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Volume 6 Number 1 page 22-36

Design And Development Of A Differential Relay Prototype Using SCR For Single-Phase Transformers

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ABSTRACT

This study discusses the design and development of a SCR-based differential relay prototype for a single-phase load transformer, focusing on signal processing by the ADC module. The methods used include hardware design, simulation using MULTISIM, and experiments to determine the optimal parameters of the shunt resistor (R shunt) and capacitor to improve the relay response. The results show that the use of a current transformer (CT) with a ratio of 1000: 1 produces a secondary current that is too small (2.6mA - 7.7mA) to trigger the relay directly. By connecting two CTs in series and reversing the phase of one of them, the resulting voltage increases so that it is sufficient to activate the ADC module. The addition of R shunt (10K potentiometer) allows the secondary voltage to approach zero under normal conditions, while the use of a 4.7µF / 16V polar capacitor optimizes the performance of differential relay protection without sacrificing the indicator display function.

Keywords: Differential relay, SCR, current transformer (CT), and ADC

INTRODUCTION

The electric power system has a very vital role in supporting various sectors of life, including industry, transportation, and households. One of the main components in the electric power system is the transformer, which functions to change the level of electric voltage as needed. In its operation, the transformer must be protected from disturbances that can damage equipment and disrupt the continuity of electricity services. One of the disturbances that often occurs is differential current due to internal damage such as short circuits or insulation failures.(Arif & Yahya, 2021).

Differential relay-based protection systems are a reliable solution for detecting internal faults in transformers by comparing the primary and secondary side currents. Recent studies have shown that the use of modern technologies such as digital algorithms and silicon-based devices can improve the performance of differential relays, especially in terms of response speed and detection accuracy.(Ngema et al., 2022). Silicon Controlled Rectifier (SCR) is one of the potential components to improve transformer protection performance. Previous research has proposed an approach that combines modern electronic technology with differential protection principles to improve system reliability and efficiency.(Zulkarnaini & Hafni, 2020). In this context, the implementation of SCR as a key element in a differential relay is believed to provide a more affordable and responsive solution, especially for single-phase load transformers.

This paper described aims to design and build a prototype of SCR-based differential relay on a single-phase load transformer. With this technology, it is expected that the protection system can detect differential disturbances accurately and provide a fast response to protect the transformer. So far, the discussion of differential relays in lectures has only focused on the function and working principle of the current transformer itself which works based on the difference in current or voltage output from the current transformer itself, but has never discussed the ADC module that processes the current or voltage produced by the current transformer on the differential relay. On this occasion, the author wants to create an ADC sensor module using electronic components, namely SCR as switching, which will then activate the relay to disconnect and provide an alarm for its users.

LITERATURE REVIEW

Transformer

Transformer or often called a transformer is a tool that functions to change the magnitude of voltage and electric current by utilizing electromagnetic induction. In general, transformers are divided into 2 types, namely step-up transformers and step-down transformers. Transformers work based on the principle of electromagnetic induction, based on this law, if a coil (primary) is connected to an alternating voltage source (AC), an alternating flux will arise in the core wrapped in the coil. In the coil whose circuit is closed (close loop), so that the primary current flows and will cause electromagnetic in the primary coil(Saputra et al., 2023).

Because of the flux in the primary coil, self-induction occurs in the primary coil. The effect of induction from the primary coil also causes induction in the secondary coil. Induction in the secondary coil is commonly called mutual induction. Induction that occurs in the secondary coil causes magnetic flux. The magnetic flux in the secondary coil produces electromotive force (EMF). When this secondary circuit is given a load, a secondary current flows due to the electromotive force that occurs. It can be said that this transformer transmits electrical power magnetically and can only work on alternating current.(Wasripin & Triyanto, 2023).

Apart from having different shapes and sizes, transformers have main parts that are always present in every transformer, namely the iron core (core) and coils or windings. (Ashari & Asrul, 2023).

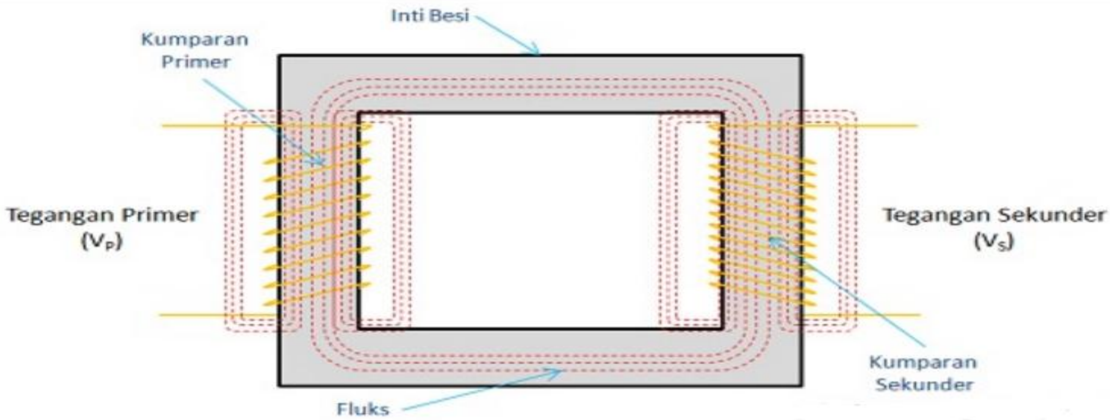

Figure 1. Main Parts of a Transformer

The iron core functions as a place or container that aims to facilitate the path of flux, and this arises because of the electric current that passes through the coil. And the iron core is made of thin insulated iron plates, in order to reduce the heat on the iron core. However, along with the advancement of technology, the core of a transformer is not always made of thin iron plates, especially in power supply devices that already use switching systems and some measuring

International Journal of Economic, Technology and Social Sciences
e-ISSN 2775-2976
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url: https://jurnal.ceredindonesia.or.id/index.php/injects
Volume 6 Number 1 page 22-36

instruments whose cores are made of ferrite or iron powder (Djafar et al., 2023).

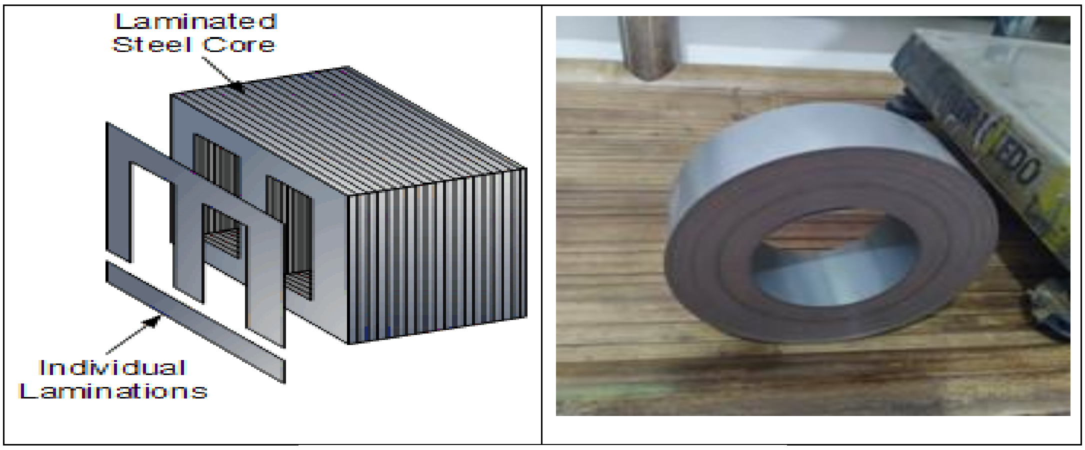

Figure 2. Ferrite Core Transformer

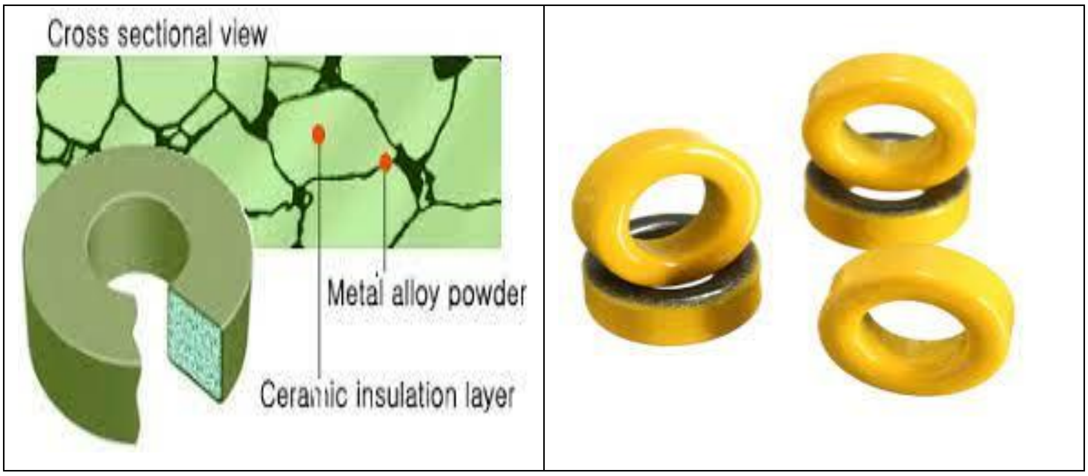

Figure 3. Iron Powder Core Transformer

Transformer coil is a coil of insulated wire that forms a coil. The coil generally consists of a primary and secondary coil that has been well insulated and the coil will later become a tool for transforming voltage and current.(Dendi et al., 2022).

Isolation Transformer

Transformers that generally have the same winding equation between primary and secondary are called isolation transformers. This type of transformer always has at least 2 coils, the coils on the input (primary) section will always be separate from the output (secondary) section. So if measured, the primary coil will not be connected to the secondary coil. Its function is to limit the direct relationship between the primary and secondary currents without changing the voltage and current values. Disturbances that appear such as over-voltage, voltage distortion, transient symptoms generated by non-linear workloads such as motors. This protection is provided for electrical equipment that is very sensitive to disturbances such as PLCs, DCSs,

International Journal of Economic, Technology and Social Sciences
url: https://jurnal.ceredindonesia.or.id/index.php/injects
Volume 6 Number 1 page 22-36

power meters, and other electronic equipment.(Suganda & Muis, 2021).

In the construction of an isolation transformer in each coil, both primary and secondary coils, both are covered by a metal shield (metallic shield), another shield is also placed between the primary and secondary coils (inter-winding shield). The presence of shields in an isolation transformer construction serves to prevent high frequency transfer, either due to noise or transients that go to the secondary circuit connected to the load. This can be done by the isolation transformer by reducing the capacitance between the primary and secondary coils due to the addition of an electrostatic shield in the isolation transformer construction, thus the distribution of noise and transient voltage can be reduced(Oktaviani et al., 2021).

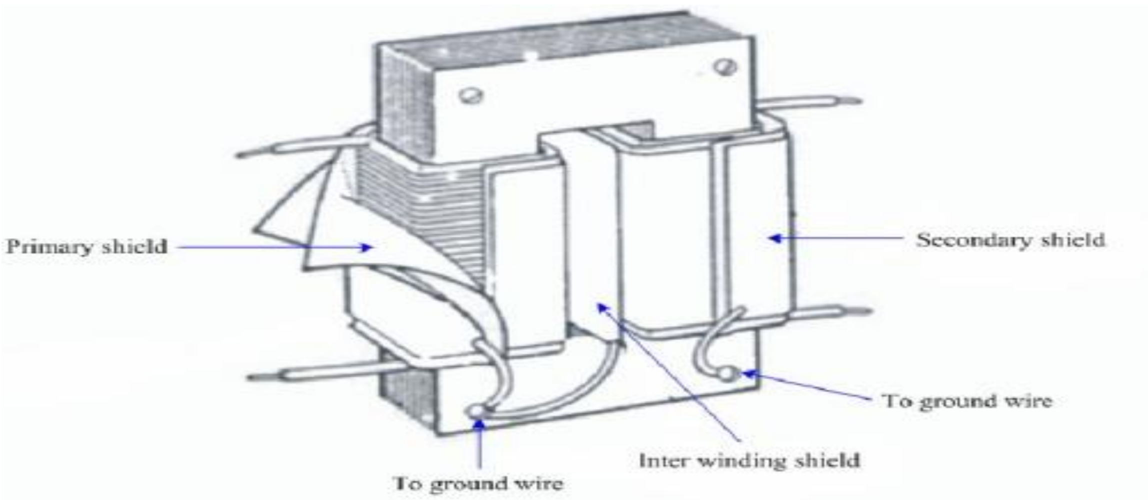

Figure 4. Isolation Transformer

Measuring transformers are often referred to as instrument transformers. These transformers function to measure equipment in the electrical power system. Electricity that passes through the primary coil is then induced into the secondary coil to be converted into a smaller voltage and current so that it can be calculated(US & Silitonga, 2022).

The comparison between the primary and secondary coils is arranged in such a way that there is no error even though the results shown are not the actual results. The results shown must be calculated with a certain formula according to the number of turns between the primary and secondary coils. The measuring transformer is specifically designed for measurements in power systems.(Pangastuti, 2021). This transformer is widely used in power systems because it has advantages, including:

a. Provides electrical isolation for the power system
b. Resistant to loads of various levels
c. High level of reliability
d. Physically it is simpler in form, and
e. Economically cheaper

The measuring transformer consists of:

a. Voltage transformer (Voltage transformer / Potential Transformer or PT)
b. TransformerCurrent (Current Transformer or CT)

The current and voltage on the power equipment to be protected are changed by current transformers and voltage transformers to lower levels for relay operation. These lower levels are necessary for two reasons, namely:

a. The lower input level to the relays makes the components used to construct the protection module physically quite small, therefore from an economic perspective the cost will be cheaper.
b. And for humans (workers) who work with these relays, they can work in a safe environment.

The power consumed by this transformer to do its work is not that great, because the connected load only consists of relays and ADC modules for measuring instruments (metering) which may only be used at certain times.(US & Silitonga, 2022). The load on a measuring transformer (CT and PT) is known as the load (Burden) of the transformer. The term load usually describes the impedance connected to the secondary coil of the transformer, but can also specify the volt ampere delivered to the load. TransformerThe current is divided into 2 classes, both of which have accuracy standards of 2.5% and 10%, namely:

a. Class H current transformer (high leakage reactance)
b. Class L current transformer (low leakage reactance)

Protection system is a complete arrangement of protection devices consisting of main devices and other devices needed to perform protection functions. Disturbances in the distribution system can be caused by natural factors, human negligence, or equipment damage. Disturbances in the electric power system consist of temporary disturbances that can disappear by themselves or by momentarily disconnecting the disturbed part from the voltage source and permanent disturbances, where to free it requires corrective action to eliminate the cause of the disturbance.(Azis & Febrianti, 2019).

There are several basic aspects of the protection system, namely:

1. Reliability
   Reliability is defined as the degree of certainty that a relay or relay system will operate correctly. In other words, dependability indicates the ability of a protection system to perform correctly when required, while safety is its ability to avoid errors and problems outside the specific operating room zone.
2. Selectivity
   Selectivity (also known as relay coordination) is the old process and setting of protective relays that surpass other relays so that they operate as quickly as possible in their primary zone. This is necessary to allow the primary relay to be assigned to the backup.
3. Clear Operation Speed
   It is highly desirable that the protection isolates the problem or fault zone as quickly as possible, thus speed is very important for the protected area to operate stably.
4. Simplicity
   A protective relay system should be simple and actually as easy as possible to achieve the clear objective results. And protection, should be considered very carefully.
5. Economy
   The basis for obtaining maximum protection for minimum cost, as cost is always a major factor. In addition, this may involve greater difficulties in installation and operation, as well as higher maintenance costs.(Nasution et al., 2021).

International Journal of Economic, Technology and Social Sciences
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url: https://jurnal.ceredindonesia.or.id/index.php/injects
Volume 6 Number 1 page 22-36

As with other electrical equipment, transformers require safety equipment that can protect, secure or minimize damage and interference to the transformer. To protect large-capacity power transformers, especially in the Main Substation (GI) from damage, a protective relay is installed that can recognize abnormal conditions in the electric power system and take steps deemed necessary to ensure the separation of interference with the smallest possible interference to normal operations, among the protections available on large-capacity power transformers, one of which is the differential relay.(Azis & Febrianti, 2019)

Differential Relay

A differential relay is a relay whose working principle is based on balance, which compares the secondary currents of the current transformer installed at the terminals of the equipment or electrical installation being protected.(Farabi & Putri, 2022). Differential relay is very selective and its working system is very fast, Differential relay has a principle in normal conditions, the current flowing through the secured electrical equipment (Generator, Transformer). If there is a disturbance outside the safety area, the differential relay does not work as in Figure 2.7 below, when the primary side of both CTs is supplied with current and current, with the ratio of CT1 and CT2 going to the Relay being the same, the Relay does not work, because the circulation of the disturbance current is outside the working area of the differential relay and does not affect the current flowing to the CT installed on the protection device(Keumala et al., 2021).

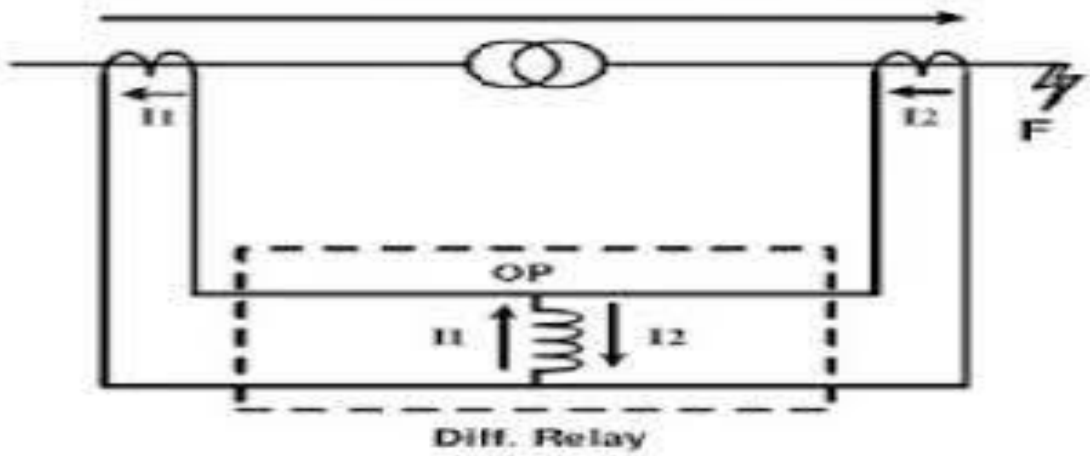

Figure 5. Fault Occurs Outside the Differential Relay Working Range

If a differential relay is installed as protection for an equipment and there is a disturbance in its protected area, the differential relay must work, as shown in Figure 2. When CT1 flows current I, there is no current flowing in CT2 (I = 0), because the fault current flows at the fault point so that no current flows in CT2, so on the secondary side of CT2 there is no current flowing (I = 0) which results in I ≠ I (1 ≠ 0) so that the differential relay works.(Salih et al., 2021).

International Journal of Economic, Technology and Social Sciences
url: https://jurnal.ceredindonesia.or.id/index.php/injects
Volume 6 Number 1 page 22-36

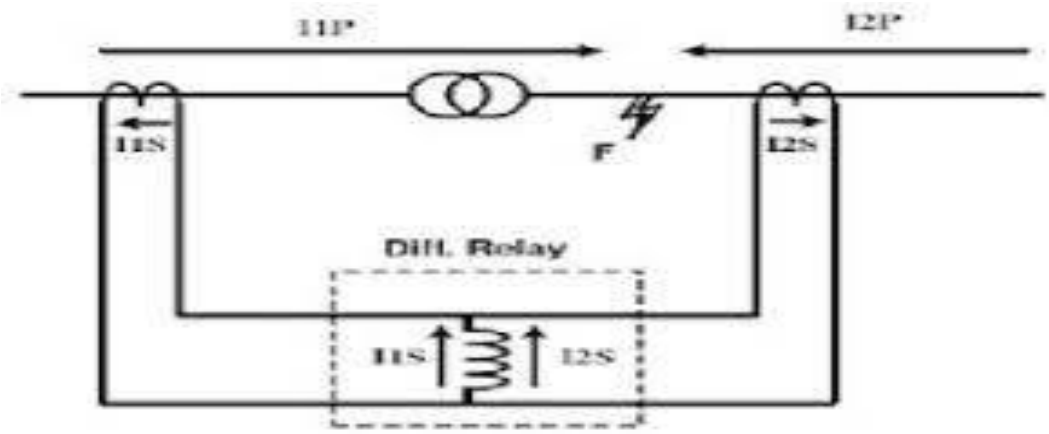

Figure 6. Disturbance Occurs Within the Differential Relay Working Range

METHODOLOGY

The research plan starts from January 18, 2025 to March 19, 2025. Initial preparation of the work to make this research is planned to begin in December 2024 with the initial stage of literature study, then continued with data collection obtained from the research results to determine what components are needed to make a differential relay module, both the number and value of the components. The software used is the Multisim program which is used to simulate all data related to the components needed to make a differential relay. The implementation of the research was carried out with data calculations starting in December. After the calculation results were obtained, they were then simulated using the Multisim program after the calculation and determination stage of use, value, and the number of components needed. The tools and materials used in this study are as in Table 1 below:

Table 1. Research Tools and Materials

No	Materials and Equipment	Specification	Amount
1	Power transformer	Toroidal transformer 2000VA 220v/130v 1 phase	1
2	Differential relay sensor current transformer.	Rated Input Current: 5A Rated Output Current: 5mA Ratio 1000:1 Linear Range: 0 - 10A (100 Ω) Linearity : 0.2% Precision : + 0.2	2
3	Ampere meter, Volt meter and Frequency Meter.		2
4	Adapter	12V 1A	1
5	Single cable		2 meters
6	Stranded cable		2 meters
7	DC Socket		1
8	Trimpot	Multiturn 100K	1
9	Capacitor	Polar 4.7uF/50v	1
10	Capacitor	Non-Polar	1
11	Buzzer	Active 3-24V	1

International Journal of Economic, Technology and Social Sciences
e-ISSN 2775-2976
International Journal of Economic, Technology and Social Sciences
url: https://jurnal.ceredindonesia.or.id/index.php/injects
Volume 6 Number 1 page 22-36

No	Materials and Equipment	Specification	Amount
12	Relay	80A 250vac NO NC	1
13	Terminal	3 pin	2
14	Terminal	2 pin	1
15	Solder	Dekko 40W 220V	1
16	Tin		Enough
17	PCB		Enough
18	Heater Element	1000W/220V	3
19	Binding Post		13
20	Switch		4
21	Power cable	2x1.5mm	1
22	Box		1
23	Cutting pliers		1
24	Drill	Cordless	1
25	Drill bit		Necessary
25	SCR	2P4M	1
26	Diode	- Bridge 2A 1000v	1
27	Diode	- Diode 1N4004	2
28	Resistor	8k 1/8w±5%	1
29	Display	- Voltmeter - IDiff (Amp)	1
30	MCB	Schneider 10A	1

The research was carried out by designing a prototype tool and simulating the results of the experiment using MULTISIM software. Furthermore, conducting experiments and testing and determining the values of capacitors and resistors to obtain the SCR response to changes in voltage given by the CT transformer after that conducting an analysis in order to draw final conclusions. For data sampling, 3 (three) load limits were taken by looking at the response of the SCR, the load samples taken were at 50%, 100% and >150%. The test point that will be the point for taking measurement data is the differential voltage between the two CTs that go to the Bridge rectifier diode and the voltage that has been rectified that goes to the SCR Gate leg after going through the trimpot.

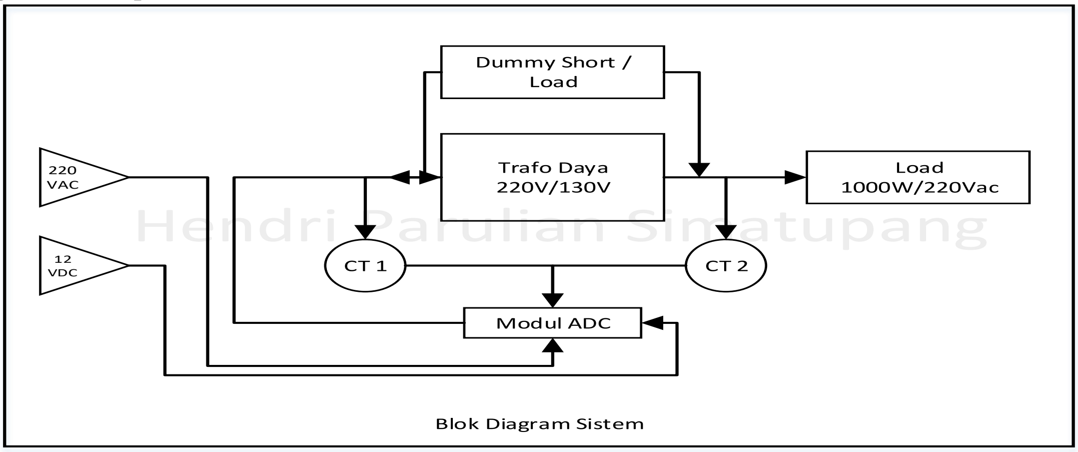

Figure 7. System Block Diagram

Injects International Journal of Economic, Technology and Social Sciences
e-ISSN 2775-2976
International Journal of Economic, Technology and Social Sciences
url: https://jurnal.ceredindonesia.or.id/index.php/injects
Volume 6 Number 1 page 22-36

From Figure 7 the block diagram of the tool above, the function of each block can be explained as follows:

1. 220VAC is the main power source that becomes the main supply for the load, after going through the NC (Normally Close) Relay and power transformer.
2. 12VDC is a source of electrical energy that supplies the ADC module (protection relay, buzzer and SCR supply).
3. RYP is a Protection Relay with NC (Normally Close) contacts that function as a connector for the main supply to the power transformer in normal conditions or without interference and will automatically protect or disconnect the main supply if there is a disturbance detected by differential protection which is accompanied by the NC (Normally Close) relay contact becoming the NO (Normally Open) contact.
4. CT1 is a current transformer that functions as a current detector on the primary side of the transformer.
5. CT2 is a current transformer that functions as a current detector on the secondary side of the transformer.
6. The power transformer as the main transformer that reduces the source voltage from 220vac to 130vac which will be used as a load supply with a transformer capacity of ±2000 VA.
7. Load is an electrical equipment used to consume electrical energy according to the amount of power according to the specifications on the name plate and the one currently used is a 1000W water heater element at a voltage of 220Vac as many as 3 (three) pieces. 2 (two) elements are used as the main load (at 100% load) while 1 (one) element will be used as an additional load (150%) and can also be used as a disturbance load to provide a disturbance signal to the Differential Relay Module.

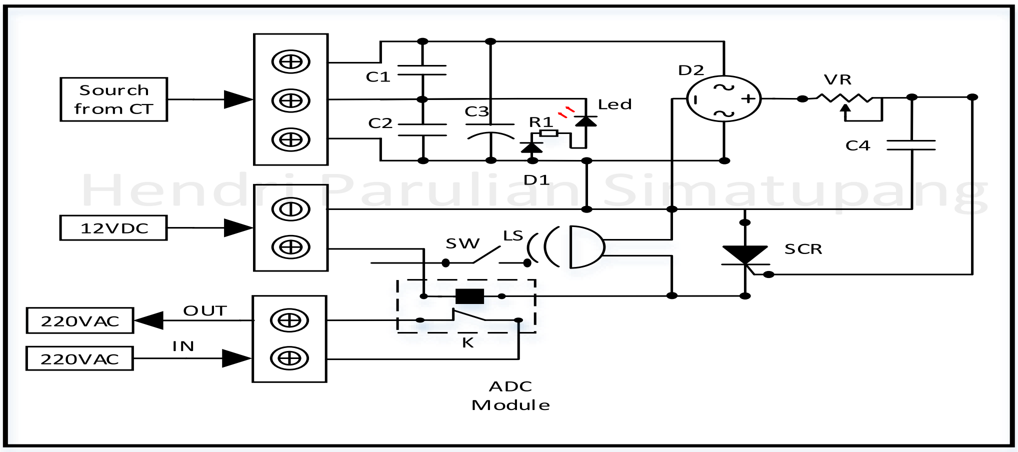

Figure 8. Differential Relay ADC Module

From Figure 8 the block diagram of the tool above, the function of each block can be explained as follows:

1. 220VAC IN is the voltage source that enters the NC (Normaly Close Relay) contact before going to the transformer.

International Journal of Economic, Technology and Social Sciences
e-ISSN 2775-2976
International Journal of Economic, Technology and Social Sciences
url: https://jurnal.ceredindonesia.or.id/index.php/injects
Volume 6 Number 1 page 22-36

2. 220VAC OUT is the voltage source that enters the transformer after going through the NC (Normally Close Relay) contact.
3. Source from CT is the voltage that comes out of 2 differential CTs.
4. 12VDC is a voltage source that is the main supply for the ADC module, including SCR, relay and buzzer.
5. C1, C2 and C3 are capacitors that function to accommodate the same CT ratio but different induced currents between CTs.
6. D1, R1 and Led are a series of indications of disturbance. Led will light up instantly if there is disturbance and turn off instantly if the disturbance has disappeared.
7. D2 is a bridge diode that functions to rectify the AC voltage originating from the differential transformer whose DC voltage is used as a trigger on the SCR Gate.
8. VR is a variable resistor (Multiturn Trimpot) which is used to regulate the amount of voltage entering the SCR gate or to regulate the sensitivity of the SCR.
9. C4 is a non-polar capacitor that functions as a ripple voltage dampener before reaching the SCR gate.
10. SCR (Silicon Controlled Rectifier) or often called a thyristor which functions as a switch based on the voltage entering through the Gate.
11. An active buzzer is a speaker that will emit a loud sound when given a voltage of 3-24vdc.
12. *Relay*is a switch that will work when the coil is given a voltage of 12Vdc, when the relay is active, the voltage source going to the transformer will be disconnected.

RESULTS AND DISCUSSION

Voltage on Each CT Before Series and Without R Shunt

a. No burden

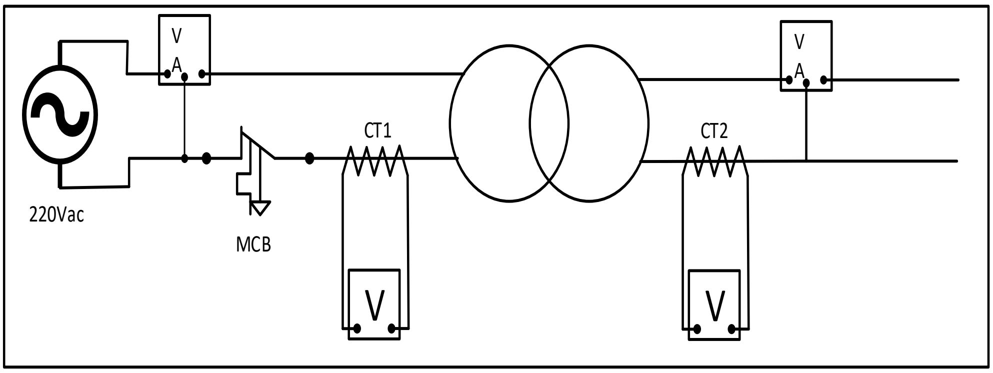

Figure 9. Wiring for voltage testing of each CT before being in series, without R Shunt and without load.

Table 2. Test results for each CT before being in series, without R Shunt and without load.

Primary		Secondary		Voltage	
Voltage	Curren t	Voltage	Current	CT1	CT2
237 Vac	0 A	140 Vac	0 A	0.014 Vac	0.012 Vac

International Journal of Economic, Technology and Social Sciences
e-ISSN 2775-2976
International Journal of Economic, Technology and Social Sciences
url: https://jurnal.ceredindonesia.or.id/index.php/injects
Volume 6 Number 1 page 22-36

b. Normal Load

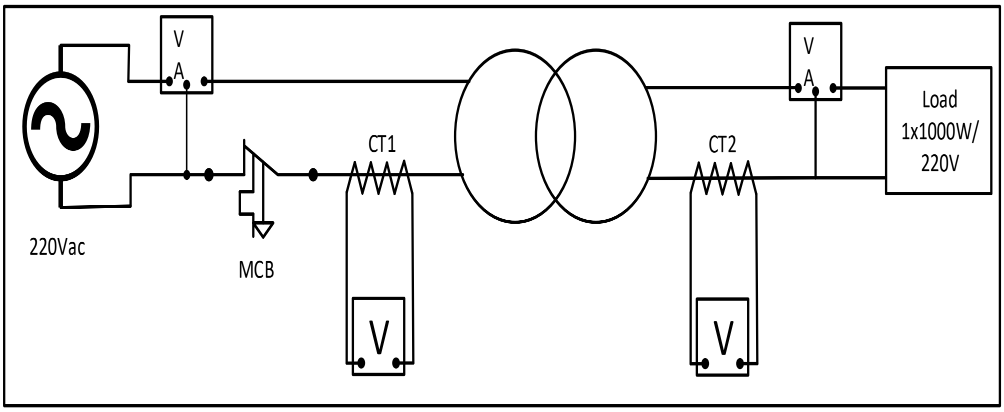

Figure 10. Wiring for voltage testing of each CT before being in series, without R Shunt and with normal load.

Table 3. Test results for each CT before being in series, without R Shunt and with normal load.

Primary		Secondary		Voltage	
Voltage	**Current**	**Voltage**	**Current**	**CT1**	**CT2**
233 Vac	1.3 A	136 Vac	2.3 A	4.79 Vac	3.435 V

c. Normal Load and Disturbances on Primary and Secondary Sides

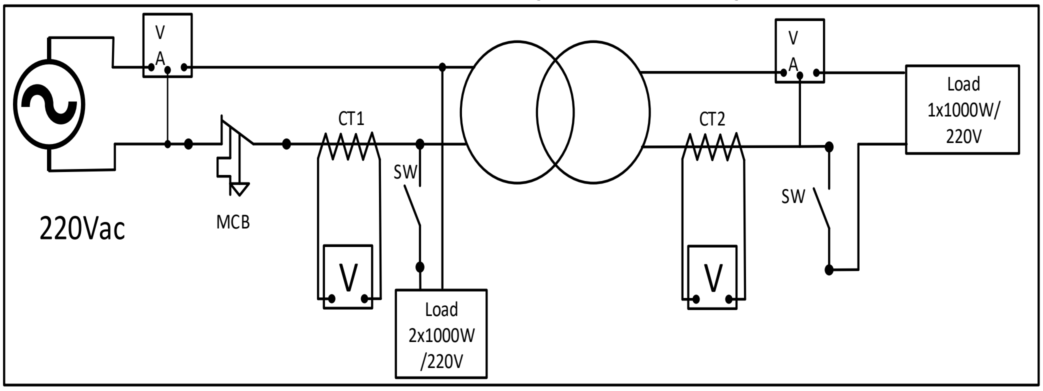

Figure 11. Wiring voltage testing for each CT before being in series, without R Shunt with normal load and fault on the primary side.

Table 4. Test results for each CT before being in series, without R Shunt with normal load and disturbance on the primary side.

Primary		Secondary		Voltage	
Voltage	**Current**	**Voltage**	**Current**	**CT1**	**CT2**
220 Vac	9.2 A	129 Vac	2.2 A	5.56 Vac	3,435 Vac

International Journal of Economic, Technology and Social Sciences
e-ISSN 2775-2976
International Journal of Economic, Technology and Social Sciences
url: https://jurnal.ceredindonesia.or.id/index.php/injects
Volume 6 Number 1 page 22-36

Voltage on CT After CT1 and CT2 are in series, R Shunt on CT1, Already Connected to Differential Relay Module, Connected to Display and with Capacitor

a. No burden

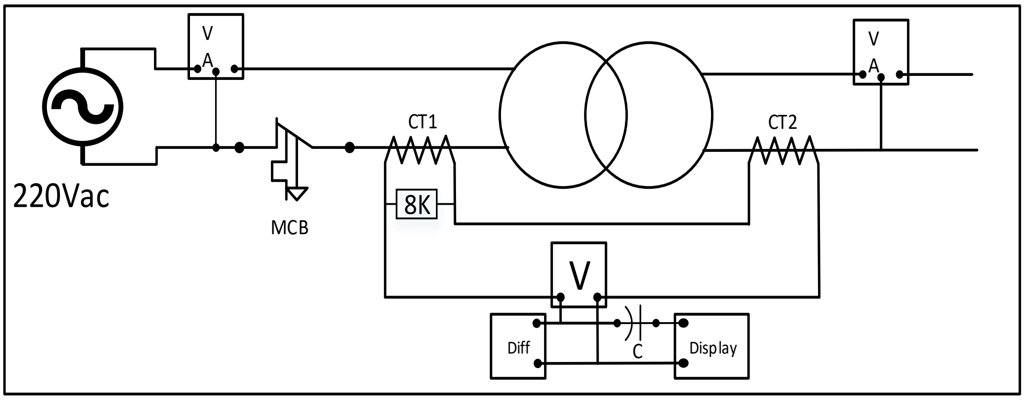

Figure 12. Wiring for testing voltage on CT after CT1 and CT2 are in series, with R Shunt on CT1, already connected to the Differential Relay module and connected to the display with a capacitor and no load.

Table 5. Results of voltage testing on CT after CT1 and CT2 are in series, with R Shunt on CT1, already connected to the Differential Relay module and connected to the display with a capacitor and without load.

Primary		Secondary		Voltage	Differential Relay	
Voltage	Current	Voltage	Current	CT	IDiff	Relay
234 Vac	0 A	140 Vac	0 A	1,460 Vac	0 A	No Protection

In the picture above, it is known that there is a disturbance (F1 and F2) in the differential relay protection area (CT1 and CT2), so that the current flows from point B to point A which will activate the relay. As we know in the picture above, CT 1 and CT 2 are connected in parallel at each secondary terminal by reversing the polarity or phase of one of the CTs so that when there is the same current on each CT it will be 0 (Zero). This condition can be applied to a large capacity current transformer (CT) which generally has a secondary current of 1-5 Amps so that it can provide a signal to activate the relay and provide a signal of how much the current difference occurs (differential current) when a disturbance occurs. However, in the research that I did this time, there were several main obstacles that were a challenge for me personally, including:

1. Too small fault current on the secondary side of the CT
2. The ratio of the power transformer I use is different (220V to 130V) but uses the same current transformer (10A/10mA). So with normal load conditions the voltage on the secondary side of each CT will be different.
3. With the addition of a differential current reading display, the current supply to the differential relay ADC module is reduced, which causes the differential relay to not work normally.

In this research I made a small version prototype that only has a fault current of 2.6 - 7.7

Amps on the primary side of the current transformer (CT) with a ratio of 1000: 1 so that the current on the secondary side of the current transformer is only 2.6mA - 7.7 milli Amps, with such conditions the current generated by the current transformer (CT) is very small to be used to Trigger a relay and display the indicator reading the magnitude of the current difference (I differential). So I made the two current transformers (CT) connected in series by reversing the phase on one of the CTs so that the voltage value produced by each CT is one of them to be reduced. Thus the voltage generated by the two current transformers (CT) in series is sufficient to Trigger the ADC relay differential module. Meanwhile, to overcome the same current transformer ratio with different currents on the primary side of the CT which also results in differences on the secondary side of the current transformer (CT), I added an R shunt in the form of a variable resistor (10K potential) on the secondary side of the CT that has been connected in series which will later function to make the secondary side voltage after being connected in series close to 0 (zero) at normal load conditions (without interference). then the CT voltage that has been connected in series and added with R shunt is connected to the ADC relay differential module, the differential relay functions properly after the R shunt is set as needed. However, when it will be connected to the display indicator for reading the current difference (I diff) all the voltage produced by the current transformer (CT) is used for display needs so that the differential relay protection cannot function properly as expected. The solution that I found when conducting various experiments by adding a 4.7uF/16V polar capacitor connected in series with one of the cables leading to the display for reading the current difference (I diff) then the differential relay protection returned to functioning normally after setting the value of R shunt and setting the sensitivity of the ADC Relay Differential module.

CONCLUSION.

From the results of the research conducted, several conclusions can be drawn, namely:

1. The use of a current transformer (CT) with a ratio of 1000:1 produces a very small secondary current (2.6mA - 7.7mA), which is not enough to directly trigger the relay and display the indicator.
2. By connecting two current transformers (CT) in series and reversing the phase of one of them, the resulting voltage is increased, enough to activate the ADC module on the differential relay.
3. To overcome the current difference due to the same transformer ratio but different primary current, a variable resistor (10K potentiometer) is used as a shunt R on the secondary side of the series CT, so that the secondary voltage approaches zero under normal load conditions.
4. All the voltage produced by the current transformer (CT) is absorbed by the current difference reading indicator display (I diff), so that the differential relay protection does not function properly.
5. By adding a 4.7uF/16V polar capacitor in series to one of the cables leading to the display, the differential relay protection returned to normal function after resetting the R shunt and the sensitivity of the differential relay ADC module.

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Volume 6 Number 1 page 22-36

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