RESEARCH ARTICLE

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Hardware Model of Inverse Definite Minimum Time (IDMT) Protection Scheme Using Numerical Relay

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Abstract

Protection plays a crucial role in power system engineering, especially current protection. Hence, the authors have modelled and simulated various operating characteristics of overcurrent relay in MATrix LABoratory (MATLAB)/Simulink environment in this paper. The proposed work has been divided in two phases. In the first part, modeling of inverse definite minimum yime (IDMT) overcurrent relay on MATLAB/Simulink platform has been done, and the simulation has been carried out. The second part IDMT type overcurrent relay has been implemented on AVR microcontroller with intelligent current sensing techniques and control for validation of the simulation results. Different types of faults and different IDMT fault characteristics on the developed model have been tested. The results obtained with the hardware model and Simulink model are compared, and it is noted that both results are in line with each other.

Keywords: Abnormal, fault, Inverse definite minimum time, Microcontroller, Overcurrent.

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Introduction

The structure of a power system is dynamic in nature as day-by-day, many things are integrating and changing, which creates major issues in its operation and control strategies. One of the issues is protection against overcurrent. An overcurrent relay protects against overcurrent. The basic operation of the overcurrent relay is to sense the abnormality (in terms of current) and send the signal to the circuit breaker (CB) to turn it on or off. Figure 1 shows the logical diagram of an overcurrent relay. The relay issues a trip signal based on the characteristics selected.[1]

The relay issues a trip signal instantly in case of instantaneous overcurrent relay. Whereas, in the case of a definite time overcurrent relay, it issues a trip signal after a specific time to incorporate transient conditions.

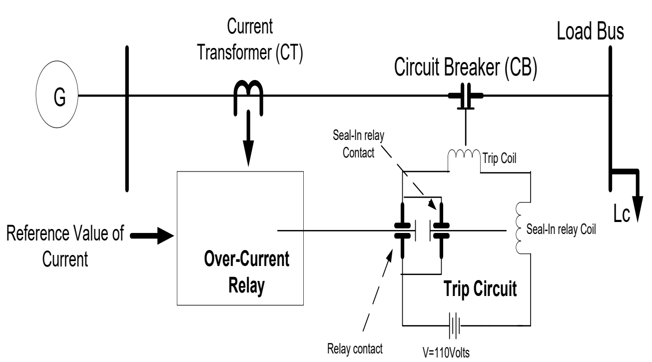

Figure 1: Logical diagram of overcurrent relay

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Based on the operating time, overcurrent relays are classified as follows:

1. Instantaneous Overcurrent Relay
2. Definite Time Overcurrent Relay
3. Inverse Definite Minimum Time (IDMT) Relay

A significant improvement is seen in fault clearing time as we move towards the source if we use IDMT relays.[2] The selection of particular operating characteristics of IDMT relay ensures reliability and selective protection of the power system.

Numerical relays embedded with microcontrollers are used to protect the system components, as they are more efficient than microcontroller-based relays in terms of operation and accuracy. Therefore, a power system engineer needs to realize various characteristics of IDMT overcurrent relay using numerical protection technique.

Some works related to the IDMT protection scheme's performance, simulation of IDMT, and overcurrent relay characteristics have been reported[1,3,4] respectively. It has been described a power system laboratory use of the laboratory for teaching and conducting research.[5,6] Researchers have presented the setting of the inverse definite minimum time (IDMT) overcurrent relay for both radial and interconnected ring systems have been presented.[7]

The rest of the paper is organized as follows. Section II deals with the problem statement. Section III presents software implementation of the proposed problem. Section IV focuses on the hardware part. Simulation results and hardware results are presented in Sections V and VI. Finally, in Section VII, conclusions are drawn.

Problem Statement

Over the past few years, different laboratories focusing on teaching and exploring the areas of power system protection have been reported. IDMT overcurrent protection is widely used for both primary and secondary protection of electrical power systems among these protection schemes. Therefore, this work aims to design and implement numerical IDMT overcurrent relay characteristics for a given electrical system as defined by IEC 60255 standards in MATLAB/Simulink and in a hardware environment.

Software Implementation

The detailed model of an Overcurrent relay using IDMT characteristics has been implemented on Sim Power System toolbox of MATLAB Simulink.

Figure 2 shows the Simulink model of an electrical system consisting of a 3 phase feeding power to load. The system parameters are as below:

- Source Voltage = 415 V
- Source Resistance = 0.0008929 Ω
- Source Inductance = 16.58µH
- Ratio = 5.833

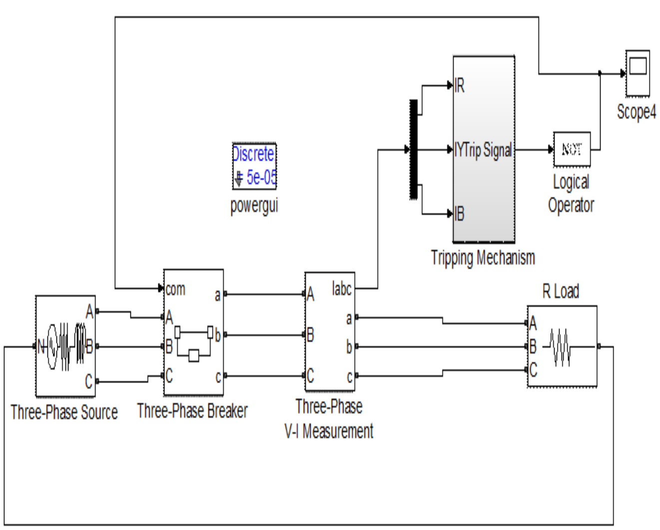

Figure 2: Simulink model for IDMT protection

The tripping mechanism consists of the Simulink model shown in Figure 2 consists of a control mechanism for the three phases that implement IDMT overcurrent protection. The output of each control mechanism is a trip signal at logic 0 in the case of Non-fault condition and at logic 1 at case Fault condition. The trip signal output for each phase is given to the OR block whose output is a Trip/No-Trip signal to Circuit Breaker.

The control mechanism (as shown in Figure 3.) for one of the phases consists of input current for respective time. The RMS block converts instantaneous current into root-mean-square (RMS) value over a running window of 20 ms. The relational operator 1 has two inputs; one is the fixed threshold/pickup value.

In this case, Ipu = 2.6 A.

The output of the relational operator is 1 in the case when line current is more than Ipu, which happens in the case of a fault condition. The standard operating time of Inverse definite Minimum Time (IDMT) characteristics is calculated by

$$t = \frac{K}{\left(\frac{I_f}{I_{pu}} \right)^{\alpha} - 1} \times TMS \qquad (1)$$

Since the system is not interconnected hence transcranial magnetic stimulation (TMS) is equal to 1. The ratio is given $\frac{I_f}{I_{pu}}$ to a function block which executes the function $\left(\frac{I_f}{I_{pu}} \right)^{\alpha} - 1$. The dividing block implements IDMT characteristics

$$t = \frac{K}{\left(\frac{I_f}{I_{pu}} \right)^{\alpha} - 1}$$

Where,

K = 0.14 for standard Inverse Time Characteristics.

= 13.5 for Very Inverse Time Characteristics.

= 80 for Extreme Inverse Time Characteristics.

= 120 for Long Inverse Time Characteristics.

The relational operator 2 ensures the operation of IDMT Overcurrent relay after operating time 't' as per the selected

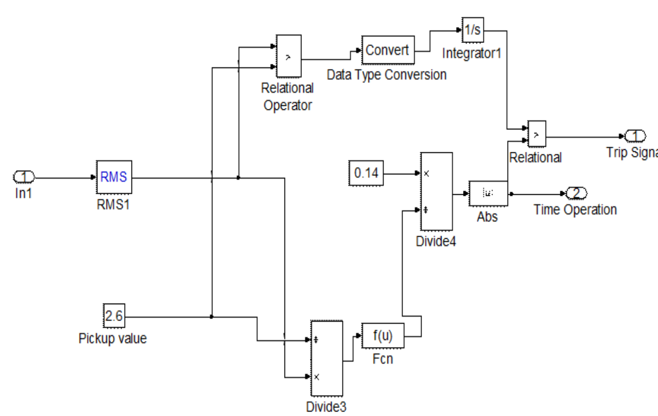

Figure 3: Simulink model of control mechanism

IDMT characteristics. A similar tripping mechanism is also implemented for other lines.

The output of each control mechanism is given as input to a OR block that issues a trip signal at a fault condition in any of the three lines.

Hardware Implementation

Figure 4 shows the hardware setup of IDMT relay in which three current sensing IC's (ACS712) are used to sense the current. Connector are used for input-output connections. DC jack is used to input from adapter (12 V, 1 A) and capacitors (100 μF and 1000 μF) used as capacitor filter. IC ULN2803 is used as a driver IC. Relay is used to actuate the contactor. Push-button is used to start, stop, and reset the circuit. The microcontroller ATMEGA16 (L) is used to control the operation of the IDMT Relay as per the program dumped in it. The crystal oscillator is used to provide 16 MHz frequency to the microcontroller, LCD display is used to display the reading and trip indication.

Here, the microcontroller is used to control the operation of the IDMT Relay. In this work ATMEGA16 (L) i.e., low-power CMOS 8-bit micro-controller has been used. The programing of ATMEGA16 (L) is done by using Bascom software. The microcontroller has been interfaced with the LCD display, which will show the current of each phase, pick up value, and display the operating time of the contractor at the time of the fault. Also interfaced two potentiometers, in which one potentiometer is used to set the current pickup value, and another is used to set the IDMT characteristics. Depending upon the position of the potentiometer, the IDMT characteristics are set. If the potentiometer position is between 0 to 90°, then the normal inverse IDMT characteristic is set, for potentiometer position between 90–180° very inverse IDMT characteristics, for 180–270° extremely inverse characteristics, and for another 90°, i.e., between 270–360° long time, inverse IDMT characteristics are set.

The microcontroller takes input from the current sensing IC ACS712, and it compares the input value of current with the pickup set value of current. If the value of the system current is higher than the pickup set value, the microcontroller will

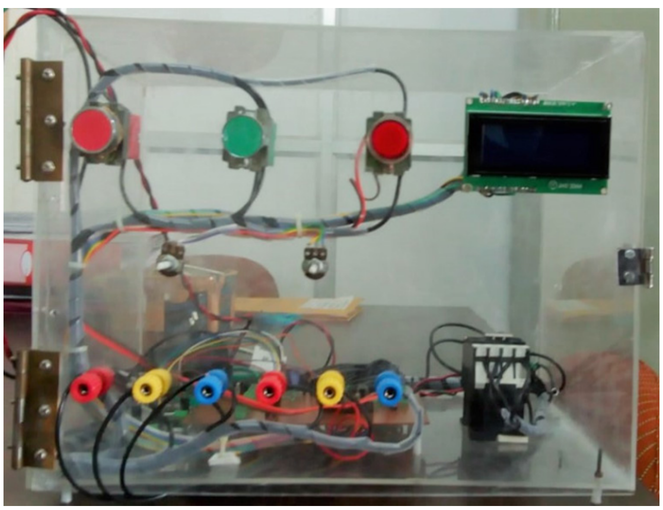

Figure 4: Hardware setup of IDMT numerical relay

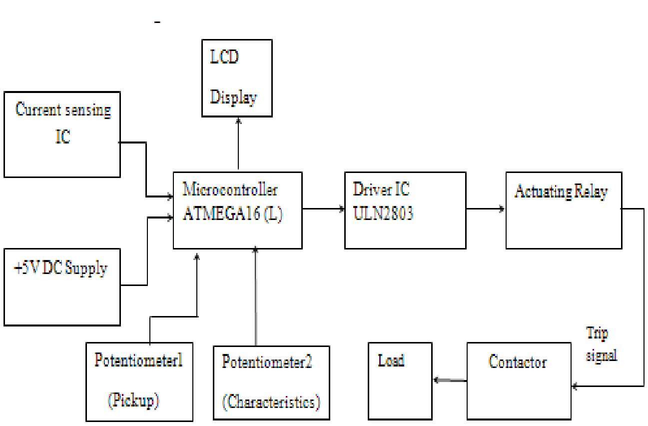

Figure 5: Block diagram of interfacing of microcontroller with the device

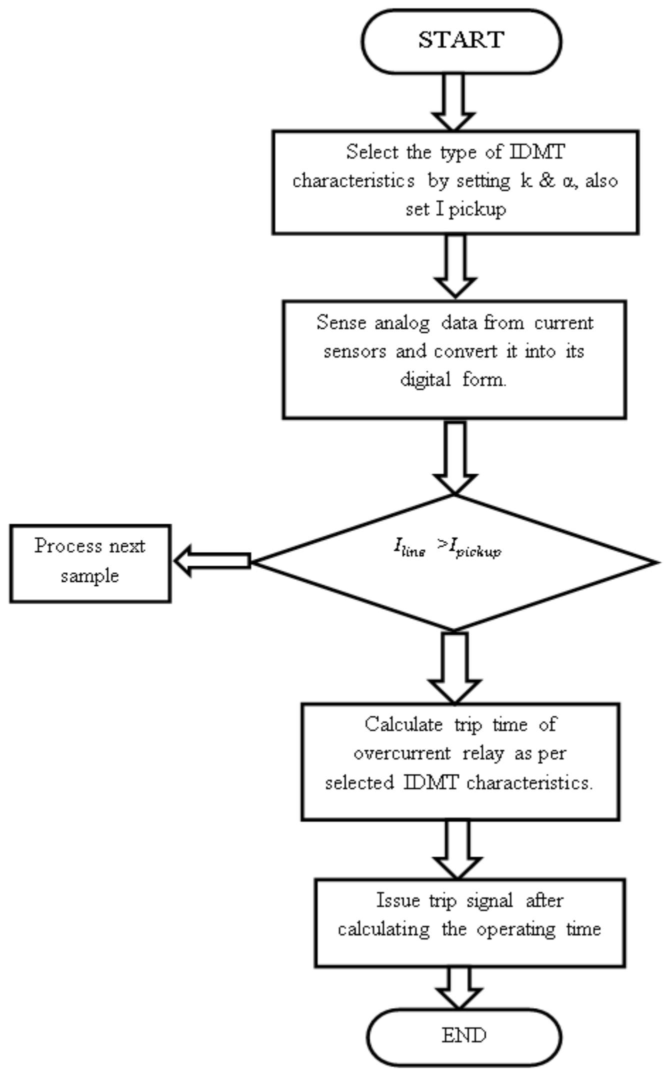

Figure 6: Schematic of IDMT relay

issue a signal to the driving IC ULN2803 to actuate the relay. Driving IC consists of transistors, resulting in high current gain in the output, which drives the actuating relay, and the relay will issue a trip signal to the contactor, which will disconnect the faulty part from the healthy system.

The flow chart for implementing IDMT overcurrent relay in micro-controller is shown in Figure 6.

Simulation Results

The results obtained for the various IDMT characteristics from the Simulink model and the output waveform for various relays are shown in Figures. 7 to 14. Logic 1 indicates the trip signal issued by Circuit Breaker. Faults were simulated at different locations and with different fault resistances to vary the value of fault current . The results were focused on the operation time of the relay,.

A. Normal Inverse Time Characteristics

Case-1: Figure 7 shows the result obtained for Normal Inverse Time Characteristics, fault current I_f. And operating time was found to be 4.56 A and 12.39 s, respectively.

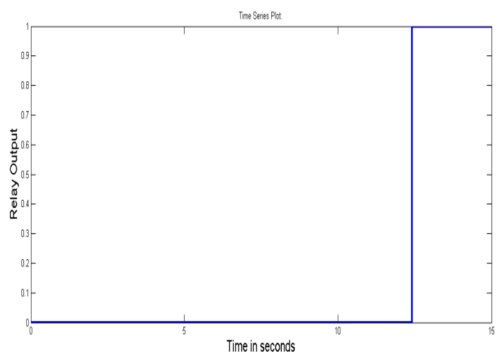

Figure 7: Output for normal time inverse characteristics

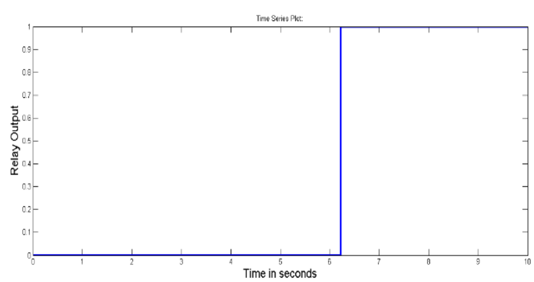

Figure 8: Output for normal time inverse characteristics

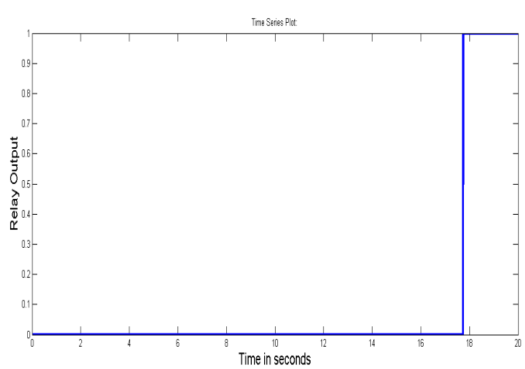

Figure 9: Output for very inverse time characteristics

Case-2: Figure 8 shows the result obtained for Normal Inverse Time Characteristics, fault current I_f and operating time T_{op} was found to be 7.94 A and 6.20 s, respectively.

B. Very Inverse Time Characteristics

Case-1: Figure 9 shows the result obtained for Very Inverse Time Characteristics, fault current I_f, and operating time T_{op} was found to be 4.58 A and 17.72 s, respectively.

Case-2: Figure 10 shows the result obtained for Very Inverse Time Characteristics, fault current I_f and operating time T_{op} was found to be 8.22 A and 6.24 s, respectively.

C. Extreme Inverse Time Characteristics

Case-1: Figure 11 shows the result obtained for Extreme Inverse Time Characteristics, fault current I_f and operating time T_{op} was found to be 4.45 A and 41.47 s, respectively.

Case-2: Figre 12 shows the result obtained for Extreme Inverse Time Characteristics, fault current I_f and operating time T_{op} was found to be 8.37 A and 8.54 s, respectively.

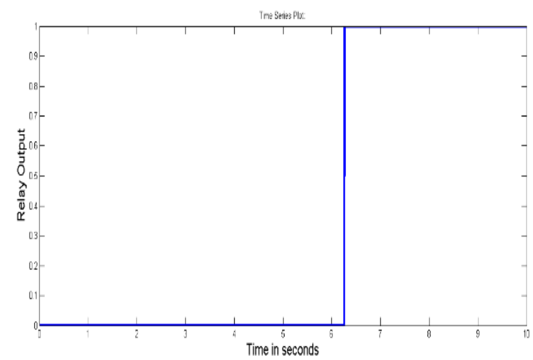

Figure 10: Output for very inverse time characteristics

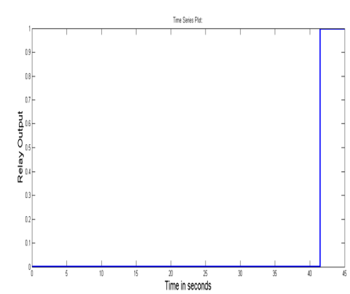

Figure 11: Output for extreme inverse time characteristics

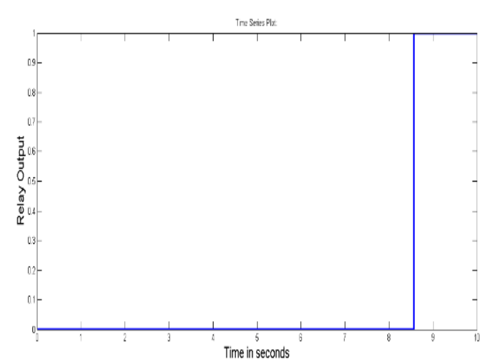

Figure 12: Output for extreme inverse time characteristics

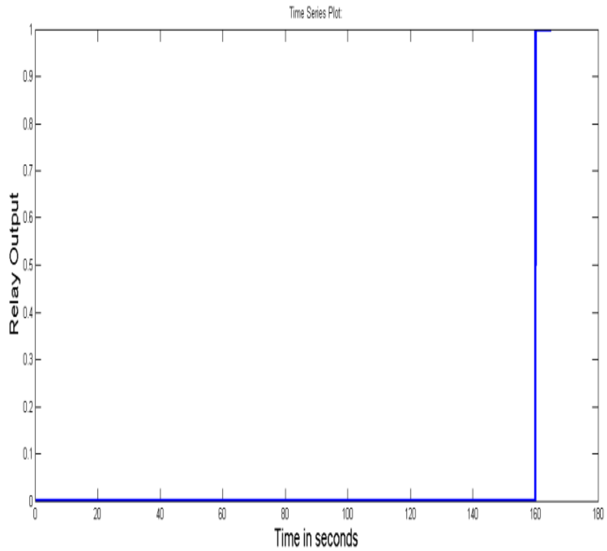

Figure 13: Output for long inverse time characteristics

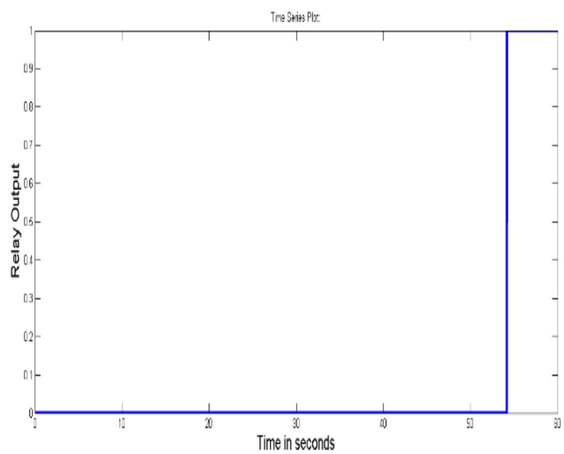

Figure 14: Output for long inverse time characteristics

D. Long Inverse Time Characteristics

Case-1: Fig. 13 shows the result obtained for Long Inverse Time Characteristics, fault current I_f and operating time T_{op} was found to be 4.55 A and 160 s, respectively.

Case-2: Fig. 14 shows the result obtained for Long Inverse Time Characteristics, fault current I_f, and operating time was found to be 8.36 A and 54.16 s, respectively.

Hardware Results

The results captured for the various characteristics of IDMT protection from the experimental setup are shown below; waveform was observed on digital storage oscilloscope (DSO) during various faults conditions, and fault current (I_f) and operating time (T_{op}) were calculated.

The results obtained for the various IDMT characteristics from the hardware model and the output waveform for various relays are shown in Figures 15 to 17. All these figures show the condition of contactor operation at fault condition (i.e., open or close status), in which the X-axis is the time in seconds, and the Y-axis is the voltage output of driver IC.

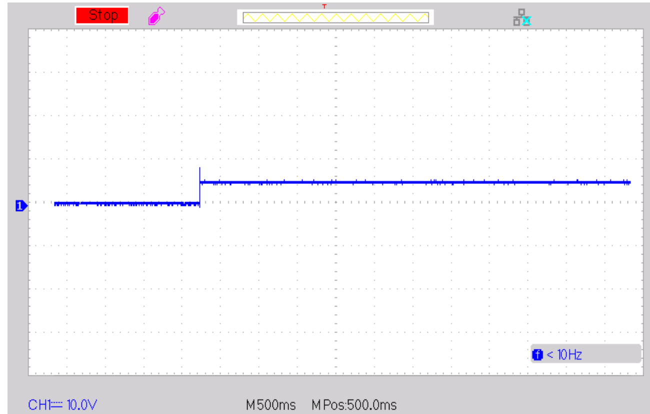

Figure 15: Experimental results for normal time inverse characteristics

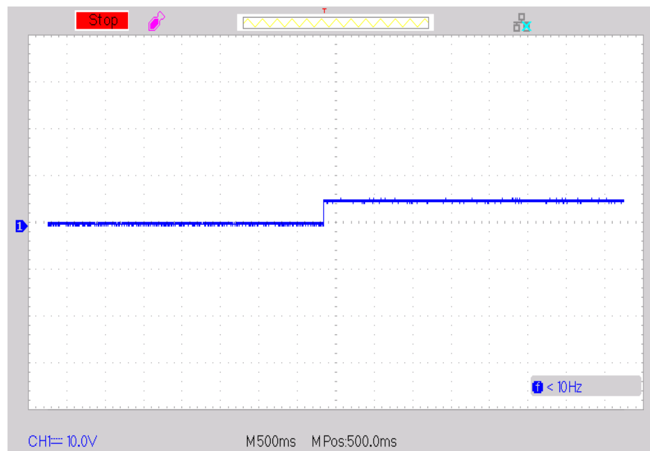

Figure 16: Experimental results for very inverse time characteristics

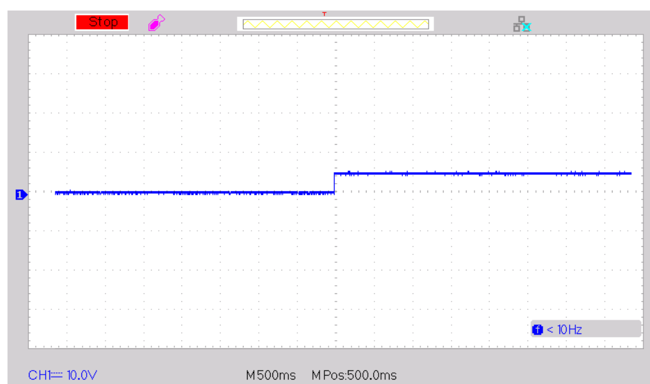

Fig.ure17: Experimental results for extreme inverse time characteristics

Normal Inverse Time Characteristics

Case-1: During the condition where fault current I_f and operating time T_{op} was found to be 4.55 A and 12.43 s, respectively.

6.2 Very Inverse Time Characteristics

Case-1: During the condition where fault current I_f and operating time T_{op} was found to be 4.56 A and 17.89 s respectively.

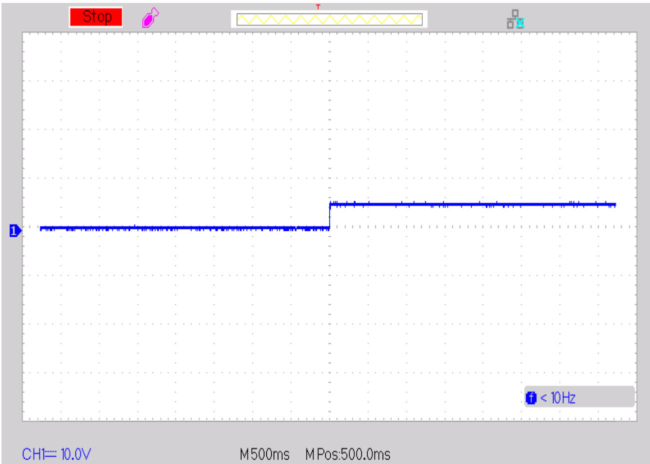

Figure 18: Experimental results for long inverse time characteristics

Table I: Comparison of simulation results and hardware results

Sr. No	Name of Charac-teristics	*Simulation results* Fault current (I_f) in ampere	*Simulation results* Operating Time (T_{op}) in seconds	*Hardware results* Fault current (I_f) in ampere	*Hardware results* Operating Time (T_{op}) in seconds
1	Normal inverse	4.56	12.39	4.55	12.43
		7.94	6.20	7.91	6.22
2	Very inverse	4.58	17.72	4.56	17.89
		8.22	6.24	8.20	6.28
3	Extreme inverse	4.45	41.47	4.43	41.54
		8.37	8.54	8.35	8.58
4	Long inverse	4.55	160	4.54	160.14
		8.36	54.16	8.35	54.26

Extreme Inverse Time Characteristics

Case-1: During the condition where fault current I_f and operating time T_{op} was found to be 4.43 A and 41.54 s, respectively.

6.3 *Long Inverse Time Characteristics*

Case-1: During the condition where fault current I_f and operating time T_{op} was found to be 4.54 A and 160.14 s respectively.

Hence, from the Table I results, the hardware results are in line with the results of the designed Simulink model. IDMT relay developed in this project has a delay of 60 ms, which is introduced due to measurement in each current cycle plus a delay approximately of 10 ms for processing the signals, which may introduce a total delay of 70 ms in actual tripping time excluding the delay of operation of the electromagnetic relay and the contactor.

Conclusion

The development of a laboratory prototype for the IDMT protection scheme has been successfully achieved in this work. The design development of various characteristics of IDMT numerical relay is carried out in both software simulation and hardware setup, and its results are verified. The characteristics curve of Inverse Time Overcurrent Relay is initiated using a specific equation to calculate the operating time. This proposed protection scheme is carried out in the MATLAB Simulink environment, and its performance is visualized virtually. This work very nicely demonstrates the IDMT protection scheme using a numerical relay.

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