論 文
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에폭시 스페이서에 내장되는 전류센서와 전압센서의 출력특성

Output Characteristics of Current Sensor and Voltage Sensor Built in Epoxy Spacer

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Abstract - In the distribution networks, it is necessary to develop small and light voltage and current sensor for compact and digitalized switchgears. For this purpose, some researches have been continuing till now, CT(current transformer) and VT(voltage transformer) are one of that research. But conventional CT and VT have some problems, that is, have big size and saturation characteristics because of used to iron core. In this paper, CS(current sensor) and VS(voltage sensor), have some merits measuring of current and voltage magnitude as a alternated conventional equipment, were studied. So, this paper shows the process CS and VS design method, equivalent circuit and output result, respectively. As a result of this test, proposed CS and VS have linearity for the output, no saturation.

Key Words : Current sensor, Voltage sensor, Rogowski coil, Epoxy spacer

1. Introduction

Using iron core for electrical equipment were much demanded during long time ago. Instrument transformer (IT) is one of the these utility. This core is not complexity and shows good characteristics within typical core size. This product is made stacking the silicon steel and for the purpose of stack the steel is get rid of eddy current. But this iron core is heavy weight for oneself and is composed of easy to rust, so that result influence on the output characteristics. The most hazardous demerits of iron core can influence on IT output because of saturation. This saturation is caused error because of exciting current(leakage current). That is, IT has linearity till measured current and voltage but if their is over the range of threshold then caused error. For improving measurement current, in recent years the Rogowski-coil(RC) method of measuring electric current has developed from a laboratory curiosity to a versatile measuring system with many application throughout industry and in research. This current sensor was called ECT(electronic current transducer(sensor)). ECT is fully contained which have electronic circuit connected with ECT. And for improving measurement voltage, RC divider (resistor-capacitor), R divider (resistor) and C divider (capacitor) were introduced and used. These dividers have different merits according to using environment. This paper used to R-divider because of following items.

- excellent steady state accuracy
- excellent transient performance
- cast resin insulation is completely insensitivity to surges

The paper describes principle of sensing of ECT/EVT, electronic circuit for ECT and their measuring results.

2. Measuring principle of ECT/EVT

2.1. ECT(electronic current transformer)

ECT is basically using the RC measuring method. RC measuring consists of an 'air' cored toroidal winding encircling the conductor to be measured current. ECT is called RC measuring system and electronic circuit; amplifier and filter, etc; connected to secondary part. RC shows good linearity at wide range but their output signalis small and their output seriously affected by external noise. So, it needs that function of amplifier and function of shielding from inflow disturbance. Output voltage can calculate using Ampere's Law and their driving process is following equation.

$$\oint H \bullet dL = I \tag{1}$$

Equation (1) shows Ampere's law. This is an electric

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current produces a magnetic field. In physics, Ampere's law is the magnetic equivalent of Gauss's law, discovered by Ampere. It relates the circulating magnetic field in a closed loop to the electric current passing the rough the loop.

Equation (2) and (3) are present output voltage coil and ECT from induced mutual inductance.

$$V_{coil} = -M\frac{di}{dt},$$

$$V_{coil} = -2\pi fIM \text{ (for sinusoidal)} \quad (2)$$

$$V_{out} = M\frac{I}{\tau} \quad (3)$$

where, M : mutual inductance, $\tau = RC$: time constant

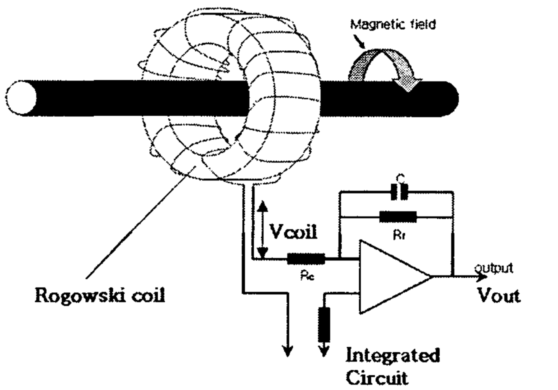

Fig. 1 Principal and component of ECT (rogowski coil with electric circuit)

Technical benefits of introducing rogowski coil for current sensors are extensive dynamic range, non-saturated characteristics, high degree accuracy, compact size and right weight. So it was ready to apply this current sensor for distribution systems. But in order to enhance sensing accuracy within ±1.0%, it is needed to overcome the following problems:

1) Coil winding problems to achieve uniform magnetic field characteristics
2) Cross talk effect due to the adjacent external current
3) Output voltage measurement errors according to the temperature variation
4) Effect of output voltage due to the external radiational noise
5) Output errors caused by assembly conditions

The assembly feature of designed rogowski coil is of shield for noise reduction, plate for the adhesion of rogowski coil in the define place and shielding mesh for the signal line. The most important thing to consider for the rogowski coil design is to derive the shield structure for reducing external noise and to consider the assembly freedom and economical aspects of the mechanical components. As a respect of circumstance, this RC was performed epoxy molding, and molding temperature usually over 130℃. So instead of air core, teflon core was used. Most of all, air core cannot use as the core because of need something purpose of support with RC when molding process. Fig. 1 shows the diagram about principle of RC.

2.2. EVT(electronic voltage transformer)

EVT used to resistive voltage divider. Resistive voltage dividers are available for the measurement of MV class voltages. High voltage was measured by sensing the low voltage branch value and adjusting voltage ratio of the apparatus. That is, output voltage can acquire equation (4) and Fig. 2 shows the principal of resistive voltage divider.

$$V_{out} = \frac{R_{small}}{R_{high} + R_{small}} V_{high} \quad (4)$$

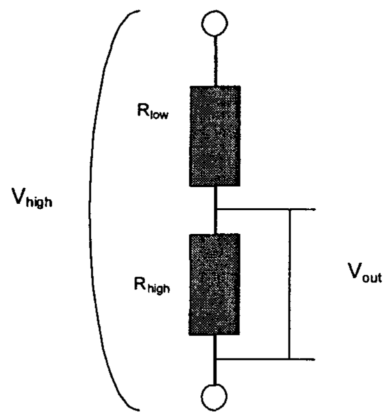

Fig. 2 Principal of EVT(resistive voltage divider type)

High voltage was measured by sensor the low voltage branch value and adjusting voltage ratio of the apparatus. But in order to enhance sensing accuracy within ±1.0%, it is needed to overcome the following problems:

1) Resistor value variation according to the temperature change
2) Stray capacitances of high voltage and low voltage branch

3) Effect of output voltage due to the external radiational noise
4) Enhancing reliability of high voltage resistor concerning thermal wattage.

To solve this problem, most of all, divider was used non-inductive resistor all of high and low part. The assembly of the designed voltage sensor are consist of high voltage resistor, low voltage resistor, high voltage shield for reducing electric field, and low voltage shield to minimize the external noise penetration. The size of low voltage shield has coincide with the capacitance, i.e., to reduce the total capacitance value in the electrical circuit, its size must be carefully considered, and the voltage shield should consider the stray capacitance in order to minimize the phase error. Thus, applicable high voltage resistor was to get profitable insulation and temperature characteristics, and also sufficient thermal wattage. In order to minimize errors of voltage division ratio, voltage divider set was selected, which has uniform voltage division ratio between high voltage and low voltage branch. Finally, design of corona mesh for protecting high voltage resistor used FEM(finite element method) analysis and basis on that results decided size and shape of corona mesh.

3. Design specification

3.1 Specification of ECT/EVT

Rated specification of ECT/EVT for design shows table 1.

Table 1 Fault simulation results

ECT		EVT	
Rated voltage	24kV	Rated voltage	24kV (22.9kV)
Measured current range	10-2500A	Ratio	10000:1
Output	180mV	Output	$2.29/\sqrt{3}$
Insulation level	24/50/125kV	Insulation level	24/50/125 kV
Error	± 1%	Error	± 1%
Fault current	40kA/3sec	Type	Resistive divider
Primary component	Rogowski coil	-	-

Table 2 Design specification of ECT

No.	Items	Design specification
1	Core size	260 mm
2	Coil diameter	0.4 mm
3	Core thickness	9.4 mm
4	Turns	2100 turn/m
5	Inductance	0.42 mH
6	DC Resistance	8.27 Ω
7	Sensitivity	0.082 mV/A
8	Output voltage	51.66 at 630A

Table 3 Design specification of EVT

No.	Items	Design specification
1	Ratio	10000 : 1
2	Primary resistance	600 MΩ
3	Secondary resistance	60 kΩ

As design of ECT, acquiring output 180mV is so difficult because ECT has small signal. So, Due to this reason secondary part must used amplifier and integrated circuit at the same time.

Important thing when design ECT, amplifier was used to output voltage 180mV. Based on this specification, ECT/EVT design was performed and their results are shown table 2.

3.2 Electronic circuit

Integrated circuit(IC) is applicable to ECT. ECT has very small signal. To acquire wanted output characteristic, their output would be amplitude. In this paper, as a part of electronic circuit are used integration and amplitude circuit. Amplifier multiple decided 20 times. That is, because measured primary current have wide range. And wanting output will be acquired using variable resistor. Besides, ECT's final output easily exposed to noise. So, concerned about noise grounding problem is very important thing because their characteristics are effect on output. To overcome this problem this paper was used virtual ground system. As this system, capaciously capacitor is connected to the circuit and that capacitor is instead of the ground, so called virtual ground. Another merit of virtual ground can actively manage for the noise. Fig. 3 and 4 show the amplifier circuit diagram, and virtual ground circuit diagram, respectively.

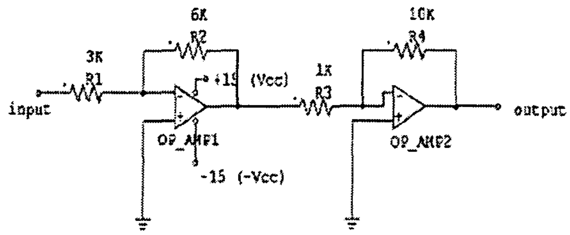

Fig. 3 Operational amplifier diagram(multiple : 20)

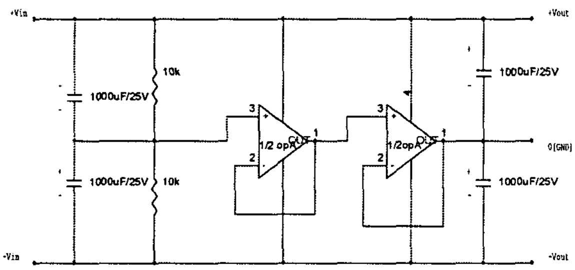

Fig. 4 Virtual ground system

4. Result and discussion

Point of view this paper is combined ECT/EVT within epoxy spacer. ECT/EVT is contained all together in the epoxy. So, their mountain is limited because of narrow space. And EVT must designed consideration with insulation condition. EVT output was influenced by their condition. To solve this problem, using FEM analysis positioned the EVT/ECT. Final decision is increasing of thickness, so ECT is positioned between insert and EVT is positioned not influenced by insulation condition (not showing this manuscript). Processing of epoxy molding in spacer performs vacuum condition and coil doesn't hurt due to heating. Their measuring result shows the following.

Table 4 shows measuring equipment for ECT and Table 5 shows measuring result. And Fig. 5 shows the linearity.

Table 4 Measuring equipment for ECT/EVT

Equipment	Specification
Current measuring system	Input : 200Vac, output : 0-2000A
Multi-meter	Portable multi-meter
Vernier calipers	Digital type
Double bridge	Analog meter (for resistance)
LCR meter	Digital(type:PM6304) - for Inductance

Table 5 Measuring result of ECT/EVT

Input[A]	Output[mV]		Error[%]
	Theoretical	Measured	
50	4.1	4.12	-0.12
100	8.2	8.3	-1.2
200	16.4	16.4	0
300	24.6	24.4	0.8
400	32.4	32.4	0
500	41	41.2	-0.5
630	51.66	51.6	0.1
700	57.4	57	0.7
800	65.6	65	0.9
900	73.8	74.5	-0.95
1000	82	82	0
1260	103.32	102.4	0.9

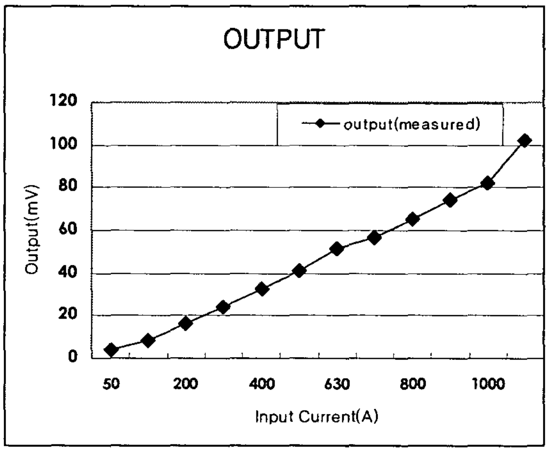

Fig. 5 Linearity characteristic of ECT

These results don't perform amplitude. Error don't exceeds ±1% and shows good result as a linearity. And these results are average value of ten specimens. Not showing at this paper, inductance and DC resistance was measured. That result is equal to the designed value.

Table 6 Output characteristics of EVT

	Resistance characteristic [Ω]			Output characteristic[V]			
	Design	Mea-sure	Error	Input Voltage	Out-put	Mea-sure	Error
High resistor	600M	599.9M	-0.1M	13200	1.32	1.329	+0.009
Low resistor	60k	60.4k	0.4k				

Table 6 shows output result of EVT. Their result is good and error don't exceeds ±1%.

5. Conclusion

ECT and EVT were manufactured and measured of their output in this paper. In the introduction, as ECT/EVT merits was mentioned no saturation, linearity and exact output, etc,. These merits was proved measuring output. That is, ECT/EVT has a good linearity, no saturation (table 5 and 6). Of course, not showing this paper, insulation tests were passed (withstand voltage test, impulse test, PD test, etc,). But to apply this equipment in the field, another type test need and pass through of EMI test.

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