measuring DC current using the resistance of the wire itself, which can simply replace the current sampling resistance usually used in DC current measurement, making the wire itself a simple and reliable non-destructive sampling of large DC current Measuring sensor. Since there is no change to the original circuit state, the heating loss and connection points of the access sampling resistor are avoided, thereby greatly improving the reliability of the circuit.

1. Introduction
We all know that the measurement of DC current is indirect measurement based on Ohm's law by measuring the terminal voltage across the current sampling resistor. For example, to measure the magnitude of the current in a DC circuit, the usual approach is to connect a current sampling resistor (also called a shunt resistor) with a small resistance value in series in this DC circuit. We first measure the voltage across the current sampling resistor. Then we use Ohm's law to calculate the actual current based on this voltage value (AC current can be measured by a current transformer, which is beyond the scope of this article). For small current circuits, this is no problem, but for currents of hundreds of amperes or more, the addition of current sampling resistors will cause the following problems:

1.1. Increase circuit loss
By formula
\[ p = I^2R \] (1)

It can be seen that when the resistance is a fixed value, since the power is proportional to the square of the current, even a small current sampling resistance value will greatly increase the circuit loss due to the large current.

1.2. Destroy the original actual working state
Due to the addition of current sampling resistor, the original working state of the circuit is changed;

1.3. Reduce the reliability of the circuit
Since the connection of the current sampling resistor will inevitably increase the number of contacts and connectors in the circuit, once the contacts are loose or poorly contacted, it is easy to cause a vicious cycle of heat caused by heat in the case of high current in the circuit, which will eventually cause the circuit to burn and open, resulting in the circuit malfunction.
1.4. It is easy to burn the ammeter

Only a small voltage can be applied to the two ends of the ammeter head, and only a small current can pass through itself. Once the main circuit is broken due to a large current, it is very likely that all currents and voltages are directly applied to the ammeter head, making the ammeter head burned.

2. Solution

Since the DC current measurement is to obtain the measured voltage through the current sampling resistor, we can use the wire's own resistance as the current sampling resistor to realize the lossless sampling of the current. This is our basic idea.

The majority of ordinary wires are copper wires, and we will take copper wires as an example. Check the manual and find that the resistivity of metallic copper \( \rho = 1.678 \times 10^{-8} \Omega \cdot \text{m} \) (normal temperature, 20°C, unless otherwise specified, the same below), according to the resistance calculation formula

\[
R = \rho \frac{L}{A} \tag{2}
\]

It can be calculated: the resistance of a copper wire with a cross-sectional area of 1mm\(^2\) and a length of 1m is 0.01678Ω=1.678\times10^{-2}\Omega; the same can be calculated for a 1m resistance with a cross-sectional area of 4 mm\(^2\) and a length of about 0.00416Ω=4.16\times10^{-3}\Ω, The cross-sectional area is 8 mm\(^2\) and the length of 1m resistance is about 0.00208Ω=2.08\times10^{-3}\Ω

Specific to an actual ammeter, its sampling resistance is related to the ammeter range and meter sensitivity and other parameters, but the resistance value is very small, generally expressed by the voltage drop on the sampling resistance at full scale. For example, if there is a DC ammeter with a range of 100A, when the sampling resistance is full-scale, the voltage drop \( U_A \) (the actual voltage applied to the meter head) is 75mV, we can calculate the meter head according to Ohm's law Internal resistance value

\[
r_A = \frac{U_A}{I} = \frac{75 \times 10^{-3} \text{V}}{100 \text{A}} = 7.5 \times 10^{-4} \text{Ω}
\]

According to the previous calculation, we know that the resistance of a copper wire with a length of 1m and a cross-sectional area of 4mm\(^2\) is 4.16\times10^{-3} Ω. We can calculate the corresponding copper wire resistance when the sample resistance of the meter in the above example is 7.5\times10^{-4} Ω. length:

\[
L_A=7.5\times10^{-4}Ω/4.16\times10^{-3}Ω\times1m=0.180m
\]

That is, the length is 18.0cm. If the cross-sectional area of our normal wire is exactly 4mm\(^2\), we only need to select a section with a length of 18.0 cm at any position of the wire, and draw out two leads at both ends of the section with a length of 18.0 cm. The current detection signal we need is connected in parallel to the current sampling input terminal of the ammeter (head of the ammeter) to complete the non-destructive sampling and detection of the current.

Of course, if the wire area is 8mm\(^2\), it can be calculated that its length is about 36.0cm, and the remaining cross-sectional area of the wire can be calculated by this method.

3. Check

The above is the theoretical calculation value. Because the actual cross-section of the standard wire may not be standard and other reasons, there may be a certain error with the actual situation, we can perform simple verification. Here is a simple verification method:

Take a 12V DC power supply, connect the standard ammeter (the current file of the digital multimeter is a simple standard ammeter) and the sampling wire in series in the circuit, and the load can be connected to a resistive load with appropriate resistance, such as a car headlight bulb. Because it is a series circuit, the current in the entire circuit is the same. Fine-tune the position of the sampling point until the ammeter reading is consistent with the standard ammeter. Finally, spot welding or tin
welding is used for the sampling signal lines of the two sampling points on the wire. Fix it and complete the insulation work, then the sampling resistor production and verification are completed.

4. Error analysis
According to formula (2), the resistance of a section of wire is determined by 3 factors:

4.1. The length of the wire;

4.2. The cross-sectional area of the wire;

4.3. The resistivity of the conductors making up this wire.

These three factors are all related to conductor temperature or ambient temperature. Experiments show that when the temperature range does not change much, the resistivity of pure metal changes relatively regularly with temperature, and there is approximately the following linear relationship [1]:

\[ \rho = \rho_0 (1 + \alpha t) \]  

(3)

In the formula, \( \rho \) is the resistivity at \( t \) ℃, \( \rho_0 \) represents the resistivity at 0 ℃, and \( \alpha \) is called the temperature coefficient of resistance [2]. Experiments have also proved that the alpha value of most metal materials (including metallic copper) is approximately equal to 0.004 [3]. Metal has the characteristics of thermal expansion and contraction, and the linear expansion of metal is only 0.001% for every 1 ℃ increase in temperature [4]. Therefore, when considering the change of metal resistance with temperature, we can ignore the change of the conductor length \( L \) and cross-sectional area \( S \).

| material                  | \( \alpha (1/\text{℃}) \) |
|---------------------------|---------------------------|
| silver                    | 4.0×10^-3                |
| copper                    | 4.3×10^-3                |
| aluminum                  | 4.7×10^-3                |
| iron                      | 5×10^-3                  |
| Manganese Copper Alloy    | 1×10^-5                  |
| (84%Cu,12%Mn,4%Ni)        |                           |

Table 1. The \( \alpha \) value of several metals [5].

According to formula (2), multiply both ends of formula (3) by \( L/S \) to obtain:

\[ R = R_0 \left(1 + \alpha t \right) \]  

(4)

In the formula, \( R = \rho \frac{L}{S} \) means the resistance of metal at \( t \) ℃, and \( R_0 = \rho_0 \frac{L}{S} \) means the resistance at 0 ℃. It is concluded that the resistance of most metals (including copper) has an approximate linear relationship with its temperature in the vicinity of room temperature [6].

Of course, there are a few metal materials that have extremely small resistance temperature coefficients, and these materials have become the selection materials for manufacturing standard resistors, such as manganese copper, etc. some metals have superconducting properties at very low temperatures, which are beyond the scope of this article.

According to the above analysis, when the ambient temperature changes or heat is generated due to a large current, the resistance value of the copper wire will change by about four thousandths per degree Celsius.

The two ends of the formula (4) are multiplied by the current \( I \) respectively to obtain:

\[ U = U_0 (1 + \alpha t) \]  

(5)

Where \( U \) is the current sampling voltage obtained at \( t \) ℃, and \( U_0 \) is the current sampling signal voltage at 0 ℃.

According to formula (5), a conclusion can be drawn about the current measurement error: the
obtained current signal voltage (i.e., the measured value) is approximately proportional to the
temperature of the conductor, and the measured value increases by about 0.4% (α≈0.004 compared to
0°C), this is the main source of error.

Now that we know that the error mainly comes from temperature changes, in order to reduce the
error in actual use, we can choose the temperature closest to the actual use when calibrating, for
example, the room temperature is 20°C instead of the theoretical 0°C, so that it is closer to the real
Temperature, and according to formula (5) we can know that after such correction, the measured value
will be smaller than the actual value when the correction temperature is below 20°C, and will be larger
if it is above 20°C.

Considering that for high-current circuits, in addition to environmental temperature changes, large
cross-section wires generally have a relatively small impact on heat due to current passing (otherwise
it is a typical wire cross-section selection improperly, you need to choose another wire cross-section),
therefore, this error It is suitable for occasions that do not require high accuracy, but require low cost
and high reliability.

For places with higher requirements for errors, it can also be corrected by adding temperature
measurement and temperature compensation, which will not be repeated here.

5. Examples
The actual verification was carried out with the domestic automobile Baojun 310W. The positive
electrode of the main battery of the car is connected to the positive electrode of the 200AH lithium
phosphate spare auxiliary battery at the trunk by two parallel 4mm² insulated copper wires via a
120A fuse, and the relay is turned on and off to control the connection of the two batteries or
Disconnect, the two batteries share the ground. A section of about 36cm is selected in the middle of
the parallel 4mm² insulated copper wire. After checking with the method described in this article, the
sampling signal line is led out and connected to the current-voltage integration with a range of 100A
and a full-scale voltage drop of 75mV In the digital header. The car is turned off, and the electricity is
supplied by the auxiliary battery, and the main battery is floated at the same time (the voltage of the
battery pack composed of 4 strings of lithium iron phosphate batteries is greater than 12.8V, and the
standard voltage of the nominal 12V lead-acid battery is generally around 12.3V) . The engine works,
the main and auxiliary batteries are connected in parallel, and the car generator charges the main and
auxiliary batteries at the same time. Since the normal working voltage of the lithium iron phosphate
secondary battery is higher than that of the lead-acid battery, the main battery is always in a floating
state, and there is basically no loss of power. Moreover, at the moment the car starts, the auxiliary
battery can also provide a large starting current to the main battery. The experimental data is as
follows: if only the Acc switch is turned on, the auxiliary battery will provide about 1~2A current to
the main battery when listening to music at medium volume, and the current will increase to 2~5A
when the main power switch is turned on; the auxiliary battery can be detected when the car starts.
There is about 80~90A auxiliary starting current to the main battery. After the car is started, the
normal charging current to the secondary battery will vary according to the power of the secondary
battery. It will gradually decrease from the maximum 60A until it becomes 0A when it is fully charged.
If the secondary battery is also connected to a large load, such as during driving An 800W electric
pressure cooker powered by an inverter is connected to the auxiliary battery, and the maximum current
can be increased to nearly 70A. Since the rated current of the car generator is 100A, there is no
overcurrent or overload, and the current at this time is provided by the generator and the main battery
to the auxiliary battery. The vehicle has been driving for more than two years, more than 40,000
kilometers, and it has accumulated more than 4 months for cooking with this power system in the field
and traveling. Everything has been displayed normally and has been running normally.
6. Conclusion

6.1. Advantages of this sensor.

6.1.1. No additional circuit loss is added.

6.1.2. Did not cause any damage to the original circuit.

6.1.3. The circuit is simple, no additional resistance and contacts are added, and the reliability is greatly improved.

6.2. Disadvantages of this sensor.
The accuracy of the measured value is affected by temperature, and there is a linear error that can be corrected.

references
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