

AN-1212 Transformer Overload Protection

In this application note, we will describe how to design and implement a power transformer overload protection system, which will help protect the transformer from overload situations. A transformer will be overloaded when its load exceeds its nameplate rating. This can occur due to contingencies on the transmission lines, any failure or fault in power systems, or economic considerations. When a power transformer is overloaded, its operating temperature will increase, which has a negative effect on the lifespan of the transformer.

Transformer Background

A power transformer is one of the most important and expensive components in a power network. They allow efficient transmission and distribution of electricity through different voltage levels. If a power transformer suffers an outage, it may affect the reliability of the entire network and have considerable economic impact on the system.

Using power transformers efficiently requires planning and control. Normally, transformers are designed to operate within its nameplate ratings.

Since an overloaded power transformer will have an operating temperature increase which harms its lifespan, it is essential to model the heat transfer characteristics between windings and oil in order to predict the hot-spot temperature in the transformer as a function of the load, while considering the cooling characteristics.

The overloading may also occur because of economic considerations. If the transformer is maintained properly so that it is always within specifications, it will last longer before needing to be replaced. Accelerated aging is one of the main consequences of overloading power transformers.

The Four Types of Overloading in a Power System

Normal life expectancy loading

Normal life expectancy occurs when the power transformer has a continuous hot-spot temperature of 98°C for non-thermally upgraded paper, and 110 °C for the thermally upgraded paper. However, it is permissible to operate the transformer over this temperature for a short time during a period, providing that the transformer has operated for a long time under this temperature. The exact end of life of transformers are unknown, however, according to International Electrotechnical Commission (IEC), there are different predictions for insulation life depending on mechanical properties such as, retained tensile strength and/or retained degree of polymerization.

Planned overloading

This type of loading occurs when the utility operator plans to overload the transformer during a specific time that is more typical in utility operation. The hot-spot temperature may rise to 120-130°C during this type of loading. No-system outage, planned repetitive loads and shorter life expectancy are the characteristics of this type of loading. For this loading type, calculations can be made to define the time period in which the acceptable loss of life can be achieved.

Long-term Overloading

In this type of overloading, the transformer is operated beyond its nameplate rating for a long time, from several hours to several months, carrying emergency loads. It might occur one or two times during the normal life of the transformer. Long-term overloading occurs because of an outage in a power system or contingencies on the transmission system. However, the risk of failure is greater than the planned overloading and the hot spot temperature can rise to 120°C -140°C under operation. For this loading type, calculations can be made in order to evaluate the acceptable loss of insulation life during a specific load cycle.

Short-term Overloading

Short term overloading is the heavy loading of a transformer during a short time that causes the temperature to increase rapidly and exceed the limits defined by the name plate ratings. In this type of loading, the hot-spot temperature may rise to 180°C for a short time period with the severe loss of insulation life. The main characteristics of this type of loading are:

- Highly unlikely operation conditions on the transmission system.
- It is expected to occur one or two times over the normal life of a transformer and it usually lasts for a short time (less than half an hour).
- The risk of failure even is greater than long term overloading, due to the bubble and gas formation in the oil.

Risks of Overloading

There are certain risks of overloading of transformers. They are mentioned below.

- Gas bubbling from the insulated conductors and insulation adjacent to the metallic structural parts may reduce and jeopardize the dielectric strength.
- Temporary deterioration of the mechanical properties at higher temperatures could reduce the short-circuit strength.
- Mechanical or dielectric failures due to thermal expansion of conductors, insulation materials, and structural parts.
- Increasing pressure in the bushings could result in leaking gaskets, loss of oil and extreme dielectric failure.
- Increased resistance in the contacts of the tap-changer that may result from an increase of oildecomposition products.
- Breaking of very high current in the tap-changer could be risky.
- Oil expansion in the tank may occur when the top-oil temperature rises above the standard limitation.
- The voltage regulation through the transformer may increase due to the increased apparent power loading and possibly dropping power factor.

The block diagram representation of transformer overload protection is shown in figure 1. It consists of one current transformer connected on the primary side of the transformer. Two HL-52S relay modules are connected on both the primary and secondary sides.

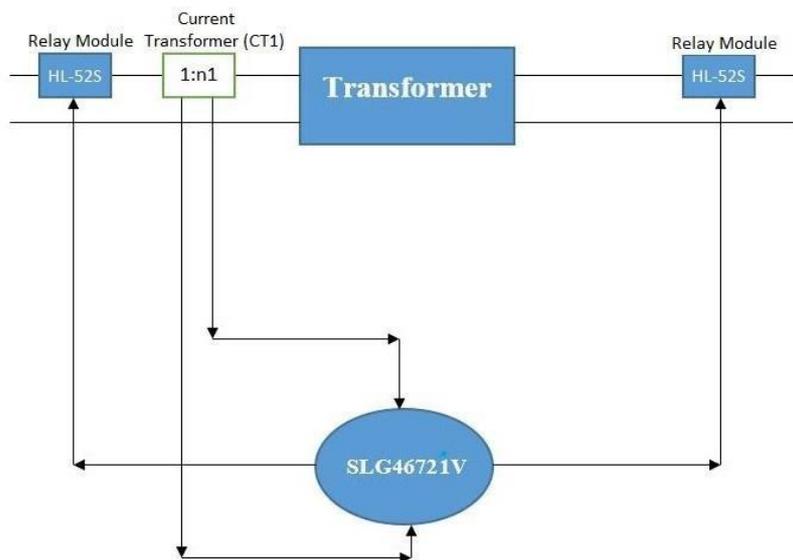


Figure 1. Block diagram of Transformer Overload Protection

In the flow diagram, first the current from primary side current transformer has been taken. If current of CT1 is 1A, then normal current flow LED is turned on. If the CT1 current is greater than 1.67A then transformer overload condition has been detected and as a result, a trip signal is given to the primary and secondary HL-52S relay modules to isolate the transformer from the power system. The piezoelectric buzzer and overload indication LED are also turned on in this case.

Moreover, if $1.0A < \text{current} < 1.2A$ then it means that there is no overload situation on the transformer. Usually normal current of 1.2A flows in the CT secondary (CT rating 1A plus 0.2 margin value). The

complete flow diagram is shown in figure 2.

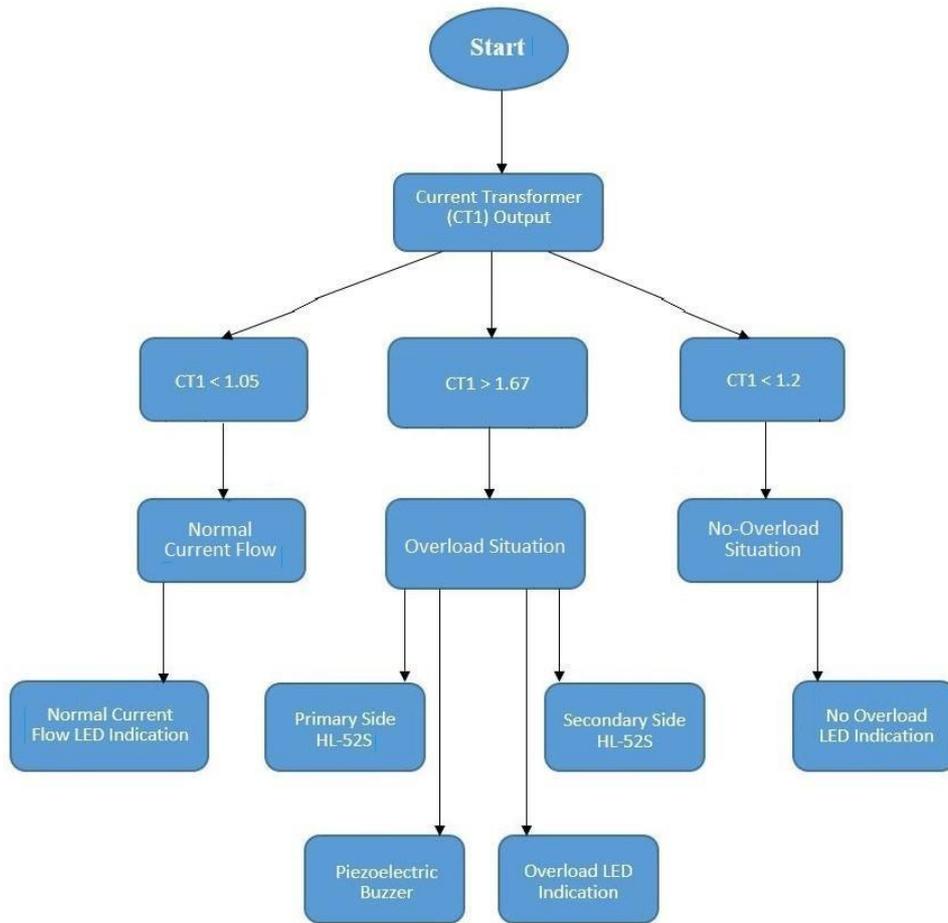


Figure 2. Flow diagram of Transformer monitoring

The top-level schematic for the overload protection of the transformer is shown in figure 3.

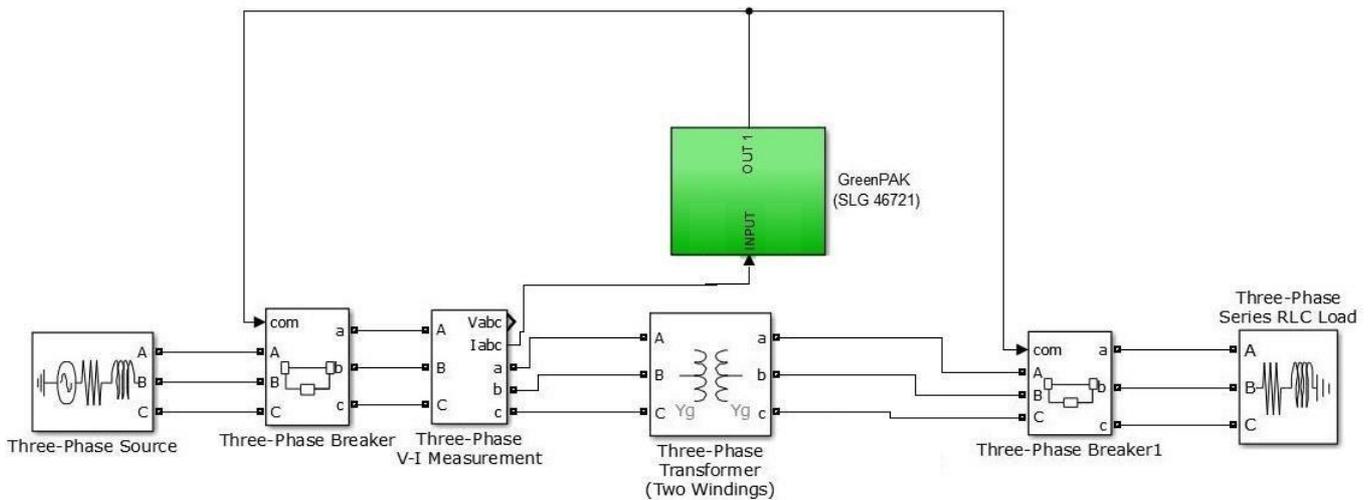


Figure 3. Top Level Schematic

Components Description

In this application note, one current transformer and two HL-52S relay modules have been used. The description of each component is given below.

HL-52S Relay Module

The HL-52S Relay module allows a wide range of inputs to control larger loads and devices like AC or DC Motors, electromagnets, solenoids, and incandescent light bulbs. The relay shield uses one QIANJI JQC-3F high-quality relay with rated load 10A/250V AC, 10A/125V AC, 10A/28V DC, 10A/30V DC. The relay output state is individually indicated by a light-emitting diode.

The features of the module are given below.

- Control signal: TTL level
- Rated load: 10A/250V AC, 10A/125V AC, 10A/28V DC, 10A/30V DC
- Contact action time: 10ms/5ms
- COM- Common pin
- NC- Normally Closed, this terminal remains closed at low logic level
- NO- Normally Open, this terminal remains open for low logic level

We will use the HL-52S one channel relay module. The high voltage output connector has 3 pins, the middle one is the common pin and as we can see from the markings one of the two other pins is for normally open connection and the other one for normally closed connection. The relay module is shown in figure 4. Its output contacts are normally closed. They become open when a high logic is applied at input (IN) pin.

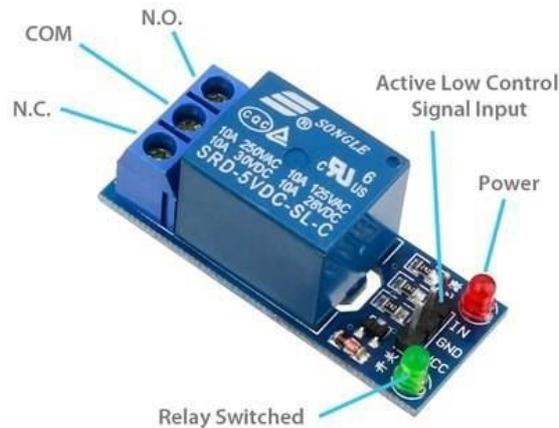


Figure 4. HL-52S Relay Module

The basic construction of relay module is shown in Figures 5 and 6. Figure 5 shows the relay module in the normally closed state when low logic input is applied. In this case, the current flows through the circuit. In figure 6, when a digital high logic is applied at input pin, the switch changes its position and makes a contact with normally open. In this case, the circuit is opened and no current flows.

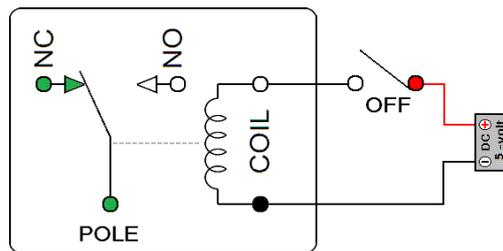


Figure 5. Relay Module Normally Closed Circuit Position

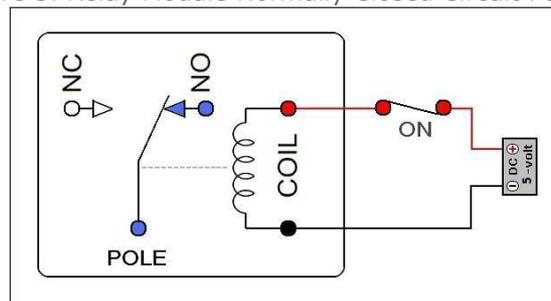


Figure 6. Relay Module Normally Open Circuit Position

Current Transformer

A current transformer is a type of transformer that is used to measure AC Current. It produces an alternating current (AC) in its secondary that is proportional to the AC current in its primary. Current transformers, together with voltage transformers (VTs) or potential transformers (PTs), which are designed for measurement, are known as Instrument Transformers.

The main tasks of instrument transformers are:

- To transform currents from a usually high value to a value easy to handle for relays and instruments.
To insulate the metering circuit from the primary high voltage system.
- To provide possibilities of standardizing the instruments and relays to a few rated currents and voltages.

When you need to measure a current that is too large for your ammeter, a current transformer can be used to provide an isolated lower current in its secondary that is proportional to the current in the primary circuit. The induced secondary current is then suitable for measuring instruments or processing in electronic equipment. Current transformers have very little effect on the primary circuit. A CT is connected in series with the transmission line due to its very low input resistance.



Figure 7. Current Transformer

Most current transformers have the standard secondary rating of 5 or 1 amps with the primary and secondary currents being expressed as a ratio such as 100/5 or 100/1 respectively. This means that in the case of 100/5 CT, the primary current is 20 times greater than the secondary current so when 100 amps are flowing in the primary conductor it will result in 5 amps flowing in the secondary winding.

By increasing the number of secondary windings (N_2), the secondary current can be made much smaller than the current in the primary circuit being measured because as N_2 increases, I_2 goes down by a proportional amount. In other words, an inverse proportion relates the number of turns and the current in the primary and secondary windings.

A current transformer, like any other transformer, must satisfy the amp-turn equation and this turns ratio is equal to:

$$\text{Turn Ratio} = n = \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

From which we get:

$$I_s = \frac{N_p}{N_s} \times I_p$$

Where,

- N_p = Number of turns in the primary windings
- N_s = Number of turns in the secondary windings
- I_p = Current in the primary windings
- I_s = Current in the secondary windings

The current ratio is set by the turns ratio, and as the primary usually consists of one or two turns while the secondary can have several hundred turns, the ratio between the primary and secondary can be quite large. For example, assume that the current rating of the primary winding is 100A. The secondary winding has the standard rating of 5A. The ratio between the primary and the secondary currents is 100A-to-5A, or 20:1. In other words, the primary current is 20 times greater than the secondary current.

In GreenPAK™ mixed signal array, there are analog voltage comparators. Therefore, it is necessary to convert the CT current into voltages. For this purpose, we have connected a shunt resistance R_{shunt} in parallel with the CT. The voltage across R_{shunt} has been measured and it is fed to the GreenPAK design. It is shown in figure 8.

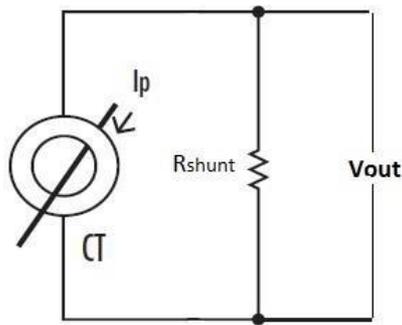


Figure 8. Shunt Resistance in parallel with CT

The value of Rshunt can be found as follows. Consider we have a CT with standard turn ratio 1:50.

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

The normal current flowing in the primary of the CT is 50 A. The secondary current can be found as follows.

$$I_s = \frac{1}{50} \times 50 = 1$$

For normal current flowing in the primary winding, the secondary current is 1A. To obtain 1V corresponding to this current, the Rshunt can be found as follows.

$$R_{shunt} = \frac{1.0}{1} = 1\Omega$$

For this value of Rshunt, there would be 1V corresponding to 1A current in the secondary winding of CT.

GreenPAK Design

In the GreenPAK design, the output voltage from shunt resistor connected in parallel with CT of 1A rating has been taken and it is applied at three PINs named PIN6, PIN10, and PIN13. One analog comparator is attached to each pin individually. Here, three different conditions have been checked. If the voltage from shunt resistor is approximately equal to 1V then the normal current flow LED indication is turned on. If the voltage is less than 1.2V and greater than 1V then there is a nooverload condition. Moreover, if the voltage is greater than 1.67V then the transformer is over loaded and it needs to be isolated from the power system in order to protect it. In this case, signals to the primary and secondary sides HL-52S relay modules have been provided and they will isolate the transformer. The signals to the overload LED indication and piezoelectric buzzer have also been provided. In this way, the transformer is properly protected from overload conditions using this GreenPAK design. It is shown in figure 9.

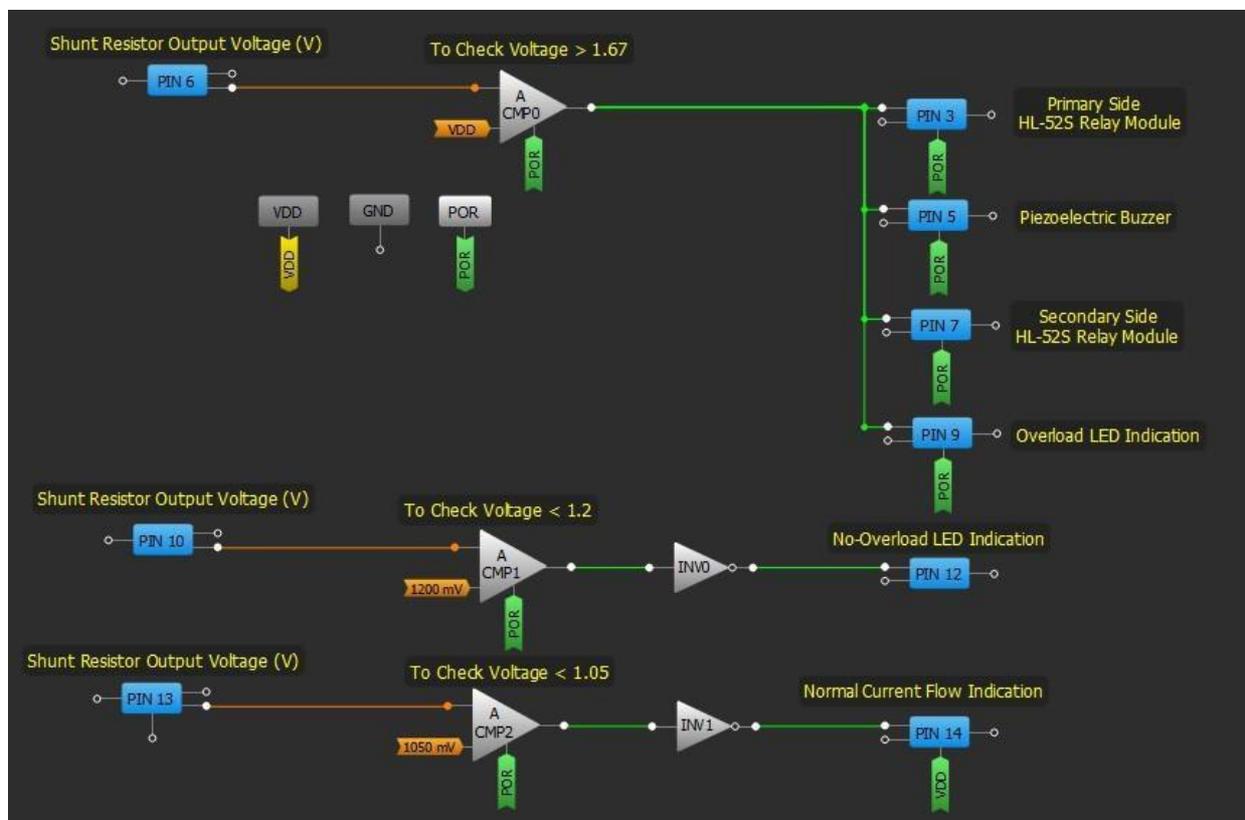


Figure 9. GreenPAK design of Transformer Overload Protection

Conclusion

In this application note, we designed transformer overload protection using the SLG46721V as a main controlling element. The proposed design isolated the transformer from the power system in case of overload situations in order to avoid the heating of transformer body and a decrease in its expected life. The proposed design can be used in combination with transformer differential protection and overcurrent protection to completely protect the transformer from damage due to various faults.

Hardware Implementation

The complete hardware components used for transformer overload protection are shown in figure 10.

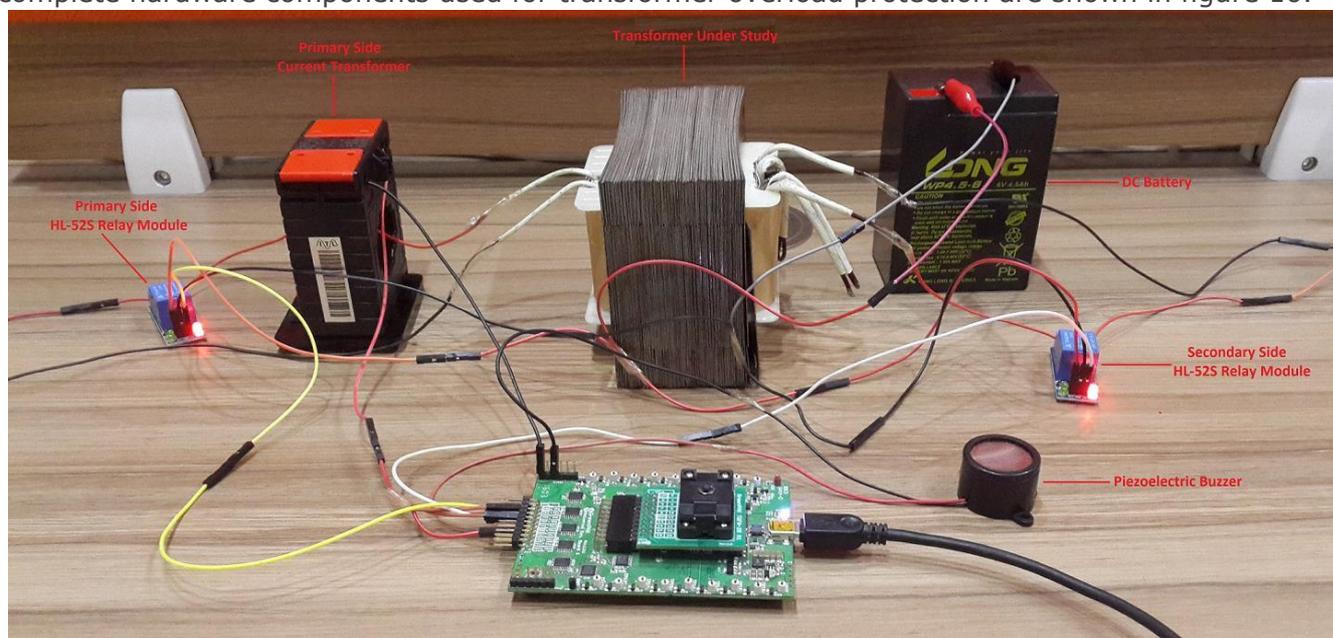


Figure 10. Hardware demonstration

The function of each used component is mentioned below.

Primary Side HL-52S Relay Module: It is used to isolate the primary side of the transformer in case of overloading of the transformer.

Primary Side Current Transformer: It is used to measure the current flowing in the primary side of the transformer.

Transformer Under Study: The transformer that has been used to protect it from overload situations.

DC Battery: It has been used to supply VCC to the primary and secondary sides HL-52S relay modules.

Secondary Side HL-52S Relay Module: It is used to isolate the secondary side of the transformer in case of overload of the transformer.

Piezoelectric Buzzer: It has been used to indicate the overload situation.

The top view of hardware is shown in figure 11.

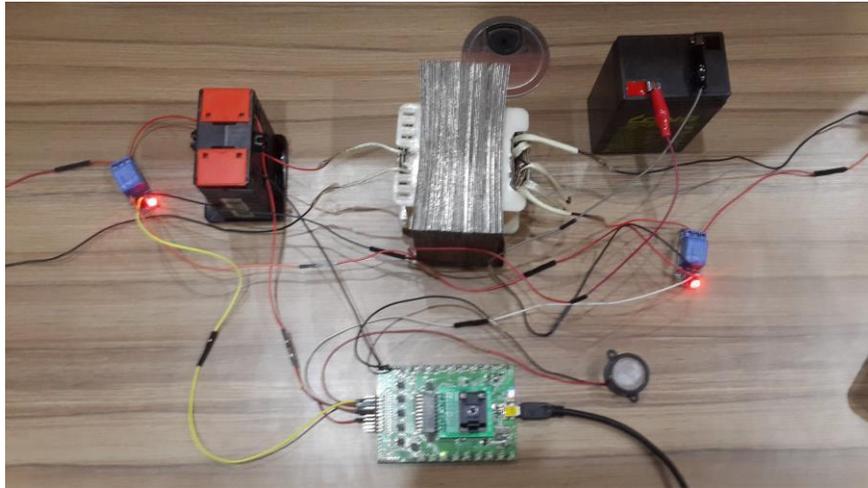


Figure 11. Hardware Top View

A ring main CT has been used. The conductor has to pass through it from which the current has to be measured. The connections of CT are shown in figure 12.



Figure 12. Ring main Current Transformer



Figure 13. Normal Voltage (1V)
LED Indication



Figure 14. No Overload voltage
($1.0 < V < 1.2$) LED Indication



Figure 15. Overload Voltage LED
Side during Overload

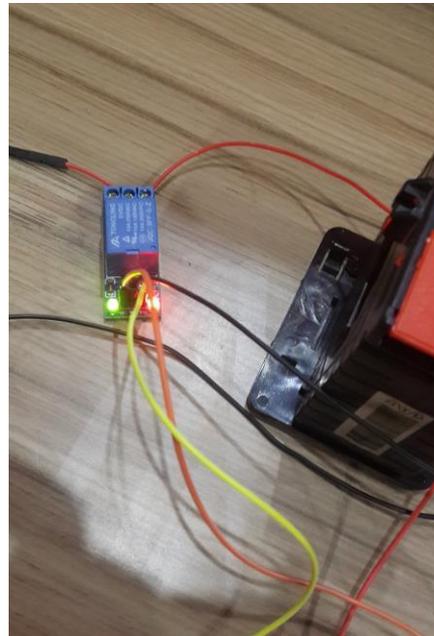


Figure 16. Switching of Relay
Contacts (NC to NO) on Indication Primary
Situation

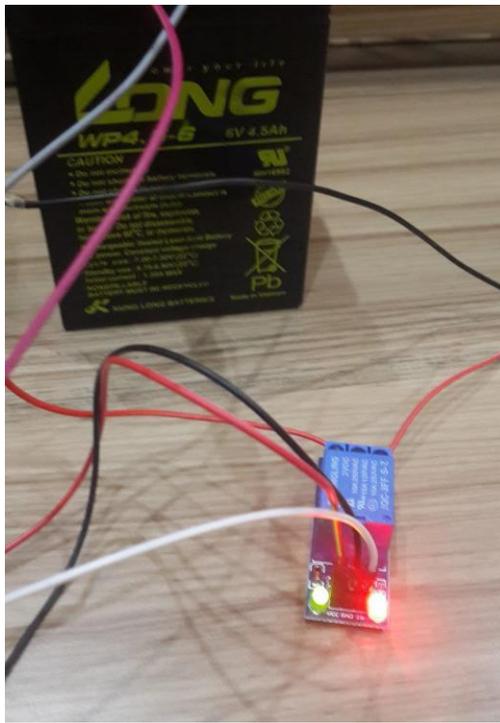


Figure 17. Switching of Relay Contacts (NC to NO) on Secondary Side due to Overload Situation



Figure 18. Indication of Overload using Piezoelectric Buzzer

Files

- [AN-1212 Transformer Overload Protection.gp3](#) - (24 KB)

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