EMBEDDED APPLICATION OF VOLTAGE AND CURRENT SENSORS IN THE DISTRIBUTION TRANSFORMER

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ABSTRACT

The embedded application of voltage and current sensors to the distribution transformer is presented. The structure, working principle and design methods of the equipment, which combines the distribution transformer and the voltage and current sensors together, are described. Through comparison with the existing voltage and current transforming methods, the new design has excellent performances and prominent economic benefits.

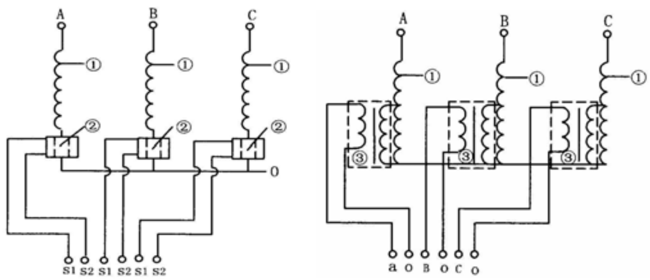
INTRODUCTION

Wide application of micro-processor based measurement, control, protection, and metering devices in power system has brought changes to the design of voltage and current transforming equipments. The voltage and current sensors, which have advantages such as simple insulation design, small volume, low loss, cost effective and reduced influences to primary system, have drawn wide attentions of power academics and engineers. As the sensors are designed, manufactured, and installed separately with the primary equipment, they are not compatible each other well, affecting the application of the sensors. A new method that integrates voltage and current sensors with distribution transformers is presented. The new design makes rational use of existing resources of a distribution transformer to realize external measurement, protection and metering functions. It can simplify the secondary circuit, reduce material cost and energy loss, and improve reliability.

THE DESIGN PINCIPLE OF EMBEDED SENSOR'S

The standard metering, measurement and protection current signals are extracted by one or more current sensors, which are installed near the neutral point of primary coils inside the transformer. The primary coil of transformer is considered as high voltage divider with a tapping point near neutral point of each primary coil. The tapping point is connected to a minitype voltage sensor, which output the standard metering, measurement and protection voltage signals. While secondary current signal is obtained using a current sensor installed at neutral point. Both voltage and current sensors are placed at low voltage side, and are much safer. There should be proper insulation between sensor and primary coils to prevent the sensors from damage of network overvoltage. The outputs of the sensors are connected to metering, measurement and protection devices as shown in Figure 1.

Minitype current and voltage sensor need electromagnetic shield to make the metering, measurement and relay signals be free of the electromagnetic interface. For the signal accuracy of metering, measurement and relay, the standard output current and voltage signals need to be compensated by error. The outputs of the current and voltage sensor, which are isolated, shielded and compensated, use V-v, or Y-y, or zero-sequence, or open-delta connection mode that can be selected or combined arbitrarily for different application of metering, measurement and relay. The different sensors would be used according to the different purpose to improve the reliability.



a. Embedded current sensor, b. Embedded voltage sensor

Figure 1 Schematic diagram of measurement circuits, primary coil of transformer; current sensor; voltage sensor

THE CHOICE OF SENSOR

current sensor

The current sensor for metering purpose uses the special penetrate ultra crystalline micro current transformer with wide load characteristic. Figure 2 shows the electric diagram of the current sensor. The relationship between the primary and secondary side of current transformer is:

$$i(t) = K_i i_T(t) \qquad 1$$

where $i(t)$ means the current of main circuit of electric energy meter, $i_T(t)$ means the secondary side current of the current transformer, k_i means the ratio of the current transformer.

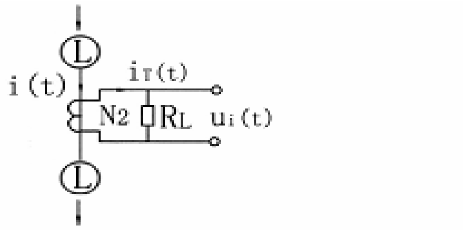


Fig.2 The diagram of current sensor, R_L is Load Resistance

The input current of impenetrate minitype current transformer is the current of high voltage side with the current range from no-load current to 1.5 times of load current of transformer. The outputs of transformer are supplied to the current meter or electric energy metering module for measurement of current or high voltage electric energy metering. The error can be measured directly or measured totally for the composed metering devices of electric energy.

Voltage sensor

The primary coil of transformer is considered as high voltage divider, the voltage is by the ratio of turn number $U_1/U_2 = N_1/N_2$. The voltage divider coil is obtained from the primary coil of the transformer and the voltage is 500V or 100V, and the outputs of voltage divider coil are connected to minitype voltage sonsors. Figure 3 shows the electric scheme. The output voltage of the sensor is

$$u(t) = K_u U_u(t) \qquad 2$$

where $u(t)$ is the measured voltage, $U_u(t)$ is the equivalent voltage to the divider.

The input voltage coil of minitype voltage transformer should reserve the tap of ±5% by the ratio of turn number $U_1/U_2=N_1/N_2$. Through the coaxial tap switch of transformer, the voltage of transformer with a regulation of ±5% keeps paces with the input voltage coil regulation of minitype voltage transformer, so the ratio of voltage is constant. The output voltage of minitype voltage transformer is 100V or $100/\sqrt{3}$ V, so the ratio is 10kV/0.1kV or $0.1/\sqrt{3}$kV. The output voltage is supplied directly to the voltage meter or electric energy metering module for the measurement of voltage or high voltage electric energy metering. The error can be measured directly or measured totally for the composed metering devices of electric energy.

The sampling of protection current

Rogowski coil is used to replace the current transformer for protection. The input current of Rogowski coil is the current of high voltage of the transformer. When the current is the protective current, the output voltage of Rogowski coil is the protective voltage and the control relay unit performs the function of protection. The protective fault current can be set. The principle of Rogowski coil is based on the law of electromagnetic induction and Ampere ring circuit as Figure 4.

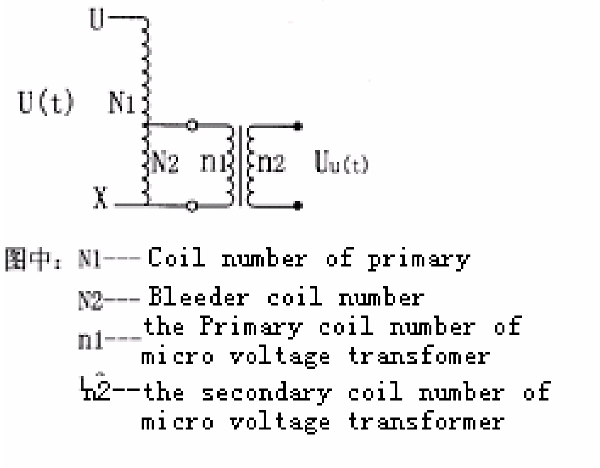


Fig.3 The diagram of voltage sensor

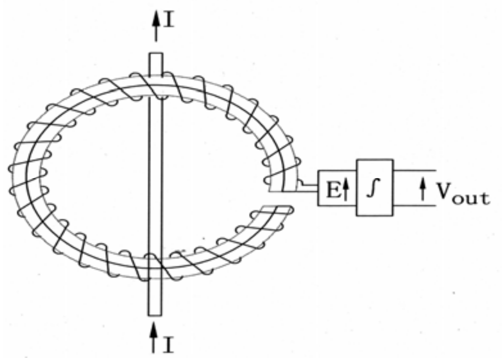


Fig.4 The diagram of Rogowski coil

When the measured current flows through the axes of the coil, the output electromotive force is:

$$e(t) = M\frac{di}{dt} \qquad 3$$

where, M means the coefficient of mutual induction, which is proportional to turns of coil N and area S .

Because the output voltage of Rogowski coil is proportional with the time derivative of current, the electronic or digital integrator to integrate the output voltage and get the signal that is proportional with the primary current. The input is the primary current of transformer, the output voltage can be selected with $1.625/\sqrt{3}$V, or $3.25/\sqrt{3}$V, or $4/\sqrt{3}$V, or $6.5/\sqrt{3}$ V. It has no saturation and remanence, so the output is completely linear ,which can improve the protective performance.

ASSEMBLY

The high voltage insulation process is applied to the sensors according to the voltage level of the transformer to withstand impulse voltage and different over voltages and isolate the high voltage and low voltage sides. The sensor is embedded inside the transformer and the insulation process is very easy by using the existing insulation inside the transformer. The sensor can obtain the insulation by processing the input and output terminal of the sensors. For example, the voltage ratio of 10kV transformer is 12/42/75kV. The installation of the sensors will not change the parameters of the transformer. The picture of a assembled transformer with embedded sensors is shown as the figure 5. The output terminal will use omni seal multicore connector. When needed, the measurement unit, protection unit and monitoring device can be installed in the control box by connecting the armoured cable terminal to control box of the transformer shield. The current, voltage and electric energy meters can also be installed. Then the inspection tests and accuracy measurement can be done independently or by combination in order to do acceptance test and periodical test. The control box should have lead sealing lock.

Figure 5 The picture of assembled transformer with embedded sensors

ELECTRIC ENERGY METERING

The standard voltage transformed by the minitype voltage transformer and the standard current transformed by the impenetrate minitype current transformer are sent to the multiplicator,as shown in Fig.6. The multiplicator multiplies the instantaneous voltage and current with an output of direct voltage, which is proportional with the mean power in a period. Then the direct voltage is converted to pulse frequent signal with the voltage/frequency converter. Through frequency splitting and counting in a period the electric quantity is displayed. High voltage electric energy metering devices are composed of the electric energy metering units with the output current from the minitype voltage transformer and the output voltage from the minitype voltage transformer. It decreased the transforming procedure from current to voltage and the sample manganese copper resistor can be removed from the electric instruments. So the high voltage electric energy devices made by minitype transformer is with wide load characteristic up to 12 times. By the current range from no-load current to 1.5 times of load current of transformer, there are three types of metering devices: 2.5-30A is for the transformer of 160kVA and below, 5-60Af is for 200-800kVA, 15-180 A is for 1000kVA and above.

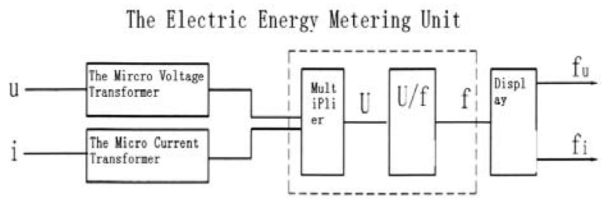


Figure 6 Diagram of electric energy metering unit

Practical tests shows the error is smooth in the measuring range and has no metering dead angle and has no electric energy leaking. The error of measurement is in the range of +0.2%-+0.5% and Its accuracy is two times better than the existing metering methods. The error curves keeps flat in the range of measurement and has no dead space and reduced metering. Because the most variation is 0.3%, so through adjustment the accuracy can be better. After the sensors and metering units are added, the actual data of open circuit loss test is shown in Table 1. This shows that the combined equipments have little impact on the open circuit loss of transformer. So the effect of energy saving is obvious .The power loss is near to 0 and lower than 3.25W.

Table 1 test table before and after sensor

	A phase	B phase	C phase
Without sensors	133.7	129.25	133.75
With voltage sensors	136.85	132.35	137
With current sensors	136.85	132.35	137
Difference	3.15	0	3.25

INSPECTION

The usual way to verify the performances of sensors is to measure accuracy characteristics of the sensors. It is different from the conventional measurement methods. Considering the custom of the commissioning test, we need test the transformer and metering device separately.

The inspection of the transformer

For part acceptance test of the transformer, the output terminal of the sensor should be drawn out and the output of the current transformer should be short-circuited. Then the whole acceptance test of the transformer could continue.

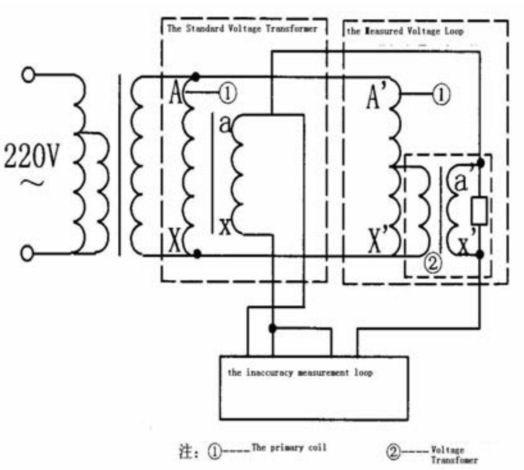


Fig7 Illustration of voltage accuracy measurement, Primary coil of transformer, voltage transformer

Accuracy measurement of the current sensor

The measurement method of the current transformer is the same as method used with the conventional current transformer. The primary coil of the transformer is considered as the primary coil of the current transformer and the output coil of the minitype current transformer as the secondary coil. Short circuit the secondary coil of the transformer and change the primary input from null load current to 1.5 times rated load current. If the rated current of the transformer is In, the current applied would be 0.5%In, 1%In, 5%In, 10%In, 20%In, 80%In, 100%In, 120%In, 150%In. The corresponding accuracy value should meet the accuracy requirement. They would be 0.2(S), 0.5(S) and 1(S).

Accuracy measurement of voltage sensor

The measurement circuit is shown as in Figure 7. When measuring the accuracy, the AX, BX, CX of the transformer is considered as the primary terminal AX of the voltage transformer and the secondary terminal ax, bx, cx of the minitype voltage transformer as the secondary terminal ax. The test should meet the requirement when measuring the secondary terminal of each phase of the voltage when the voltage changed under 80%, 100%, 120% of rated voltage and each phase voltage fluctuated at -5%, 0, +5%. The accuracy should be the class 0.2, 0.5, and 1.

Accuracy measurement of the electric energy meter

The accuracy of the electric energy meter can be computed from the accuracy of the voltage transformer (TV), current transformer (TA) and electric energy meter by routine method. The total uncertainty is defined by the formula. It can be gotten from the value of the electric energy metering loop by comparing the value of measured high-voltage electric energy metering value and the data of a standard meter.

$$\gamma = \frac{measured \cdot kWh - standard \cdot kWh}{Statndard \cdot kWh} \times 100 \qquad 4$$

CONCLUSION

The combination design of the transformer and the metering, measurement, protection sensors, together with the related metering and protection units is presented The new design has satisfactory accuracy. It can reduce power loss and improve operation reliability. Through comparison with the existing metering methods, the new design has excellent performances and prominent economic benefits.

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Rong Bo, was born in 1960 in Zibo, Shandong Province, China. He is currently the general manager and chief engineer of Zibo measurement & protection Lab. Main research interests are voltage and current transformers, electrical energy metering.

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