



## Design and build an *Arduino-Based* Inverse Time and Constant Time Overcurrent Protection Relay

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**ABSTRACT:** This study discusses the design and implementation of a overcurrent protection system using two types of relays, namely *Inverse Time Overcurrent Relays* and *Constant Time Overcurrent Relays* based on Arduino Uno microcontrollers. The system is designed to detect and respond to overcurrent disturbances that occur at resistor loads using current sensors, relay modules, and LCD displays. In an *inverse time system*, the disconnection time depends on the magnitude of the interference current, where the larger the current, the faster the relay works. On the other hand, in a *constant time system*, the relay will cut off the current at a predetermined time, regardless of the size of the current. The Arduino Uno acts as a controller brain that processes data from the current sensor and determines the disconnection logic. The test was carried out to evaluate the relay working time characteristics of the interference current variation as well as the effect of the multiplier factor value on the disconnection speed. In addition, the system is also equipped with a PZEM-004T CT module for *real-time* monitoring of electrical parameters and a 16×2 LCD display as a user interface. The test results show that the system is able to work effectively according to the characteristics of each type of relay. This prototype offers a practical and economical solution in the simulation of electrical protection systems, particularly in microcontroller-based learning and development environments.

**KEYWORDS:** Arduino, Constant Time, Current Protection, Current Sensor, Inverse Time, PZEM-004T CT, Overcurrent Relay.

### INTRODUCTION

In electrical systems, protection against current interruptions is more critical to maintain the reliability and safety of installations. Overcurrents that are not addressed immediately can lead to equipment damage, fires, and even overall system failures. One commonly used protection method is the use of overcurrent relays, which can work based on specific time characteristics. The two types of overcurrent relays that are widely applied are Inverse Time Overcurrent Relays and Constant Time Overcurrent Relays.

Inverse Time Overcurrent Relays have a characteristic where the greater the fault current, the faster the relay disconnection time. In contrast, Constant Time Overcurrent Relays decide the current based on a fixed time, without considering the magnitude of the interference current. The application of this protection system is based on the Arduino Uno microcontroller, which plays a role in reading data from the current sensor, processing the data, and controlling the relay module.

This research aims to design and build a prototype of an Arduino-based overcurrent protection system that is able to simulate the work of the two types of relays. The test was carried out to observe the characteristics of the disconnection time to current variations, as well as to evaluate the effect of the multiplier setting on the disconnection speed of the system. In addition, to improve the ease of monitoring, the system is equipped with a PZEM-004T CT module that allows real-time measurement of electrical parameters, and uses a 16×2 LCD as the user interface.

### MATERIALS AND METHODS

#### A. Basic Theory

A protective relay is a device designed to detect abnormal conditions in an electric power system, such as overcurrent, short circuits, or ground disturbances. The goal is to isolate the compromised parts of the system to prevent further damage and maintain the continuity of electrical energy distribution. *Inverse Time Overcurrent Relay* is a type of relay that has the characteristics of working time that is inversely proportional to the magnitude of the interference current, which means that the higher the current value detected exceeding the normal limit, the faster the relay responds to break the circuit. This type of relay works based on the *Inverse Time formula* as a comparison of the disconnection time performed by the relay. A basic reference to how the *Inverse Time* overcurrent relay works is shown in the image below, this.

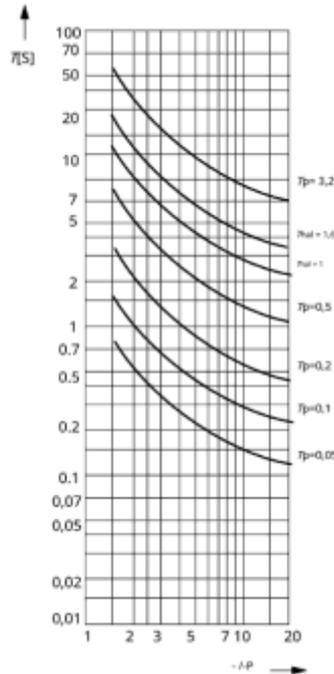


Figure 1. Basic Reference of How Inverse Time Overcurrent Relays Work

The curve drawing shows the working characteristics of the over-current protection relay of the *Inverse Time* type shows the relationship between the interference current ( $I/I_p$ ) and the relay's working time ( $t$ ), where the greater the interference current, the faster the relay responds. These curves are logarithmic scaled and each represents different Time Multiplier Setting (TMS) values, such as 0.05, 1.5, and 3.2, which determine the sensitivity of the relay uptime the smaller the TMS, the faster the relay response. This curve is important to ensure selective coordination between relays in the protection system, and includes characteristics such as normal inverse, very inverse, and extremely inverse according to system needs. In this study, the inverse standard characteristic was used to calculate the relay working time based on TMS variations. Here's the formula used.

$$t = \frac{0.14}{\left(\frac{I}{I_p}\right)^{0.02-1}} \times t_p \tag{1}$$

Explanation:

$t$  = disconnection time ;  $I$  = interference current

$I_p$  = maximum current ;  $t_p$  = times factor

Table 1.  $\alpha$  and  $\beta$  prices for Inverse characteristics

| Characteristic Curve | $\alpha$ | $\beta$ |
|----------------------|----------|---------|
| Standard Inverse     | 0,02     | 0,14    |
| Very Inverse         | 1,0      | 13,5    |
| Longtime Inverse     | 1,0      | 120     |
| Extremely Inverse    | 2,0      | 80      |

In this case, the researcher uses an *Inverse Time* relay with Standard Inverse characteristics, so the formula used is as follows

$$t = \frac{0.14}{\left(\frac{I_{hs}}{I_{set}}\right)^{0.02-1}} \times TMS \tag{2}$$



Information:

$t$  = Relay working time

$I_{hs}$  = Short-circuit current or interference current

$I_{set}$  = Relay setting current

TMS = *Time Multiple Setting*

After determining the formula used to estimate the working time of the relay, the researcher then conducted several calculations of the interference current using a multiplier factor or TMS as the target that must be achieved by *the Inverse Time* over current protection relay. The first one uses a multiplier factor of 0.05 for its own curve can be seen in figure 2. The target curve with a multiplier factor of 0.05 is below.

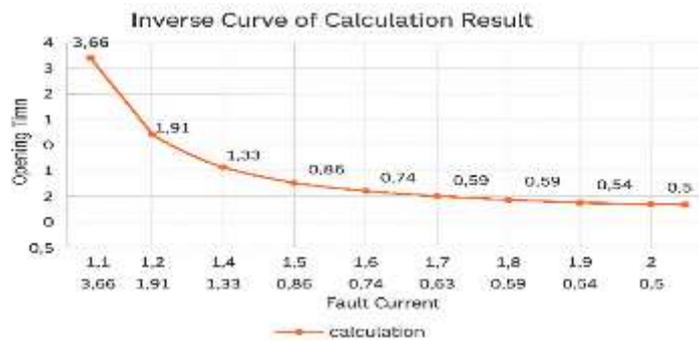


Figure 2 Target Curve with a Multiplier Factor of 0.05

Then for the data of the calculation results, it can be seen in table 2 of the calculation results with a multiplier factor of 0.05. Furthermore, the researcher calculated with the same setting current value of 1A, which was changed only to TMS or the relay factor using 1.5 which caused the relay sensitivity to be longer than the previous one, which was 0.05. The following target curve used as a reference for the relay performance results can be seen in figure 3 of the target curve with a multiplier factor of 1.5. Tiered (hierarchical) protection system. In systems like this, downstream relays typically use *Inverse Time* to respond more quickly to major disturbances. Meanwhile, the upstream relay as represented by this curve will use a fixed time setting (e.g. 10 seconds) to give the downstream relay a chance to resolve the interference, and only work if the relay fails. This function is referred to as *backup protection*.

Table 2. Inverse Time Relay Calculation Results with a Multiplier Factor of 0.05

| No | Set Current (A) | Multiplying Factor | Formula  | Opening Time (sec) |
|----|-----------------|--------------------|--|--------------------|
| 1  | 1               | 0,05               | $t = \frac{0,14}{\left(\frac{I}{I_p}\right)^{0,02}} \times 0,05$ | 3,66               |
| 2  | 1.1             | 0,05               |  | 1,91               |
| 3  | 1.2             | 0,05               |  | 1,33               |
| 4  | 1.3             | 0,05               |  | 1,03               |
| 5  | 1.4             | 0,05               |  | 0,86               |
| 6  | 1.5             | 0,05               |  | 0,74               |
| 7  | 1.6             | 0,05               |  | 0,63               |
| 8  | 1.7             | 0,05               |  | 0,54               |
| 9  | 1.8             | 0,05               |  | 0,50               |
| 10 | 2               | 0,05               |  | 0,50               |

Then for the calculation data, it can be seen in table 4 the calculation results with a multiplier factor of 3.2. Furthermore, *Constant Time* relays are a type of protection relay that works with a fixed working time, regardless of the size of the fault current. These relays are commonly used in electrical power distribution systems to provide reliable and fast protection against interference in the grid. The advantages of this type of relay lie in the simplicity of its setup and the constant stability of working time, thus facilitating the coordination process between relays. The basic reference curve of this relay illustrates the relationship between the

relay's working time and the magnitude of the interference current, where in the *constant time* relay the curve is in the form of a horizontal line. This indicates that the relay working time is fixed, even if the interference current increases. This curve is an important reference in the analysis of protection coordination to ensure that each relay performs according to its function without creating overlap with other relays. Figure 3 of the basic reference curve looks like the one below.



**Figure 3. Basic Reference How Constant Time Relays Work**

The curve drawing shows the working characteristics of the constant Time overcurrent protection relay, where the horizontal axis expresses the interference current in amperes (A), and the vertical axis indicates the relay's working time(t) in seconds. In contrast to the curved and descending Inverse Time curve, the constant time curve appears as a flat horizontal line. This indicates that the relay working time does not depend on the size of the fault current, as long as the current has exceeded the value of the pickup current ( $I > I_{set}$ ). This curve represents the definite time relay or definite minimum time lag relay that is often used in.

Fixed time characteristics are also very useful in preventing relay work that is too sensitive to insignificant current variations, such as when the load rises suddenly but not due to interference. With a fixed delay time, the system can avoid unnecessary disconnections or so-called nuisance tripping.

*B. Pre-existing research or projects*

In a study conducted by Rizky Apriyanto Susilo et al entitled "Design and Development of Overcurrent Protection Relay Inverse Definite Minimum Time Type Based on Arduino Uno," made a prototype of an overcurrent safety relay with the Inverse Definite Minimum Time type which works based on the ratio of the interference current to the normal current, the greater the interference current, the faster the circuit disconnection time. In a study conducted by Rusdiansyah et al entitled "Design of Constant Time Overcurrent Single Phase Relay Based on Arduino Uno," made a prototype of a safety relay tool using the principle of Constant Time which works at a fixed disconnection time even if there is a disturbance that exceeds the normal current limit.

The study only made a prototype of an overcurrent safety relay that only works in one mode, but in this study the researcher combined two modes that have been successfully made by the above research into a prototype of an overcurrent safety relay that works in the Inverse Time Overcurrent Relay and Constant Time Overcurrent Relay modes depending on the mode selected on the tool. The prototype of the overcurrent relay will be designed according to the basic requirements of a protection relay, namely:

1. Speed  
Protection relays need to have the ability to immediately disconnect the parts of the system that are experiencing interference. Rapid response is essential to minimize delays in separating the compromised parts from the system that is still functioning normally.
2. Sensitivity  
The relay must be able to detect interference even if there is only a slight deviation from its normal parameters. This sensitivity ensures that the relay continues to operate as it should, even if the current or voltage change is very small.
3. Reliability  
The protection relay must be able to work consistently and precisely under any known interference conditions in its design. This includes the ability to respond effectively to distractions without errors.

#### 4. Simplicity

The relay design should be made as simple as possible by paying attention to the quality of the materials, the precision of the design, and the ease of installation, operation, and maintenance. This simplicity also contributes to the increase in the reliability of the relay.

#### 5. Cost Efficiency

Economic aspects are an important consideration in the protection system. The system must be designed to be cost-efficient without neglecting its primary function. The level of protection must be adjusted to the needs of the system, because excessive and suboptimal protection can be detrimental to both. Therefore, the design of the protection system must take into account cost efficiency and needs in a balanced manner.

##### a. Arduino Uno

Arduino Uno functions as a relay work logic controller based on current data from sensors such as PZEM-004T CT. Arduino processes current data and determines the relay working time according to the protection characteristics, both *Inverse Time* and *constant time*. In addition, Arduino also controls supporting components such as LEDs and displays, so that the protection system can be tested automatically, precisely, and easily modified through programming. The display of the Arduino Uno can be seen in figure 4.



Figure 4. Arduino Uno

##### b. PZEM Module – 004T CT

PZEM-004T CT is a digital sensor module that functions to monitor electrical parameters such as current and voltage in *real-time* using a CT type current sensor. The module is connected to the Arduino via serial communication, allowing current data to be used to determine the relay working time in both *inverse* and *constant* type *overcurrent* protection systems. Thus, this module supports accuracy and efficiency in the testing of microcontroller-based protection systems. A view of the PZEM – 004T module can be seen in figure 5.



Figure 5. PZEM Module – 004T CT

##### c. LCD I2C Screen 16x2

The 16x2 LCD serves as a visual interface to display important information such as current, working time, and relay status in real-time in the testing of *inverse* and *constant* type *overcurrent* protection systems. With two compact display rows, the LCD allows for live monitoring without additional devices, thereby improving clarity and efficiency during the testing process. The display of the 16x2 LCD I2C Screen can be seen in figure 6.



Figure 6. LCD I2C Screen 16x2

d. 5V Relay Module

The relay module serves as the main actuator controlled by the Arduino to cut off the current when there is an overcurrent. Based on data from the current sensor and the programmed time logic, the Arduino activates the relay to break the load both quickly in the *Inverse Time* system and after a fixed pause in the *constant time system*. This module allows the protection system to work automatically and be responsive to interference. The display of the 5V relay module can be seen in figure 7.

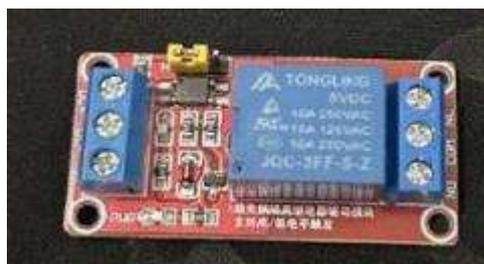


Figure 7. 5V DC Relay

C. System Diagram Blocks

The block diagram for the created tool can be seen in Figure 8. This block diagram consists of AC Supply 220V Relay Module, LCD, Arduino Uno, PZEM – 004T CT, push button and Load. Block diagrams are created to make it easier to know how the tool's system works.

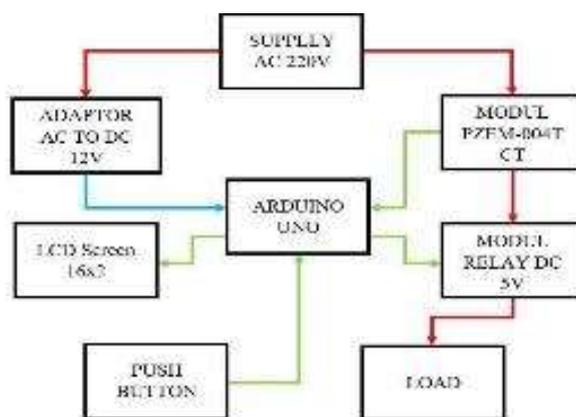


Figure 8. System Diagram Blocks

The flow of the *series of Inverse Time* and *constant Time* overcurrent relays is displayed in the image starting from displaying and selecting the mode displayed on the LCD screen and setting the desired current limit when the relay is first activated, then the relay will give the selected mode status by using a sign light as a mode marker, then the relay starts to read the current flowing towards the load and measure the current value and compare it with the current value that has been set when the relay is first turned on, when the current exceeds the setting limit then the relay will cut off the current flowing through the load, but if the

current does not exceed the limit then the relay will only display the value of the current flowing towards the load on the LCD screen provided.

#### D. Tool Construction Design

The design of the construction of the tool is focused on making containers or installation panels for all components, so that the electronic circuit is protected and easy in the testing process. The process of making the tool involves several stages, namely:

- i. Acrylic Cutting  
Using a drill to cut holes in the acrylic as a place to mount LCDs, buttons, and connectors.
- ii. Drilling and Component Installation  
The holes are made with an electric drill according to the size of the components to be installed, such as LCDs, relays. The position is adjusted for ease of installation and maintenance.
- iii. Electronic Component Assembly  
Components such as Arduino, PZEM-004T, relays, and LCDs are neatly arranged inside the box panels. The cables are connected using jumpers and flexible cables, with reinforcement using soldering and insulation.
- iv. Network Setup and Test  
After all components are installed, functional tests are carried out on each track, both *sensor inputs and relay outputs*. The network is also tested using an external power supply to ensure reliability when in use. The physical design of this tool aims to provide safety, practicality when used, and ease in the testing and calibration process.

#### E. System Planning

The system design shows an Arduino-based power measurement and control system integrated with several key components. Arduino acts as the central control of the system, receiving measurement data from the PZEM-004T module which functions to monitor electrical parameters such as voltage, current, power, and energy consumption. The measurement data is then displayed on a 16x2 LCD screen, providing *real-time* information to the user. For control functions, the system is equipped with a relay module connected to the Arduino. Relays act as electronic switches that can automatically turn electrical devices on or off based on certain conditions, such as a specified power limit. All components are connected through well-organized cables, including power cables and signal cables, taking into account their respective polarities and working voltages. Overall, the series describes an efficient power monitoring and control system, with the Arduino as the main controller, PZEM as the power sensor, LCD as the display interface, and the relay as the electrical load control actuator.

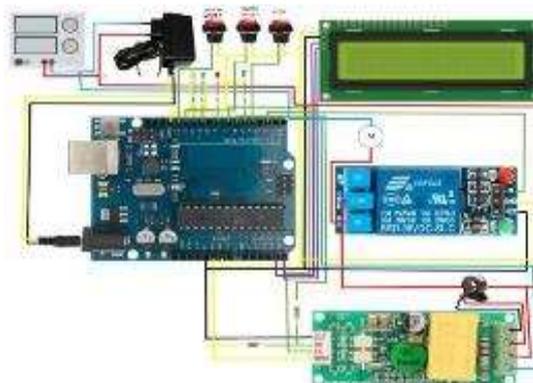


Figure 9. System Planning

## RESULTS

### A. Inverse Time Type Relay Testing

Furthermore, the researcher conducted several tests of interference currents using a multiplier factor or TMS as a target that must be achieved by the *Inverse Time over current protection relay*. The first one uses a multiplier factor of 0.05 for its own curve can be seen in figure 10. The inverse curve of the tool practicum results with a multiplier factor of 0.05 is below.

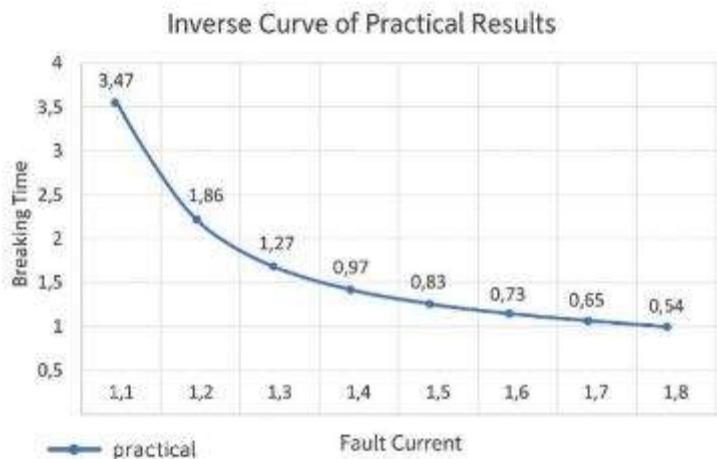


Figure 10. Inverse curve results of tool practicum

It can be seen that the curve has an inverse shape, which confirms the characteristics of the *Inverse Time relay* that the greater the interference current, the faster the relay works. At a fault current of 1.1 times the nominal current, the relay disconnects in about 3.47 seconds, but when the fault current increases to 2 times the nominal current, the disconnection time decreases drastically to only 0.5 seconds. This pattern shows that the relay is able to respond quickly to increasingly large disturbances, so the risk of damage to the system can be minimized.

Table 5. Practicum Results of Inverse Time Relay Tool with a Multiplier Factor of 0.5

| No | Setting Current (A) | Fault Current (A) | Formula  | Tripping Time (Seconds) |
|----|---------------------|-------------------|--|-------------------------|
| 1  | 1                   | 1.1               | $t = \frac{0.14}{\left(\frac{I}{I_p}\right)^{0.02}}$ | 3.47                    |
| 2  | 1                   | 1.2               |  | 5.24                    |
| 3  | 1                   | 1.3               |  | 2.96                    |
| 4  | 1                   | 1.4               |  | 0.97                    |
| 5  | 1                   | 1.5               |  | 0.73                    |
| 6  | 1                   | 1.6               |  | 0.65                    |
| 7  | 1                   | 1.7               |  | 0.59                    |
| 8  | 1                   | 1.8               |  | 0.54                    |
| 9  | 1                   | 2                 |  | 0.50                    |

- AC Supply
  - DC Supply
  - Signal Analog
  - Signal Digital
  - Neutral
  - DC
  - Neutral
  - AC
- = Normal
  - = Trip
  - = Inverse Time
  - = Constant Time

The data also shows that after the fault current exceeds 1.8 times the nominal current, the disconnection time begins to approach a constant at about 0.5 seconds. This indicates that the relay has a minimum working time limit to prevent overworking or nuisance tripping. Overall, these curves and data are consistent with the *Inverse Time* theory and show that the relays have been well calibrated during practicum. This characteristic is important for the coordination of the protection system, so that only the relays closest to the fault are working, while the other relays remain on standby.

a) Comparison of Calculation Results and Comparison with Multiplier Factor 0.5

To make it easier to compare the calculation results with the practicum results, the following comparison curve between the calculation results and the practicum can be seen in figure 12 of the comparison between the target and the practicum results curve below.

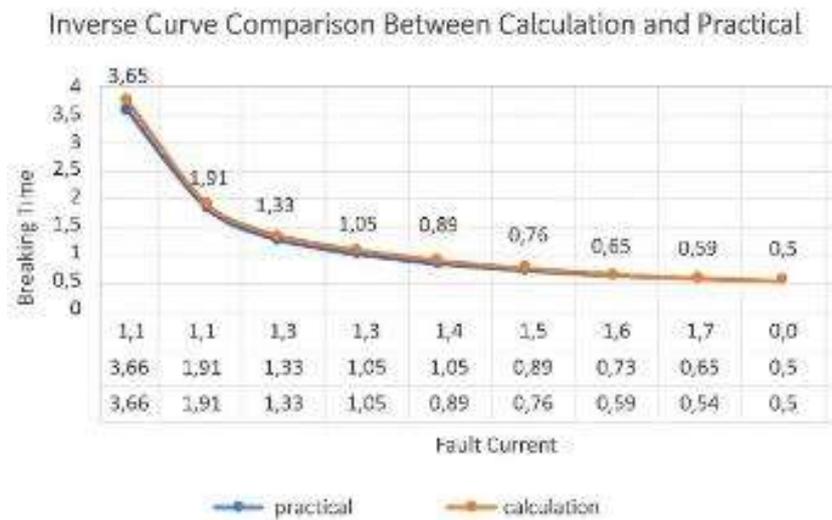


Figure 11. Inverse curve results of tool practicum

The curve above shows a comparison between the relay disconnection time based on practicum (blue line) and the results of theoretical calculations (orange line). Both show a characteristic pattern of inverse time, i.e. the greater the interference current, the faster the disconnection time. This is consistent with the working principle of inverse type overcurrent relays.

In general, the curve of the practicum results is very close to the calculation results, with slight deviation at some points, especially at disturbance currents close to the pickup value (e.g. at 1.1–1.3 times nominal current). For example, at a current of 1.1 times the nominal current, the practicum termination time is 3.47 seconds, while the calculation results show 3.66 seconds. This difference can be caused by factors such as the actual response of the device, the tolerance of the relay time, the load conditions, or the influence of reading errors during the practicum.

Starting from a current of 1.5 times nominal upwards, the two curves are almost intertwined, indicating that at high interference currents, the accuracy and reliability of the relays are getting better and in accordance with the calculation predictions. This proves that the relay settings and characteristics used in the practicum are in accordance with the *Inverse Time* relay standard.



Table 5. Results of Practicum and Calculation of Inverse Time Relay Tool with a Multiplier Factor of 0.5

| No | Setting | Fault   | Multiplying | Formula  | Disconnection |                              |
|----|---------|---------|-------------|--|---------------|------------------------------|
|    | Current | Current | Factor      |  | Practical     | Time (second)<br>Calculation |
| 1  | 1       | 1,1     | 0,05        | $t = \frac{0,14}{\left(\frac{I}{I_n}\right)^{0,05} - 1}$ | 3,47          | 3,66                         |
| 2  | 1       | 1,2     | 0,05        |  | 1,86          | 1,91                         |
| 3  | 1       | 1,3     | 0,05        |  | 1,27          | 1,33                         |
| 4  | 1       | 1,4     | 0,05        |  | 0,97          | 1,03                         |
| 5  | 1       | 1,5     | 0,05        |  | 0,83          | 0,86                         |
| 6  | 1       | 1,6     | 0,05        |  | 0,73          | 0,74                         |
| 7  | 1       | 1,7     | 0,05        |  | 0,65          | 0,65                         |
| 8  | 1       | 1,8     | 0,05        |  | 0,59          | 0,59                         |
| 9  | 1       | 1,9     | 0,05        |  | 0,54          | 0,54                         |
| 10 | 1       | 2       | 0,05        |  | 0,50          | 0,50                         |

The figure above shows a table of the results of testing the characteristics of the disconnection time of an overcurrent protection system using a fixed setting current of 1 A and a multiplier factor of 0.05. The table compares the results of the practicum and the calculation results, it is seen that the larger the fault current that passes through the system, the faster the disconnection time, indicating the nature of overcurrent protection that works faster when the fault is larger. The data showed a fairly good match between the practicum results and the calculation results, with small differences that could be caused by the tool tolerance factor or actual conditions in the field. This table is important in evaluating the reliability and accuracy of the protection system in breaking off the current of the interference in a timely manner.

Furthermore, the researcher conducted several tests of interference currents using a multiplier factor or TMS as a target that must be achieved by the *Inverse Time over current protection relay*. The one that uses a multiplier factor of 1.5 for its own curve can be seen in figure 13. The inverse curve of the tool practicum results with a multiplier factor of 1.5 is below.

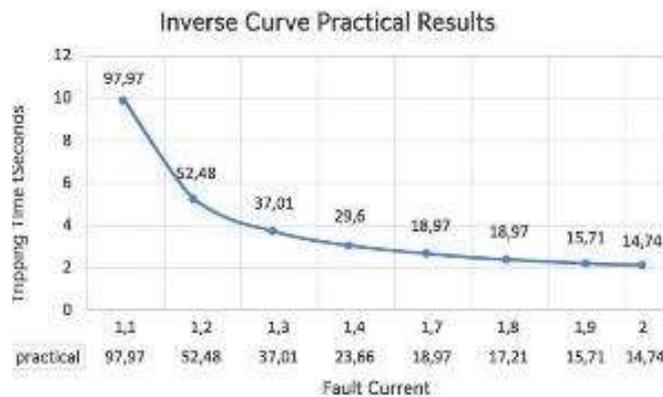


Figure 12. Inverse curve results of tool practicum

The curve above shows the inverse relationship between the fault current and the disconnection time of the overcurrent relay with TMS = 1.5, where the greater the fault current, the shorter the disconnection time. However, due to the high TMS, the overall disconnection time becomes slower than the low TMS, for example, at a current of 1.1 times the nominal disconnection time reaches 97.97 seconds and at a current of 2 times the nominal time is still around 14.74 seconds. The decrease in time is not significant after the current exceeds 1.7 times the nominal limit, close to the minimum limit. This indicates that the relay is working as per the principle of Inverse Time and TMS settings are used for protection coordination so that upstream relays have a greater delay time.



Table 6. Results of Relay Practicum on *Inverse Time* with a Multiplier Factor of 1.5

| No | Setting Current | Fault Current | Multiplying Factor | Formula   | Disconnection Time(sec) |
|----|-----------------|---------------|--------------------|---|-------------------------|
| 1  | 1               | 1,1           | 1,5                |   | 97,97                   |
| 2  | 1               | 1,2           | 1,5                |   | 52,48                   |
| 3  | 1               | 1,3           | 1,5                | $t =$   | 37,01                   |
| 4  | 1               | 1,4           | 1,5                | $\frac{0,14}{\left(\frac{I}{I_p}\right)^{0,02}} \times 3,2 - 1$ | 29,60                   |
| 5  | 1               | 1,5           | 1,5                |   | 23,96                   |
| 6  | 1               | 1,6           | 1,5                |   | 21,77                   |
| 7  | 1               | 1,7           | 1,5                |   | 18,97                   |
| 8  | 1               | 1,8           | 1,5                |   | 17,21                   |
| 9  | 1               | 1,9           | 1,5                |   | 15,71                   |
| 10 | 1               | 2             | 1,5                |   | 15,74                   |

The table in the image shows the effect of the change in interference current on the disconnection time in the overcurrent protection system, with a fixed setting current of 1 A and a multiplier factor of 1.5. Using formulas:

$$t = \frac{0,14}{\left(\frac{I}{I_p}\right)^{0,02-1}} \times 1,5 \quad (3)$$

The greater the interference current, the faster the disconnection time. This is consistent with the working principle of inverse type overcurrent relays.

Table 7. Results of Practicum and Calculation of Inverse Time Relay Tool with a Multiplier Factor of 0.5

| No | Setting Current | Fault Current | Multiplying Factor | Formula   | Disconnection Time (second) |             |
|----|-----------------|---------------|--------------------|---|-----------------------------|-------------|
|    |                 |               |                    |   | Practical                   | Calculation |
| 1  | 1               | 1,1           | 1,5                |   | 97,97                       | 110,06      |
| 2  | 1               | 1,2           | 1,5                |   | 52,48                       | 57,48       |
| 3  | 1               | 1,3           | 1,5                | $t =$   | 37,01                       | 39,91       |
| 4  | 1               | 1,4           | 1,5                | $\frac{0,14}{\left(\frac{I}{I_p}\right)^{0,02}} \times 3,2 - 1$ | 29,60                       | 31,1        |
| 5  | 1               | 1,5           | 1,5                |   | 23,96                       | 25,79       |
| 6  | 1               | 1,6           | 1,5                |   | 21,77                       | 22,23       |
| 7  | 1               | 1,7           | 1,5                |   | 18,97                       | 19,68       |
| 8  | 1               | 1,8           | 1,5                |   | 17,21                       | 17,75       |
| 9  | 1               | 1,9           | 1,5                |   | 15,71                       | 16,25       |
| 10 | 1               | 2             | 1,5                |   | 15,74                       | 15,04       |

The table above shows the table of the results of the overcurrent relay disconnection time test with a setting current of 1 A and a time multiplier factor (TMS) of 1.5, which shows the relationship between the interference current and the disconnection time both practicum and calculation. Table It can be seen that with TMS = 1.5, the disconnection time tends to be longer than the smaller TMS setting, for example at a current of 1.1 times the nominal time, the disconnection time reaches 97.97 seconds (practicum) and 110.06 seconds (calculation). The decrease in time is less significant when the current is close to 2 times the nominal, It is seen that the increase in the interference current from 1.1 A to 2A causes a significant decrease in disconnection time. At a fault current of 1.1 A, the disconnection time reaches 97.97 seconds, but when the fault current increases to 2 A, the disconnection time decreases drastically to about 15.74 seconds. This shows that the greater the interference current with the setting current, the faster the protection system will work to disconnect the circuit, in order to prevent further damage to the electrical system.

b) Comparison of Calculation Results and Comparison with Multiplier Factor 1.5

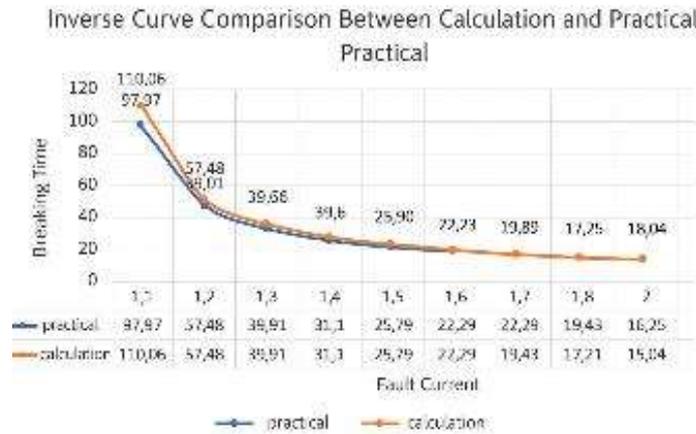


Figure 13. Inverse curve results of tool practicum

The curve above shows a comparison between the relay disconnection time based on practicum (blue line) and the results of theoretical calculations (orange line). Both show a characteristic pattern of inverse time, which is increasingly reflects the characteristics of the *sloping Inverse Time* curve. Furthermore, the researcher conducted several tests of interference currents using a multiplier factor or TMS as a target that must be achieved by *the Inverse Time over current protection relay*. The one using a multiplier factor of 3.2 for the curve itself can be seen in figure 13. The inverse curve of the tool practicum results with a multiplier factor of 3.2 is below.



Figure 14. Inverse curve results of tool practicum

The curve shows the relationship between the fault current and the relay disconnection time based on the results of the practicum with TMS = 3.2, where the greater the fault current, the shorter the disconnection time, as per the characteristics of *the Inverse Time* relay. However, because TMS is of great value, the disconnection time becomes much longer compared to the smaller TMS, as seen in the current of 1.1 times the nominal with a disconnection time of 200.59 seconds and at the current of 2 times the nominal is still 31.68 seconds. Time decrease is consistent

However, it began to slope after the flow exceeded 1.6 times the nominal amount, signaling the approach to the minimum relay working time. This condition reflects that TMS = 3.2 provides a significant and ideal delay time for backup protection functions in multi-level protection systems, giving relays closer to the fault an opportunity to work first. Overall, the results of the practicum showed that the relay operated according to the theoretical characteristics of *Inverse Time* and the TMS 3.2 setting was effective in the application of selective coordination.



Table 8. Results of Relay Practicum on *Inverse Time* with a Multiplier Factor of 3.2

| No | Setting Current | Fault Current | Mutlipaying Factor | Formula   | Disconnection Time(sec) |
|----|-----------------|---------------|--------------------|---|-------------------------|
| 1  | 1               | 1,1           | 3,2                |   | 200,59                  |
| 2  | 1               | 1,2           | 3,3                |   | 112,89                  |
| 3  | 1               | 1,3           | 3,4                | $t =$   | 82,03                   |
| 4  | 1               | 1,4           | 3,5                | $\frac{0,14}{\left(\frac{I}{I_p}\right)^{0,02}} \times 3,2 - 1$ | 62,04                   |
| 5  | 1               | 1,5           | 3,6                |   | 53,87                   |
| 6  | 1               | 1,6           | 3,7                |   | 46,39                   |
| 7  | 1               | 1,7           | 3,8                |   | 41,21                   |
| 8  | 1               | 1,8           | 3,9                |   | 37,11                   |
| 9  | 1               | 1,9           | 3,10               |   | 34,23                   |
| 10 | 1               | 2             | 3,11               |   | 31,33                   |

This table shows the results of the calculation of the disconnection time in the overcurrent protection system with a fixed setting current of 1 A and a multiplier factor of 3.2. The formula used to calculate the disconnection time is the curve above shows that the results of the practicum (blue line) and the results of theoretical calculations (orange lines) have a similar form of inverse characteristics, where the higher the interference current, the faster the relay works, according to the principle of *Inverse Time* overcurrent relay. However, in terms of value, the practicum termination time is generally slightly faster than the calculation results, especially at low current (1.1–1.3 times nominal), such as at a current of 1.1 times nominal which shows 200.59 seconds (practicum) compared to 234.79 seconds (calculation). This difference is due to the tolerance of the tool, the actual response of the system, as well as the fluctuations of the current in the test with the load of the resistor, which causes the measured current to differ from the fixed value in the theoretical calculation. Starting from a current of 1.5 times nominal upwards, the difference between the two narrows, and at a current of 2 times nominal, the practicum time (31.68 seconds) is almost the same as the calculation (32.09 seconds), indicating high accuracy. Overall, the results of the practicum with with TMS 3.2 show that the relay works according to the characteristics of the inverse, and the deviation that occurs is still within reasonable limits, so it is valid to be used as the basis for the analysis of the protection system.

Table 9. Results of Practicum and Relay Calculation on *Inverse Time* with a Multiplier Factor of 3.2

| No | Setting Current | Fault Current | Mutlipaying Factor | Formula   | Disconnection Time(sec) |
|----|-----------------|---------------|--------------------|---|-------------------------|
| 1  | 1               | 1,1           | 3,2                |   | 234,79                  |
| 2  | 1               | 1,2           | 3,3                |   | 122,63                  |
| 3  | 1               | 1,3           | 3,4                | $t =$   | 85,15                   |
| 4  | 1               | 1,4           | 3,5                | $\frac{0,14}{\left(\frac{I}{I_p}\right)^{0,02}} \times 3,2 - 1$ | 66,34                   |
| 5  | 1               | 1,5           | 3,6                |   | 47,99                   |
| 6  | 1               | 1,6           | 3,7                |   | 37,88                   |
| 7  | 1               | 1,7           | 3,8                |   | 37,88                   |
| 8  | 1               | 1,8           | 3,9                |   | 34,67                   |
| 9  | 1               | 1,9           | 3,10               |   | 32,09                   |
| 10 | 1               | 2             | 3,11               |   | 32,09                   |

The data shows that as the interference current increases from 1.1 A to 2 A, the disconnection time decreases significantly from 200.59 seconds to 31.33 seconds. This decrease indicates that the greater the interference current than the setting current, the faster the protection works to cut off the power flow, and the shorter the disconnection time. A larger multiplier factor (3.2) than the previous table also resulted in a longer disconnection time for the same fault current value, confirming the important role of the multiplier factor in determining the response speed of the protection system.

c) Comparison of Calculation Results and Comparison with Multiplier Factor 3.2

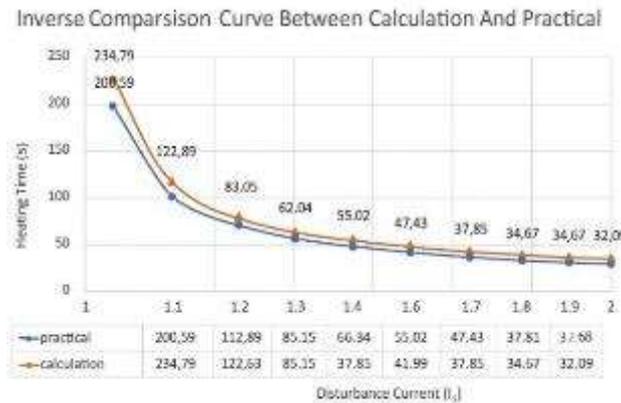


Figure 15. Inverse curve of practicum results

The figure above shows the table of the results of the overcurrent relay disconnection time test with a setting current of 1 A and a time multiplier factor (TMS) of 3.2, which compares the results of the practicum with the results of theoretical calculations. This table shows that the larger the interference current, the faster the disconnection time, according to the inverse characteristics of the relay. However, due to the large TMS value, the disconnection time becomes much longer overall, for example at a current of 1.1 times the nominal, the practicum time reaches 200.59 seconds and the calculation is 122.63 seconds. It can also be seen that the difference between the results of the practicum and the calculation is greater at low current, then shrinks as the interference current increases. These differences can be caused by the tolerance factor of the tool, current fluctuations due to resistor loads, as well as the dynamic response of the test system. Overall, this table shows that the relay works according to the principle of Inverse Time and that TMS = 3.2 provides a significant delay time, suitable for backup functions in multi-level protection systems.

From the table of test results of the tool, it can be ascertained that the disconnection time is directly proportional to the multiplier factor used, namely when the multiplier factor is larger, the relay disconnection time when there is a disturbance is longer, for example when the maximum current is set to 1A, and the value of the flowing current is detected at 1.1A, then the working time or relay trip time of each time factor It looks different, such as in the time factor of 0.05 the disconnection time that occurs is about 3.47 seconds, then in the time factor 1.5 the disconnection time that occurs is about 97.97 seconds, and when the time factor is used is 3.2, the disconnection time that occurs is very long about 200.59 seconds. . So it is better to consider so that when determining the multiplier factor on the relay, it is necessary to consider so that the disconnection time carried out by the relay is in accordance with the characteristics and durability of the tool being protected, it should also be noted that the multiplier factor in his standard inverse type relay has a rule, namely the smallest multiplier factor is 0.05 while the largest is 3.2. An image of the Inverse Time type relay test can be seen in the image below.



Figure 16. Inverse Time Type Relay Test Results

B. Constant Time Type Relay Testing

After testing the inverse time type relay, then the tester conducts a constant time type relay test, on the results of the constant time type relay test data is obtained which has been compiled as follows.



Figure 17. Constant Curve Results of Tool Practicum

The above curve illustrates the relationship between the fault current and the disconnection time in a constant time type overcurrent relay, with two horizontal curves representing the time setting of 5 seconds (blue) and 10 seconds (orange), indicating that the disconnection time remains constant even though the fault current increases from 1.1 to 1.5 times the nominal current. Characteristic

This horizontal straight line confirms that the relay works according to the principle of definite time, different from the *Inverse Time* relay whose working time decreases as the current increases. In a tiered protection system, the *constant Time* relay functions as a backup protection, where the relay only works after a certain delay time if the *Inverse Time* relay on the downstream side fails to operate. Consistency of uptime and ease of coordination make this type of relay highly effective for upstream protection, ensuring the selectivity and reliability of the overall protection system.

Table 10. Constant Time Type Relay Test Results with 5 Second Time

| No | Setting current | Fault current | Selected disconnection time(seconds) | Disconnection time (second) |
|----|-----------------|---------------|--------------------------------------|-----------------------------|
| 1  | 1               | 1,1           | 5                                    | 5                           |
| 2  | 1               | 1,2           | 5                                    | 5                           |
| 3  | 1               | 1,3           | 5                                    | 5                           |
| 4  | 1               | 1,4           | 5                                    | 5                           |
| 5  | 1               | 1,5           | 5                                    | 5                           |

This table shows the setting current and interference current data compared to the selected disconnection time on a fixed basis, i.e. 5 seconds, without taking into account the formula calculation as in the previous tables. The setting current is set at 1 A, while the interference current varies from 1.1 A to 1.5 A. Regardless of the variation in the interference current, both the “Selected Disconnection Time” and “Disconnect Time (Seconds)” columns are all worth a fixed 5 seconds. This indicates that in this case, the protection system uses a *definite time approach*, where the disconnection is carried out after a certain predetermined time, regardless of the magnitude of the interference current. This approach is commonly used in protection systems under certain conditions, such as when clarity of coordination between relays takes precedence over sensitivity to changes in interference current.

Table 11. Constant Time Type Relay Test Result with 10 Second Time

| Setting Current (A) | Fault Current (A) | Selected Breaking Time (Seconds) | Breaking Time (Seconds) |
|---------------------|-------------------|----------------------------------|-------------------------|
| 1                   | 1.1               | 10                               | 10                      |
| 1                   | 1.2               | 10                               | 10                      |
| 1                   | 1.3               | 10                               | 10                      |
| 1                   | 1.4               | 10                               | 10                      |
| 1                   | 1.5               | 10                               | 10                      |

The table above shows the results of the relay test with *constant time mode*; from the data it can be seen that the disconnection time that occurs on the relay when the fault is detected is in accordance with the time that has been set when setting the current and the relay disconnection time. For relays with *constant Time* mode that rely only on a predetermined time to break the circuit when a disturbance is detected, this type of relay is not affected by the magnitude of the interference current, the relay will only calculate the disconnection time according to the preset. For constant type relay testing documentation, you can see the figure below.



Figure 18. Constant Time Type Relay Test Results

C. Tool Performance Analysis

When testing relays with inverse or constant time modes, there is a difference in current readings between the protection device designed using the PZEM-004T module and the digital multimeter measuring device. The difference in current readings is around 0.005 Ampere. This difference occurs because the current reading by the PZEM-004T module has an accuracy tolerance of about  $\pm 0.5\%$ , so that in the current measurement of 1 Ampere, the difference of up to  $\pm 0.005$  Amperes is still reasonable and within the acceptable error limit. In addition, the digital multimeter used as a comparison also has its own measurement tolerance which also contributes to the possibility of deviation. Other factors that can affect the reading results include the resolution of the data from the sensor, the sampling frequency by the Arduino microcontroller, and the position and placement of the cable on the current transformer (CT) belonging to the PZEM-004T module. Despite the difference in values, the difference is very small and does not affect the main function of the overcurrent protection system, as the system is designed to operate at a current threshold value much higher than that deviation.

D. Factors Affecting Outcomes

In testing the tool, the researcher found that the current value generated by the resistor load is not constant or often changes by itself, sometimes making the readable current increase, and sometimes it decreases even though it is only a few milliAmps, it causes the reading of the current value read by the device to also sometimes change and greatly affects the disconnection time when the relay is in mode Inverse time, for example, when the load current produced by the resistor decreases, the disconnection time also changes to be longer, and vice versa. This causes a difference between the test results and the calculation results.



## CONCLUSION

From the results of the analysis of the three inverse curves (with TMS of 0.05, 1.5, and 3.2), it can be concluded that the curve of the practicum results has a shape consistent with the theoretical calculation curve, following the characteristics of the Inverse Time relay, namely the greater the interference current, the shorter the disconnection time.

There was a difference in the value of the disconnection time between the results of the practicum and the results of the calculation, especially at low interference currents (1.1 – 1.3 times nominal). This deviation tends to decrease at larger currents and gets smaller as the current increases, suggesting that the accuracy of the relay's performance increases under heavy fault conditions. The difference in disconnection time also varies depending on the size of the TMS:

- a. faster and the difference to the calculation is relatively small.
- b. In medium TMS (1.5), the practicum results began to approach the overall target value.
- c. At large TMS (3.2), despite the longer disconnection time, the practicum curve still follows the theoretical trend with fairly good accuracy.

Overall, the test results show that the protection relays work according to the inverse time theory, with the difference in values still within reasonable limits. This confirms that the practicum tool can represent the behavior of the relay in a real and valid manner and is used as a learning medium for the working characteristics of overflow protection relays.

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