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Research of Measurement Circuits for High Voltage Current Transformer Based on Rogowski Coils

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Abstract: The electronic current transformer plays an irreplaceable position in the field of relay protection and current measurement of the power system. Rogowski coils are used as sensor parts, and in order to improve the measurement accuracy and reliability, the circuits at the high voltage system are introduced and improved in this paper, including the analog integral element, the filtering circuit and the phase shift circuit. Simulations results proved the reliability and accuracy of the improved circuits. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: High voltage current transformer, Rogowski coils, Analog integrator, Low-pass filter, Phase shift circuit, Simulation.

1. Introduction

Along with the increasing innovation of science and technology, the voltage grade of the national power grid is increasing ceaselessly, mainly to large capacity, intelligent, big power, high voltage power and so on, leading to the bigger current of the short circuit.

Therefore, the requirements to electric current measuring instruments are more and more improved. Traditional electromagnetic current transformers and their applications have been developed mature but have some disadvantages, such as more and more complex insulation structures, heavier weight and higher cost, etc. At the same time, there are also many problems in the application process, such as ferromagnetic saturation, flammable and combustible, small dynamic range, sensitive to electromagnetic interference. The opening of the secondary circuit will yield high voltage that is potentially dangerous to the instrument and the operator, etc. [1-3].

Compared to the traditional electromagnetic current transformer (CT), electronic current transformer based on Rogowski coils has no core and doesn't exist magnetic saturation and ferromagnetic resonance problems with the characteristics of small volume, light weight, transient response range, high measurement accuracy, wide frequency response, resistance to electromagnetic interference, insulation and reliability, and low price etc. In this paper, the measurement circuits for high voltage current transformer based on Rogowski coils are researched and improved. By improving the integrator circuits, low frequency disturbance is eliminated and the phase compensation is realized, and the related simulations to improving measurement circuit were made.

2. The Principle of Rogowski Coils and the Mutual Inductance Calculation

Rogowski coils are uniformly winded coils in a nonmagnetic frame and the principle diagram is shown in Fig. 1 [4].

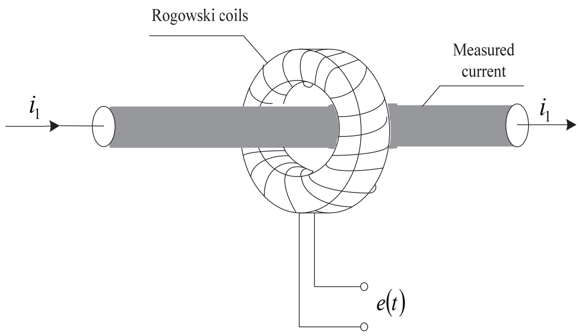


Fig. 1. Rogowski coils principle diagram.

There are usually two kinds of cross section of Rogowski coils: rectangular and circular, the structure diagram is shown in Fig. 2(a) and Fig. 2(b) [5].

The induction electric potential and the mutual inductance M of rectangular cross section for Rogowski coils are shown in the formulae (1) and (2) respectively.

$$e(t) = -\frac{d\Phi}{dt} = -\frac{\mu_0 Nh}{2\pi} In \frac{R_2}{R_1}\frac{di_1}{dt}, \quad (1)$$

$$M = \mu_0 \frac{Nh}{2\pi} In \frac{R_2}{R_1}, \quad (2)$$

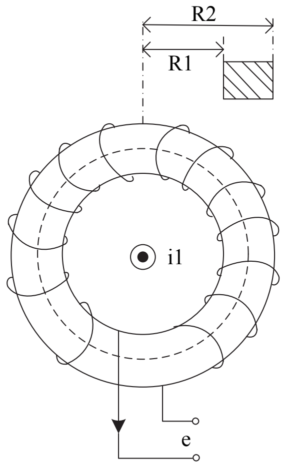
where i_1 is the current that flows in high voltage bus with the unit of A; μ_0 is vacuum magnetic conductivity; N is the coils number of turns; h is frame height with the unit of m; R_2 is the outside diameter of the skeleton with the unit of m; R_1 is the outside diameter of the skeleton with the unit of m.

The induction electric potential and the mutual inductance M of circular cross section for Rogowski coils are shown in the formula (3) and (4) respectively.

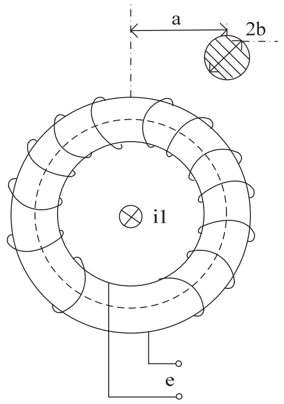
$$e(t) = -\frac{d\Phi}{dt} = -\mu_0 N(a - \sqrt{a^2 - b^2})\frac{di_1}{dt}, \quad (3)$$

$$M = \mu_0 N(a - \sqrt{a^2 - b^2}), \quad (4)$$

where a is the distance between the skeleton section center and the center of the skeleton with the unit of m; b is the skeleton section radius with the unit of m.



a) rectangular cross section.



b) circular cross section.

Fig. 2. Rogowski coils structure schematic.

Therefore, considering of the two kinds of the two circumstances above comprehensively, the induction electric potential of rectangular or circular cross section for Rogowski coils is shown in the formula (5).

$$e(t) = -M\frac{di_1}{dt} \quad (5)$$

When the structure of Rogowski coils is determined, the mutual inductance M is a constant, and the induction electric potential e (t) of Rogowski coils is proportional to the rate of the current i_1 that goes through the Rogowski coils. No matter what the shape of coils section is changed, the formula (5) is true and the phase difference between the induction electric potential $e(t)$ of Rogowski coils and current i_1 is 90°. During the industrial application, the measurement system could be improved according to the actual situation.

3. The Measurement Circuit of the Electronic Current Transformer for High Voltage

a) The Principle of the Measurement Circuit.

The electronic current transformer is based on Rogowski coils that are used as sensor parts. According to the electromagnetic induction principle of the whole current, when the measured current goes through the Rogowski coils, the induction electric potential e(t) is generated at the end coils by the magnetic field introduced from the high voltage bus current changes with time and that are proportional to di_1/dt. Due to the phase difference is 90°, the external reverse integrator is needed to attain a voltage signal that is the same phase and is proportional with current i_1. Then, the voltage signal would be converted to digital signal through an A/D converter with V/F type. Finally, it is modulated into light signal through the E/O converter.

Signal is transmitted by optical fibers to the low voltage side. The optical fiber is the link belt of the high voltage side and the low voltage side, and the electrical isolation of high voltage side and low voltage side can be realized, increasing the electromagnetic interference resistance.

In the normal working conditions of electric system, a low pass filter is needed to filter the effect of noises and to improve the accuracy of measurement. At the same time, the phase difference between output voltage and measured current is not equal to 90° because of the inductance and the stray capacitance of Rogowski coils, while the phase difference of the integrator is not completely equal to 90° in the actual. In order to meet the angle error requirement in the standard of IEC60044-8, the corresponding phase compensation must be made. The Principle diagram of the measurement circuit for high voltage is shown in Fig. 3.

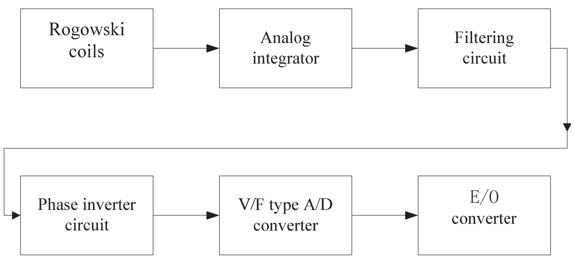


Fig. 3. Measurement circuit principle diagram of high voltage.

b) Analog Integrator.

According to the equation (5), the phase difference between output voltage and measured current is equal to 90°, so it needs an external reverse integrator. Generally, analog integrator is divided into passive integrator (simple RC passive integrator) and positive integrator, and the positive integrator is divided into the ideal integrator and integrator with inertial link.

In the practical application, whether it is the ideal integrator or integrator with inertial links, it has the amplitude frequency characteristic that the change of amplitude is inversely proportional to the change of frequency. So the low frequency interference is much higher than the working signals and the interference influences the normal working of the integral circuit, increasing measuring errors.

In order to eliminate these effects, another kind of integral circuit is adopted in this paper, shown in Fig. 4. It is same to integral circuits with inertial link that there are negative feedback links and could inhibit "integral drift" effectively. But an integral capacitance is parallel with the feedback resistance, and the drift voltage is changing slowly due to the feedback resistance, so the effects of inhibiting drift are very significant [6].

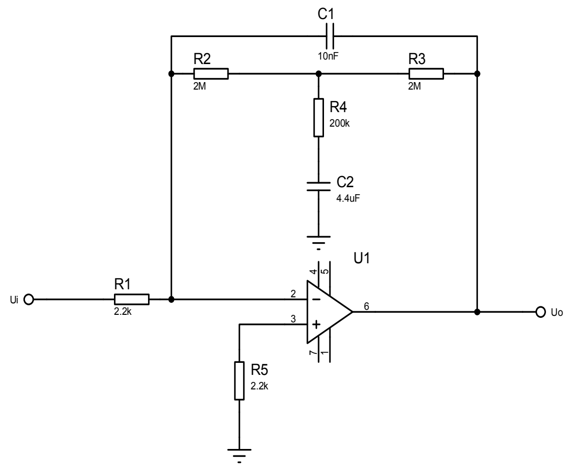


Fig. 4. Improved integral circuit filtering circuit.

The transfer function H (s) of improved integral circuit is shown in the equation (6).

$$H(s)=\frac{U_o}{U_i}=-\frac{1}{R_1}\frac{2R_2+sC_2\left(R_2^2+2R_2R_3\right)}{1+s\left(R_3C_2+2C_1R_2\right)+s^2C_1C_2\left(R_2^2+2R_2R_3\right)} \tag{6}$$

c) Filtering Circuit.

Input signal of the measurement channel needs a filter in order to improve the measurement precision and avoid the effects of noises [7]. Because the attenuation rate of the first-order filter is twenty db/ten times frequency, and the filtering effect is not ideal, the second-order Butterworth low-pass filter circuit is adopted which attenuation rate is forty db/ten times frequency that can satisfy the filtering effect. Second-order Butterworth low-pass filter circuit is shown in Fig. 5.

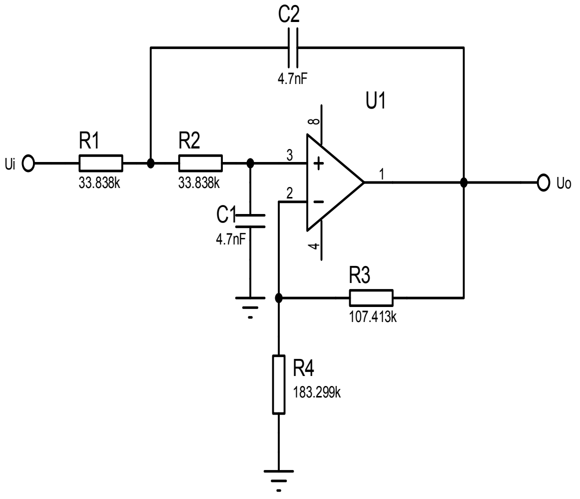


Fig. 5. Second-order Butterworth low-pass filter circuit.

The cutting-off frequency of the second-order Butterworth low-pass filter circuit is 100 Hz, and the low frequency signal can be transmitted effectively, attenuating the high frequency signal.

The first-harmonic current of the high voltage bus with the frequency of 50 Hz has a certain phase shift after filtering by the second-order Butterworth low-pass. Simulation waveform from the second-order Butterworth low-pass filter circuit is shown in Fig. 6.

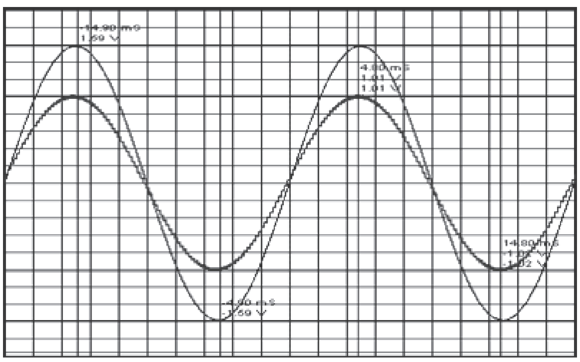


Fig. 6. Filter circuit simulation diagram.

The input signals are the sinusoidal voltage U_i with the amplitude of 2 V and the frequency of 50 Hz, in addition of an interfering sinusoidal signal with the amplitude of 200 mV and the frequency of 10 KHz. The input signal U_i is shown in thick line the output signal U_o is shown in fine line. It is known from Fig. 6 that the second-order Butterworth low-pass filter circuit can satisfy filtering effect.

d) Phase setting circuit.

Phase setting circuit can regulate the signal with a constant frequency. When the signal goes through a filtering circuit, its phase will lag a fixed value, so the phase inverter circuit is necessary to compensate it in order to decrease the error. The phase setting circuit is shown in the Fig. 7.

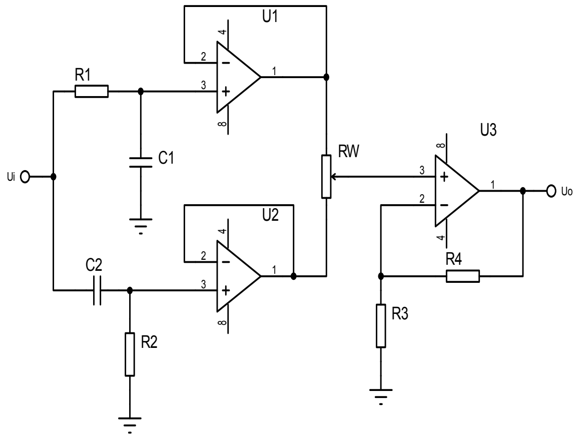


Fig. 7. Phase setting circuit.

When in the Fig. 7, $R = R_1 = R_2$, $C = C_1 = C_2$. When the period of signal is 2πRC, the angular frequency ω=1/RC, and the phase shift angle is -45° and +45°. In this case, the phase shift angle will be not more than ± 45 ° in the Fig. 7.

e) A/D Converter of the Type V/F.

The current in high voltage bus measured by electronic current transformer is the analog signal. The optical fiber for signal transmission is the bridge of high voltage side and low voltage side for the whole measurement system, so it is necessary to convert analog signals to digital signals so as to transmit by optical fibers. The A/D converter of the type V/F is adopted in this paper which circuit is shown in Fig. 8 [8].

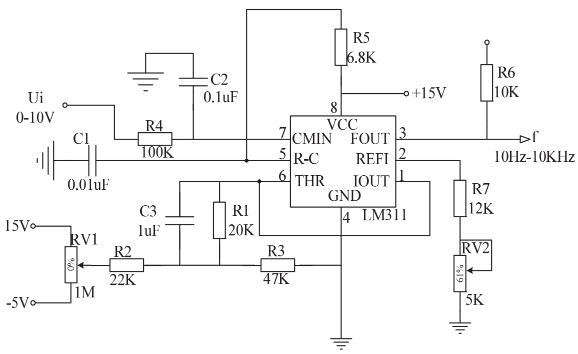


Fig. 8. A/D converter of V/F type.

When in the Fig. 8, the resistance R_s is made by R_7 = 12 kΩ and potentiometer of R_{V2} = 5 kΩ, and is to adjust the gain deviation and the deviation caused by R_1, R_5, and C_1, correcting output frequency. The function of R_4, C_2 in Fig. 8 is to improve the converting accuracy. When the components parameters of the V/F converter circuit are taken the same with the Fig. 8, the input voltage signal of 0-10 V can be converted into output frequency signal of 10 Hz-10 kHz [9].

4. Simulation to the High Voltage Measurement Circuit

The Simulation waveform of analog integral circuit is shown in Fig. 9. Where the current i_1 with the amplitude of 2,000 A and the frequency of 50 Hz pass through the high voltage bus. The simulation waveforms of the high voltage current i_1 and output voltage U_o are shown in Fig. 10.

We can conclude from the Fig. 10 that both current i_1 of high voltage bus and output voltage U_o has same phase and different amplitude [10].

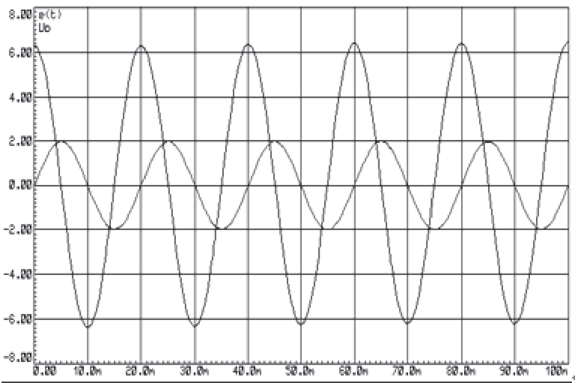


Fig. 9. Input/output waveform of analog integrator.

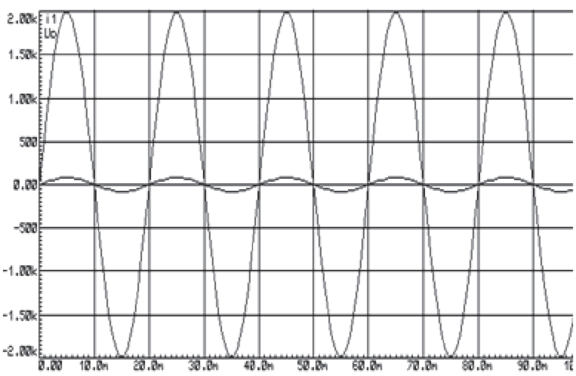


Fig. 10. Simulation waveform of current i_1 and output voltage U_o.

Conclusion

This paper mainly introduced the measurement circuit of electronic current transformer based on the Rogowski coils for high voltage, and improved the measurement circuit. It can be seen from the simulation results that the output voltage U_o of measurement circuit is linear relationship to the high voltage current i_1. The current test results show that the system can realize linear measurement of the high voltage bus current.

Acknowledgements

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References

[1]. Zhang Jianchao, Liu Xiaobo, Development of high voltage electronic transducers and their application in power system, *High Voltage Apparatus*, Vol. 45, No. 4, 2009, pp. 106-110.

[2]. Yang Guang, Liu Xingrong, Design on the primary side of active optic-electric current transformer based on the Rogowski coil, *High Voltage Apparatus*, Vol. 41, No. 1, February 2005, pp. 45-47.

[3]. Jia Chunrong, Zhang Qingling, Zhigang Di, Design of high voltage signal processing circuit of electronic current transformer, *Instrument Technique and Sensor*, No. 7, 2008, pp. 17-19.

[4]. Zhang Yuhong, Simulation analysis and design of Rogowski coil current transformer, Master Thesis, *Harbin Institute of Technology*, 2006, pp. 9-10.

[5]. Hu Juan, Research of electronic current transformer based on the Rogowski coil, Master Thesis, *Hunan University*, 2003, pp.18-21.

[6]. Guo Xiujie, Research and design on Rogowski coil sensor head of electronic current transformer for measurement, Master Thesis, *Shandong Agricultural University*, 2009, pp. 23-35.

[7]. Prabhu Ramanathan, R. Marimuthu, R. Sarjila, P. Arulmozhivarman, Performance comparisons of interface circuits for measuring capacitances, *Journal of Theoretical and Applied Information Technology*, Vol. 39, No. 1, 2012, pp. 1-5.

[8]. Rachid Dehini, Slimane Sefiane, Power quality and cost improvement by passive power filters synthesis using at colony algorithm, *Journal of Theoretical and Applied Information Technology*, Vol. 23, No. 2, 2011, pp. 70-79.

[9]. Yuan Jing, Study on laser-powered current transformer based on PCB-Rogowski coil, Master Thesis, *Yanshan University*, 2012, pp. 35-38.

[10]. Yu Guangping, Chen Na, Research of high voltage side data acquisition system for current transformer, *China New Technologies and Products*, No. 20, 2009, pp. 50-51.