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doi:10.15199/48.2022.10.08

Application of a small transformer for designing current detection and overcurrent protection circuit for laboratory tables

***Abstract**. The purpose of this research is to study, design and build over current protection circuits for low voltage AC supply for electrical and electronic circuit experiments in laboratories to prevent damage to circuits and equipment. The use of transformers as current detectors in this research focuses on 3 issues: 1. Circuit design and testing 2. Determination of voltage drop and power loss at current sensing transformer 3. Finding the efficiency of the designed circuit. This test will be performed 5 times to ensure the accuracy of the designed circuit. The research results showed that the designed circuit can cut the circuit efficiently and with precision, the designed circuit has an error of not more than 1%, can cut off the circuit when an over current occurs and prevent short-circuit and reduce the rate of damage of the device*

Streszczenie.** Celem tych badań jest zbadanie, zaprojektowanie i zbudowanie obwodów zabezpieczenia nadprądowego do zasilania prądem przemiennym niskiego napięcia do eksperymentów z obwodami elektrycznymi i elektronicznymi w laboratoriach, aby zapobiec uszkodzeniom obwodów i sprzętu. Zastosowanie transformatorów jako detektorów prądu w niniejszych badaniach skupia się na 3 zagadnieniach: 1. Projektowanie i testowanie obwodu 2. Wyznaczanie spadku napięcia i strat mocy na przekładniku prądowym 3. Znalezienie sprawności projektowanego obwodu. Ten test zostanie wykonany 5 razy, aby zapewnić dokładność zaprojektowanego obwodu. Wyniki badań wykazały, że zaprojektowany obwód może skutecznie i precyzyjnie odcinać obwód, projektowany obwód ma błąd nie większy niż 1%, może odcinać obwód w przypadku wystąpienia przetężenia i zapobiegać zwarciom oraz zmniejszać szybkość uszkodzenie urządzenia.* (Zastosowanie małego transformatora do projektowania układu detekcji prądu i zabezpieczenia nadprądowego dla stołów laboratoryjnych***)

Keywords: Efficiency, Overcurrent protection, Current sensing transformer, Faraday Law
Słowa kluczowe:.zabezpieczenie nadprądowe, czujnik prądu

1.Introduction

A transformer is a type of electrical machine that converts electrical energy into electrical energy by changing the voltage to increase (Step up Transformer) and to decrease (Step down Transformer) but does not change the power and frequency. Generally, the there are many types of transformers that are used in the electrical power system for example, according to the characteristics the steel core is normally divided by type of electrical system which is divided according to the nature of use divided by frequency of use, etc [1].

In this research, the step-down transformer is reported. A clear learning objective states that the learner will be able to learn through various processes which have been proven in this study. And some kinds of learning experiences result can be affected in effective of learning process skills [2]. However, the experiment step can create some problems, like wrong connection of switching circuit connection causing the device to malfunction. In this study, the experiment of the AC power supply unit was investigated using an isolation transformer. The secondary winding will have several junction points to obtain different voltage values. To protect the system, the fuses and original experimental were experimentally used. selection of fuses, if too large, will cause the transformer and the device was damaged before the fuse was cut[3,4,5,6]. But if the fuse size is too small, the fuse will cut frequently. Which sends the experiments that are being tested is slow and time-consuming to modify the damaged equipment and wastes the equipment [7,8].

A resistor can be used to sense current by measuring the voltage drop across the resistor. By Ohm’s law, the sensed current I = V/R. Using a low value resistor in series withthe measured current keeps the voltage drop, and lossdue to dissipation, to a minimum. This sounds simple, but because the voltage drop is low across such a small resistance, amplification of the voltage may be needed to detect it, creating additional circuit complexity.

Shunt current sensors sample a small proportional fraction of the sensed current. The current is shunted through a parallel resistor and the voltage drop measured. As withthe series resistor, the voltage drop is proportional to thecurrent being sensed.

Instead of using a dedicated shunt resistor, it is possible to use the intrinsic resistance of a conducting element in the circuit (usually a copper trace or bus bar). This approach promises very low-cost with no additional power losses. Naturally, the resistance of a copper trace is very low, and thus the resulting voltage drop is very small. To get a useful output signal, an amplifier with high gain is required. The limited gain-bandwidth-product of the amplifier will then alter the performance of this current sensing method.

Current sense transformers are typically used for AC current sensing. The circuit can be somewhat simple when using a true RMS-to-DC converter. Technology. These current sensing devicesmay use a single wire from the circuit to act as the primaryof the transformer or they may have the primary winding provided.

These AC current sense transformers develop a current in the secondary that is proportional to the sensed current in the primary. The secondary current is measured as the voltage drop across the terminating shunt resistor (R) as shown in Fig. 1. By using a low turns ratio current transformer, the current drawn through the terminating resistor is minimized. This also reduces the voltage produced across the terminating resistor, which may then require amplification if that output voltage is too low. Choice of transformer turns ratio and terminating resistor must balance the desire for low current draw against the need for sufficient output voltage.

A shunt resistors (R) have been used extensively in power electronics due to their low cost, small size, and relative simplicity, whilst providing reasonable accuracy. To achieve higher integration, higher efficiency and enable more sophisticated control techniques, the analog control loops are increasingly replaced by digital control loops. Accordingly, the current information needs to be digitalized. The small voltage drop across a shunt resistor needs amplification, which alters the bandwidth, and increases the device size and cost. Power converters, moreover, have reached a power density level, where the power losses inside shunt resistor startto become troublesome. Therefore, power electronics engineers are seeking alternatives for shunt resistors with similar accuracy but lower power losses, and with an output voltage that can be directly sampled by an analog-to-digital converter.

The purpose of this study is to provide the reader with a fundamental understanding of the techniques available for current monitoring and some understanding of the performance and limitations of each technique. Therefore we have classified the current sensing techniques based upon the underlying fundamental physical principle.

The researcher conducted a study on related theories and methods and studied. Design and determine the efficiency of transformer over current protection circuits with compound contact material for supplying AC low-voltage AC circuits for experimental circuits using reverse current to disconnect transformers[9].

2.Current sensing with Ohm's Law

Ohm's law of resistance is basically a simplification of the
Lorentz law that states:

(1) $$J = \sigma\left(E + v \times B\right).$$

J is the current density, **E** the electric field, **v** the charge velocity, **B** the magnetic flux density acting onto the charge and s the material conductivity. In most cases the velocity of the moving charges is sufficiently small that the second term
can be neglected:

(2) $$J = \sigma E.$$

This equation is known as Ohm's law of resistance and states that the voltage drop across a resistor is proportional to the flowing current. This simple relationship can be exploited to sense currents. These current sensors often provide the advantage of lower costs compared with other sensing techniques, and have the reputation of being reliable due to their simple working principle.

3. Faraday's Induction Law

Current sensors based on Faraday's law of induction are one example of sensors that provide inherent electrical isolation between the current we want to measure and the output signal. Electrical isolation enables the measurement of currents on a high and floating voltage potential by providing a ground-related output signal. In many applications safety standards demand electrical isolation, and thus make isolated current sensing techniques mandatory. The working principle can be explained starting with amperes law that defines the path integral of the magnetic flux density *B* inside the coil:

(3) $$\oint_c \overrightarrow{B} \bullet \overrightarrow{dt} = \mu_0 i_c.$$

If the current i_C is centered inside the coil, the magnetic flux density B can be simplified to:

(4) $$B = \frac{\mu_0 i_c}{2\pi r}$$

We can apply Faraday's law of induction to determine the induced voltage into the coil due to a change in the current i_c:

(5) $$v = -N\frac{d\phi}{dt} = -NA\frac{dB}{dt} = -\frac{NA\mu_0}{2\pi r}\frac{di_c}{dt}.$$

A is the cross sectional area of the coil body which is formed by the windings, and *N* the number of turns. Voltage *v* is proportional to the derivative of the primary current i_c that we want to measure. An integrator with integrating constant *k*, and infinitely high input impedance can yield the exact result:

(6) $$V_{out} = -\frac{NA\mu_0}{2\pi r}k\int_t \frac{di_c}{dt}.dt + v(0) = -k\frac{NA\mu_0}{2\pi r}i_c + V_{out}(0).$$

Equation (6) is also theoretically valid if the coil is not centered around the conductor or the coil shape is not circular [16]. This is due to the fact that in reality the winding density around the coil is never perfectly constant. Accordingly, the poorest accuracy is obtained if the conductor position is close to the clip together mechanism, where the winding density cannot be even.

4.Experimental setup

The working principle of the designed circuit is presented by Fig. 1. In order to design the overcurrent protection circuit of transformer, the sensing of the current flowing was used by the primary winding of the transformer to control the supply circuit breaker when the transformer exceeds the rated VA [10].

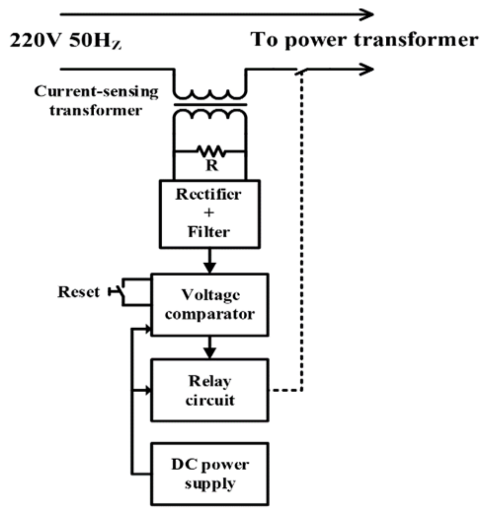

Fig.1. The working principle of the circuit designed in the research.

5.Analysis and application of power transformers as current sensing transformers

The detection method was used to detect the amount of current flowing through the primary winding of an overcurrent protected power transformer. Because of its advantages, such as it can be easily purchased, low cost, and it can be applied as a current sensing transformer.

There is a unique feature. It is a step-down transformer with a voltage on the primary winding or on the high voltage side of 220V. The secondary winding or low-voltage windings in this research will be used as a direct passage of the current to be detected. Therefore, this winding can be able to support the amount of current flowing through the primary winding of the power transformer. And the specified pressure must be an appropriate value, meaning the transformer has an appropriate Transformation ratio: VP/VS to produce a good effect on impedance transfer.

At the working as a current transformer that was to minimize the resistance transferred from the high voltage side to the low voltage side. In order to reduce the voltage, drop in series with the primary winding of the power transformer, the current can be converted to a voltage of sufficient which the value can be used as a control signal. When this transformer is used as a current-sensing transformer, the low-voltage side of the transformer is classified as the primary side. The high-voltage winding is classified as the secondary side and has a resistor placed between the terminals [11,12,13] as shown in Fig. 2.

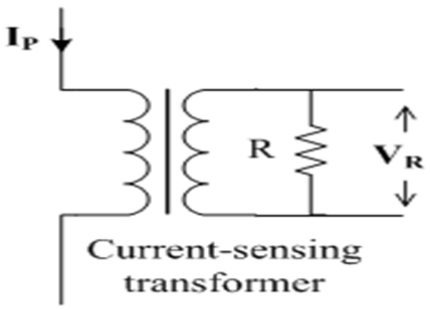

Fig.2. The resistor connection at the high voltage winding terminal of the Current sensing transformer.

The voltage applied to the resistor V_R depends on the amount of current flowing through the winding on the low voltage side or on the primary side. And, in theory, it can be obtained from equation 7.

$$V_R = \frac{V_P R}{V_S} \times I_P \quad (7)$$

where: V_R Is the voltage on the resistor (V); V_P Is the nominal voltage on primary winding side (V); V_S Is the nominal voltage on secondary Winding side (V); R Is the resistance (Ω); I_P Is the current flowing through the primary winding (A)

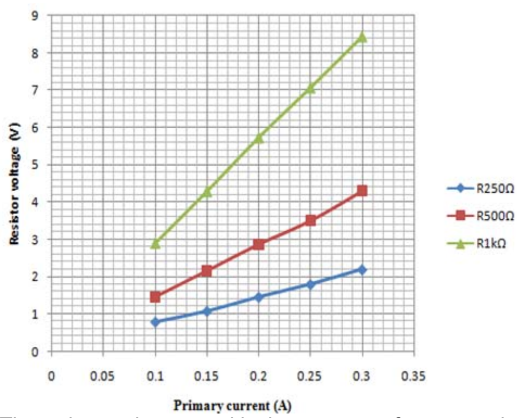

Fig.3. The voltage changes with the amount of current when the resistors have different values.

From the experimental results, the researcher has chosen a transformer with a conversion ratio of 6V/220V and a resistor 500Ω. Because of the desired conversion voltage and has a range of voltage changes that vary according to the amount of current in the range suitable for Its use as a control signal in a voltage comparator circuit. As shown in the graph in Fig.3.

6.Voltage Multiplier Rectifier Design

The voltage converted from current was presented in this part, which is an alternating voltage. It has to be converted from AC to DC and it has to be high enough to compare with the reference voltage. (Reference voltage: VRef) in a voltage comparator circuit[8]. This research will use a reference voltage of approximately 7V and since the voltage obtained from such a conversion is only 3Vrms at a current of approximately 0.22A, therefore, to obtain a DC voltage approximately equal to or greater than 7V. The researcher therefore chooses a voltage doubles rectifier circuit as shown in Fig.4. The circuit uses a resistor 6.8k Ω [14].

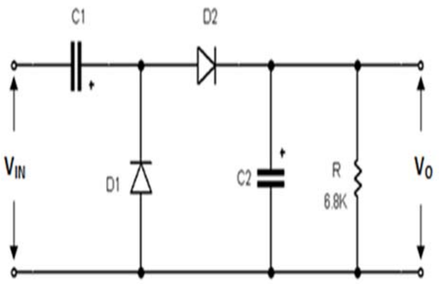

Fig. 4. Voltage multiplier circuit.

It is connected as a load to discharge energy from the capacitor and the capacitance of capacitor C_2 can be found according to equation 8.

$$C_2 = \frac{10^6}{2\, fR\left(\frac{2(\sqrt{2}V_{IN} - V_D}{V_0} - 1\right)} \quad (8)$$

where: C_2 Is the capacitance of the capacitor (μF); V_O Is the voltage at the output side (V) ; V_{IN} Is the input voltage (V) ; V_D Is the voltage drop across the diode. (V) Calculated at approximately 0.6 V; f Is the input voltage frequency (Hz); R Is the resistance (Ω)

Because the reference voltage in this research, it is approximately shown by 7V. The output voltage V_O is approximately presented by 7V. Moreover, the test results, when the current flows through the primary winding of the power transformer 0.22A, it can be converted to a voltage of approximately 3V, that is, the value V_{IN} = 3V. Therefore, when substituting the values in Equation 9, we get C_2 as follows:

$$C_2 = \frac{10^6}{2 \times 50 \times 6800 \times \left(\frac{2\left(8\sqrt{2} - 0.6\right)}{7} - 1\right)} = 36.08\mu F \quad (9)$$

The researcher chose to use C_2 = 47 μF /16V and the selected capacitor is C_1 In general practice, approximately 5 times the value of C_1 = 220 μF /16V

7.Voltage Comparator Circuit Design

The voltage comparator circuit gives the output voltage a signal that can control the relay drive. Stop the relay to immediately cut off the power supply circuit to the power transformer. In this research, the IC Op-amp number uA741 was experimentally used [15,16,17], which is the main device and the circuit is designed as shown in Fig. 5.

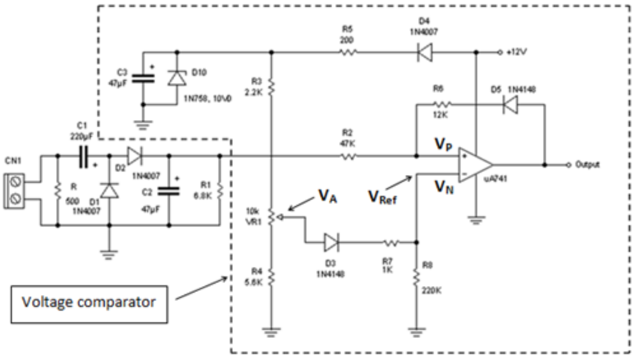

Fig.5 Voltage comparator circuit

The design of this circuit is based on the principle of a voltage divider consisting of resistors R_3, R_4 and variable resistor VR1. For practical calibration, it was allowed the circuit to cut the circuit precisely with a limited current. The resistance of each resistor can be obtained from the initial consideration that the full load current flowing through the primary of 0.22 A. Thus, the power transformer can be converted to a control voltage signal of approximately value of 7V. In addition to this point, the current flowing in side Non-inverting is very small. Therefore, there is no voltage drop on resistor R_2. Put pressure on the legs non-inverting is VP is 7V. Note that from the properties of the op-amp the potential difference between Non-inverting (VP) pin and Inverting (VN) pin is approximately 0V [18-21]. Makes me know that the reference voltage is about 7V. Since R_7 has a much lower resistance than R_8, the voltage drop at R_7 is not factored into it. Consequently, an adjustable voltage (VA) can be obtained by combining the reference voltage with the voltage drop on diode D_3 equal to 7.6V. For adjustable resistor VR1 selects a 10 kΩ was set and a variable VA voltage range considering the maximum selectable breaker current of 0.25A and the minimum selectable breaker current of 0.1A from the selected breaker current. The reference voltage can be found in Equation 10. And the adjustable voltage, Equation 11, as shown in Table 3.5 for the design of the reference voltage at the adjusted constant. To be stable at all times, the voltage supplied to the voltage divider must be kept constant. In this research, the voltage is controlled at 10V. Using diode D_{10}, Resistor R_5, Zener diode D_{10} and capacitor C_3 is connected together to form a voltage regulator circuit. The designed circuit can find the resistances R_3 and R_4 from equations 12 and 13.

$$V_{Ref} = \frac{2\left(\sqrt{2}\left(R \cdot I_P \cdot \frac{V_P}{V_S}\right) - V_D\right)}{\left(1 + \frac{1}{(2fC_2R_1)}\right)} \tag{10}$$

$$V_A = V_{Ref} + V_D \tag{11}$$

$$R_3 = \frac{\left(V_{reg} - V_{A(Max)}\right)VR1}{\left(V_{A(Max)} - V_{A(Min)}\right)} \tag{12}$$

$$R_4 = \frac{V_{A(Min)}VR1}{\left(V_{A(Max)} - V_{A(Min)}\right)} \tag{13}$$

Consider that the relay has stopped supplying power to the power transformer, which is obtained from equation 14, where the result is greater than the reference voltage.

$$V_P = \frac{\left(V_{Sat} - V_{DS}\right)\left(R_1 + R_2\right)}{R_1 + R_2 + R_6} \tag{14}$$

6.Power supply circuit analysis and design

The researcher requires a constant DC voltage of 12V and a total current of approximately 200mA. A full-wave rectifier method was applied from the 12V alternating voltage of a Multi -Tap transformer using a capacitor as a filter and IC.7812 as a voltage regulator, shown in Fig.6.[22-23]

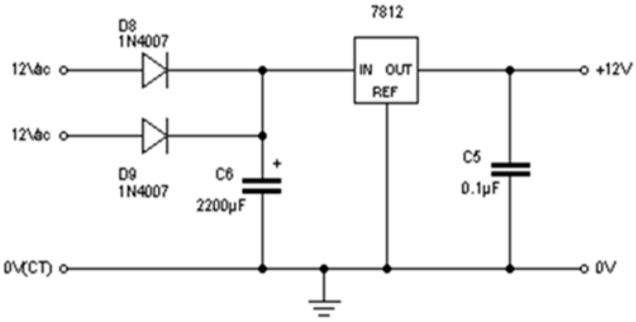

Fig.6. Power supply circuit

In Fig.6, the capacitor C_6 in the circuit must be large enough to maintain the minimum voltage while supplying at least 14.6V. This researcher sets the minimum voltage at 15.5V. It can calculate the value of the capacitance of capacitor C_6 can be calculated from equation 15.

$$\begin{aligned} C_6 &= \frac{I_{DC} \times 10^6}{2f\left(\left(\sqrt{2}V_{ac}\right) - V_D - V_{\min}\right)} \\ &= \frac{0.2 \times 10^6}{2 \times 50 \times \left(\left(\sqrt{2} \times 12\right) - 0.6 - 15.5\right)} \\ &= 2297.36\mu F \end{aligned} \tag{15}$$

From the calculations in Equation 9, the researcher chose C_6 = 2200 μF

8.Determining the voltage from a transformer with a resistor connected to it and calculating its values.

The transformer used for measuring current is used by power transformers in general electronics applications because they are easy to buy and cheap to use by using a step-down transformer to convert the current signal into a control voltage signal. The relay cuts the circuit when an over current occurs. In the design and construction of an over current protection circuit, a 48VA power transformer is used 220V/24V-12V-0-12V-24V [15]. Choose a transformer with a low-voltage winding of 500mA by testing 3 transformers together: 6V/220V,9V/220V and 12V/220V were replaced by 3 sizes of resistors 250Ω, 500Ω and $1K\Omega$ as shown in Table 1. The researcher chose a

6V/220V transformer and used a resistor 500Ω because the desired voltage is obtained and the range of voltage changes varies with the amount of current within the range suitable for use as a control signal.

Table 1 .Results of an experiment to determine the voltage variation with a resistor connected to a transformer.

V_P/V_S	$R(\Omega)$	$I_P(A)$	0.10	0.15	0.20	0.25	0.30
6V/220V	250	$V_R(V)$	0.79	1.08	1.46	1.80	2.20
	500	$V_R(V)$	1.46	2.16	2.87	3.50	4.30
	1k	$V_R(V)$	2.90	4.29	5.73	7.06	8.43
9V/220V	250	$V_R(V)$	1.06	1.50	2.05	2.54	3.08
	500	$V_R(V)$	2.04	3.04	4.00	5.10	6.04
	1k	$V_R(V)$	3.90	5.80	8.00	9.80	11.90
12/220V	250	$V_R(V)$	1.39	2.04	2.78	3.40	4.10
	500	$V_R(V)$	2.78	4.01	5.50	6.80	8.10
	1k	$V_R(V)$	5.80	7.90	10.80	13.10	16.00

9. components of the overcurrent protection circuit

The overcurrent protection circuit designed and constructed is shown in Fig.7.

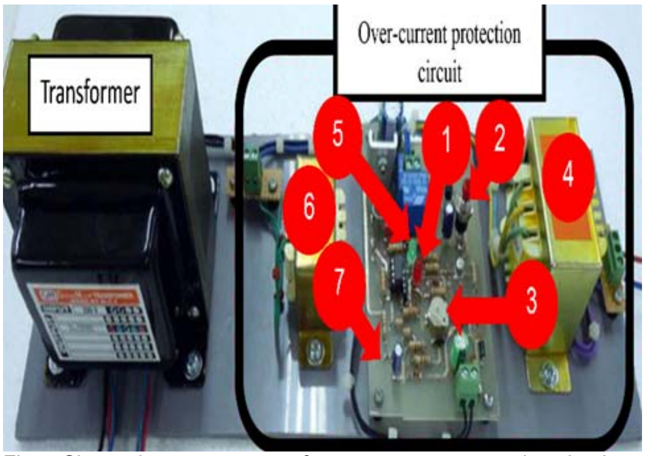

Fig.7. Shows the components of an overcurrent protection circuit at a power transformer for low voltage switching power using the feedback current method.

In Fig.7. shows a circuit built with different numbers. The details are as follows:

- 1. Is a signal lamp indicating the status of the control circuit for the relay to cut off the current Stop supplying power to the power transformer when the current is overloaded
- 2. Is the reset push button switch.
- 3. Is a variable resistor for adjusting the setting current of the circuit breaker.
- 4. Is a power transformer for supplying power to the circuit
- 5. Is a lamp indicating the status of the control circuit for the relay to connect the power supply circuit to the power transformer under normal current condition.
- 6. Is the current sensing transformer.
- 7. Is the circuit board

10.Features of the overcurrent protection circuit

Features of overcurrent protection circuits at power transformers by means of feedback current

Table 2 shows the values of the characteristics of the overcurrent protection circuits.

Input voltage	220VAC
Frequency	50Hz
Circuit breaker	> 0.22A
Maximum power consumption	6 W
The lamp shows while the circuit is connected.	Green
The lamp shows while cutting the circuit	Red
Reset	Manual

11.Operation of the transformer protection circuit

In Fig. 8, it is a circuit to protect the transformer for low-voltage supply by having an LED lamp indicating the operation. When the switch is pressed, the red LED will be on, the green LED will be off because the relay has not yet been activated. When the reset button is pressed, the relay will work. The green LED will be on. The contacts of the relay are connected to the circuit supplying the current to the power transformer.

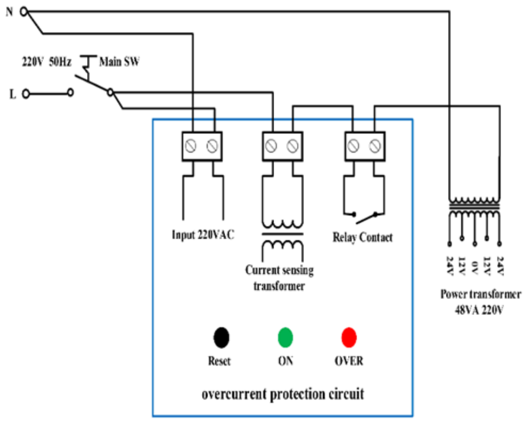

Fig.8. Operation of the transformer protection circuit.

12.Voltage drops and power loss test

A series current sensing transformer is used to pass the load current directly in Fig.9 as a voltage drop and power loss test circuit. a) This is a circuit used to test the effect of the residual voltage. When the primary current of the transformer changes by changing the load on the secondary the result is a percentage relative to the AC voltage supplied to the circuit. b) It is a circuit used to test the effect of power loss.

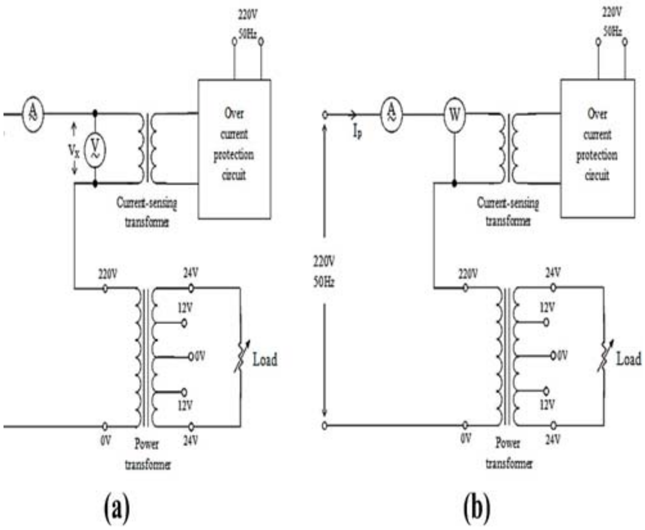

Fig. 9. Voltage drops and power loss test circuit.
a) The circuit used to test the voltage drop at the current sensing transformer. b) Circuit used in the experiment to determine the power loss at the current-sensing transformer.

13.Circuit Performance Test

The efficiency test of the circuit was to connect the load between the 12V,24V,36V and 48V. The transformer winding junction points was investigated by connecting the circuit which can be seen in Fig. 10 and increasing the load current in the circuit breaking test when the load current is available. The value is higher than the full load current and will cut off when the current exceeds the rated current at each voltage. A total of 5 tests were performed, the results of which are shown in Fig.10.

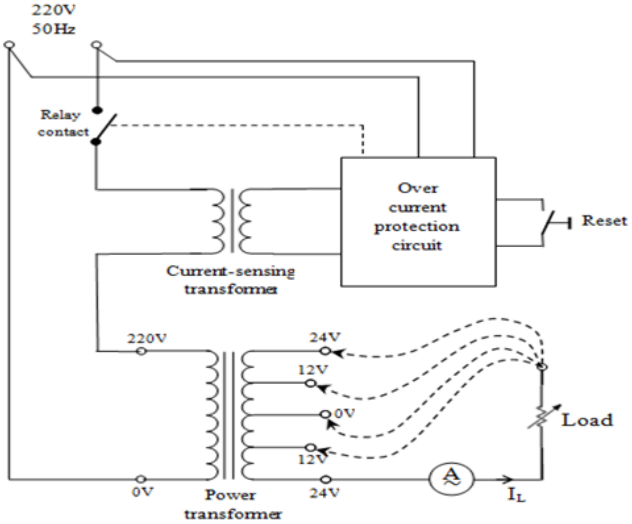

Fig.10. The circuit used to determine the efficiency of cutting current.

14.Experimental results

A. Determination of voltage drop and power loss at current sensing transformers

To determine the effect of voltage drop and power loss, there have been found that occurs when a current sensing transformer was connected by series. In order to measure the amount of current through the primary side of the transformer when adjusting the load size, it is an obvious effect to the secondary winding, as a result, the amount of primary current changes at different values. As shown in Fig. 11, it can be seen that the Primary current at 0.00A ,0.01A ,0.15A ,0.20A, 0.25A ,0.30A.Voltage drop at 0.00V., 0.14V., 0.20V., 0.28V., 0.35V., 0.43V. and voltage drop at 0.00%, 0.06%, 0.09%, 0.13%, 0.16%, 0.20 %

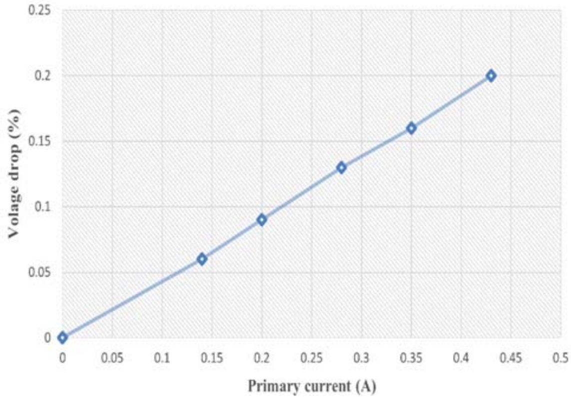

Fig.11. The percentage voltage at which the transformer senses current when the primary current is different.

To determine the power loss when the current flows in the primary, in Figure 6, it can be seen that the primary current at 0.00A., 0.01A., 0.15A., 0.20A., 0.25A, 0.30A will have power loss values at 0.00W., 0.02W., 0.04W., 0.07W, 0.15W. as shown in Fig.12.

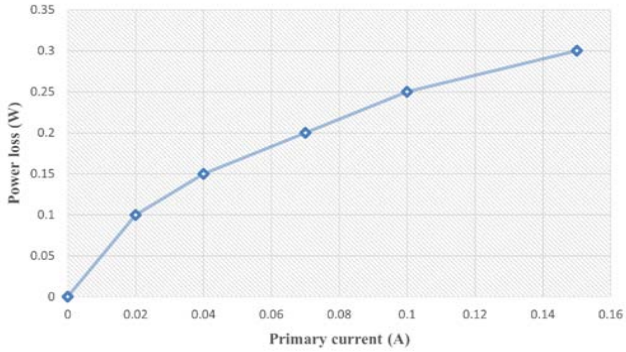

Fig.12. Power loss incurred to current sensing transformer when primary currents are of different values.

B. Circuit Efficiency Test

To determine the efficiency of the circuit breaker, the connection between the different voltage junctions and load increasing were set until the primary current of the overload transformer was found. The over current protection circuit breaker is based on the magnitude of Va, resulting in the current magnitude. At the different of the voltage between the junctions of the secondary windings, the circuit breaker was tested by 5 times for each voltage to compare the difference conditions. It can be seen that at a voltage of 12 V, a current of 4 A has shown an average test value of 4.04 A, a tolerance of 1 percent, at a voltage of 24 V. A current of 2 A has an average test value of 2.02 A. The tolerance is 1 percent at 36 V and current 1.33 A. The test average is 1.34 A. The tolerance is 0.7 percent and at voltage 48V. Current 1 A. The test average is 1.01 A. The tolerance of 1 percent is shown in Table 3.

Table 3. This is the test circuit used in the experiment.

Voltage (V)	Current Setting (A)	Tipping current (A)					Average (A)	Error (%)
		1	2	3	4	5		
12	4	4.03	4.04	4.04	4.04	4.05	4.04	1
24	2	2.02	2.02	2.01	2.02	2.02	2.02	1
36	1.33	1.34	1.35	1.34	1.34	1.34	1.34	0.7
48	1	1.01	1.01	1.01	1.02	1.01	1.01	1

15.Conclusions

In this research, the design of transformer over current protection circuit was investigated. As a result, there are two important part of factors that have an effect to the result at the current sensing transformer , including voltage drop and power loss. There have been found that the power loss and voltage drop was lost at full load. And the value presented by lessthan 85 mW and the voltage drop is less than 0.15% from the conduction of the over current protection circuit. In addition, the experiment have shown that the designed circuit can cut the circuit efficiently and with precision with a tolerance of not more than 1% and also can be used with a transformer in a small size that can be sold in the market and applied as a current sensing transformer. Selecting an appropriate current sense transformer requires knowledge of the expected maximum sensed current, frequency and duty cycle of the sensed current, as well as the desired output voltage corresponding to the expected maximum sensed current. With this information, the current transformer provides the appropriate terminating resistor value and the current sensors that meet the application conditions.

Acknowledgments

This work was supported by Plasma and Electrical Discharge Laboratory, Faculty of Industrial Education and Technology , King Mongkut's University of Technology Thonburi (KMUTT) with Srisongkhram Industrial Technology College, Nakhonphanom University, Nakhonphanom, Thailand for the financial Support.

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