ANALYSIS OF OVERCURRENT RELAY CHARACTERISTICS USING IDMT MODEL

DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

in

CONTROL AND INSTRUMENTATION

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ACKNOWLEDGEMENTS

It gives me a deep sense of pleasure to present the report of the MTech project undertaken during MTech final year. I owe special debt of gratitude to Dr. Anup Kumar sir and Prof. Rohan Pillai sir, Electrical Engineering Department for their constant support, supervision and guidance throughout the course of my work. Their sincerity, thoroughness and perseverance have been a constant source of inspiration for me. It is only their cognizant efforts that may endeavors have seen light of the day.

I want to take this opportunity to acknowledge the contribution of all faculty members of the Control and Instrumentation department for their kind assistance and cooperation during the development of my project. I also wish to express my sincere gratitude to my beloved parents and friends for their understanding and support. Above all, thanks to Almighty for blessing and guiding me throughout my life.

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CANDIDATE'S DECLARATION

I, Utkarsh Rishu, Roll No – 2k22/C&I/07 student of MTech (Control and Instrumentation), hereby declare that the project dissertation titled "**ANALYSIS OF OVERCURRENT RELAY CHARACTERISTICS USING IDMT MODEL** " which is submitted by me to Electrical Engineering Department, Delhi technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

Certified that **Utkarsh Rishu** (2k22/C&I/07) has carried out their research work presented in this thesis entitled "**ANALYSIS OF OVERCURRENT RELAY CHARACTERISTICS USING IDMT MODEL**" for the award of **Master of Technology** from Electrical Engineering Department, Delhi Technological University, Delhi under our supervision. The thesis embodies results of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or to any other University/Institution.

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ABSTRACT

The issue in the context of power system protection, leads to a critical void in design and implementation of mechanisms for protection from overcurrent under IDMT (Inverse Definite Minimum Time) settings. The above identified problem reveals a crucial gap in designs for tools overseeing the IDMT overcurrent protection of power systems. Lack of systematic prescription of design steps and procedural development in numerical IDMT overcurrent relay characteristics leads to the faults to persist in the network, despite the research and education activities conducted pertaining to power system protection. Absence of standardized methodologies and tools incurs challenge toward the reliability and the effectiveness of protection schemes. This research tends to fill this gap with the design and validation of the IDMT overcurrent relay characteristics based on IEC 60255 standards. The process that are followed are a systematic methodology development, MATLAB/Simulink simulation of the designed characteristic, its implementation and performance with respect to selectivity, speed, and reliability. This chapter details the software implementation to a great extent by taking an example of a Simulink model of an electrical system with an IDMT protection scheme. The most important highlight of this research is the scope for a proper methodology, which would function as a tool for understanding efforts to get the maximum benefits from IDMT overcurrent protection in electric power systems.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

IDMT	Inverse Definite Minimum Time
PSM	Plug Setting Multiplier
TMS	Time Multiplier Setting
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
NI/SI	Normal Inverse / Standard Inverse
VI	Very Inverse
OCR	Over Current Relay
EI	Extreme Inverse
CB	Circuit Breaker
DOCR	Directional Over Current Relay

Chapter 1

Introduction

1.1 Overview

The Inverse Definite Minimum Time (IDMT) protection is among the basic schemes that have been there to ensure that the power system is secured from disturbances and faults. The IDMT protection, through an inverse relationship between fault current magnitude and tripping time, takes advantage of the programmable features of modern numerical relays for proper setting in considerably enhancing performance. This scheme presents effective response to various fault scenarios and improves the reliability of the power system in general. The IDMT protection is based on operation principles, characteristic curves, Plug Setting Multiplier, and Time Multiplier Setting. Due to IDMT protection in coordination with numerical relays, the problems of overcurrent and short circuits in the numerous parts of the power system are solved efficiently through cost-effectiveness and reliability. Thus, relay technology moved from mechanical devices to so-called smart relays, and finally to Intelligent Electronic Devices (IEDs), where the main goal is to switch faster, more reliably, and in a smart way to meet versatile solutions required by industry. Deployment of IDMT protection, however, requires considerations such as coordination with other devices, the sensitivity-stability balance, discrimination between different faults, integration into communication networks, reliability and maintenance features, cybersecurity, compliance with standards, training of personnel, adaptability to changes, and updating the system. Properly carried-out scheming of IDMT protection is of foremost importance in grid stability and ensures an uninterrupted electric power supply.

1.2 Introduction to the IDMT Protection Scheme

Electrical power systems are always subjected to the threats and vulnerabilities of various faults and abnormalities, which may result in even the slightest deviation from stability and reliability in maintaining an electrical grid.

This is by using protective relays, which are devices that detect and isolate faults for equipment protection and hence ensuring continuity of electricity supply. An example of these advanced protection schemes is the IDMT Protection Scheme [1]. This protection scheme mainly deals with the identification of whether a state is normal or an abnormal state that emerges as either a short circuit or an overload, to take effective action quickly and prevent probable damage from occurring [2]. Overcurrent protective, opposing the conventional methods of protection, is a characteristic based one, which shows an inverse dependency on the operating time and the amplitude of fault current. Generally, in the scope of diversity of fault types that can be accommodated by a single device, IDMT protection is superior; therefore, the holding time of the protective relay is inversely reduced with increasing fault current. As a result, it can trip quickly for severe faults while retaining enough tolerance to less severe abnormalities [4].

Major constituents of the IDMT protection scheme are numerical relays (OCR), which contain well-developed algorithms and digital signal processing for accuracy in measurement and analysis of electrical quantities [5]. The relays are programmable, acquiring flexible and accurate setting in accordance with requirements of specific systems. Because it provides a balance in sensitivity and selectivity, that is widely used as protection for power distribution and transmission systems [6]. All these will be enhanced in the utilities for overall improvement in power system reliability and reduction of the time of outage that results from faults by using IDMT protection with numerical relays [7]. In essence, this contributes to the stability of the electric grid.

1.3 Fundamentals

In power systems, it is a protective relay that pick up and deal with abnormal operating conditions such as overcurrent. Time setting varies inversely with the magnitude of the fault current; that is how IDMT protection relay works. For larger fault currents, faster tripping times are presented, largely achieving protection measures that are swifter and selective [8]. Here are the basics of IDMT protection:

- **Current-Dependent Operation:**

IDMT protection relays work on the magnitude of the current flow in the power system or the protected equipment. The relay detects the current and estimates the operating time using a certain characteristic curve [9].

- **Characteristic Curve:**

The curve of the characteristic between the amplitude of the fault current and the tripping time characterizes the inverse definite-minimum-time relay. An illustration of this type of curve is the inverse-time-overcurrent curve [10]. The configuration of the curve depends on some parameters, including Plug Setting Multiplier (PSM) and Time Multiplier Setting (TMS) [11].

- **Plug Setting Multiplier (PSM):**

Therefore, PSM gives the multiple of the nominal current setting of the relay at which it could operate. PSM is designed to adjust the sensitivity of the relay. A lower PSM, therefore, denotes that the relay would be sensitive to a lower value of fault currents [12].

- **Time Multiplier Setting (TMS):**

A multiplying fine-tunes the operating time of the relay. A digitized time multiplier setting is multiplied by the inverse-time characteristic curve time to achieve tripping time [13]. Further, it has value larger hence longer time period and hence can produce coordination with other protective devices [14].

- **Inverse-Time Characteristics:**

Time to trip will reduce as the fault current increases. Such an inverse characteristic ensures greater selectivity and coordination in the system to provide the quickest possible tripping at higher fault currents [15].

- **Selectivity and Coordination:**

IDMT protection relays coordinate with the other protective devices of the power system to select a point of its operation to be performed closest to the source of the fault [16]. Proper coordination might lead to the location of the faulty part with minimum disturbance caused to the entire system for various topologies, and thus the requirement of an adaptive grid protection system is then eliminated [17].

- **Applications:**

IDMT relays are also applied extensively in the protection of feeders, transformers, motors, and distribution networks from over currents and short circuits. It is used in the protection of transformers from inrush currents.

- **Advantages:**

IDMT protection is relatively cheap and universally applied owing to its simplicity and reliability. It allows the coordination and selectivity needed in proper fault isolation in a protection scheme.

1.4 Numerical Relays: Advancements in Protection Technology

Relay technology has advanced significantly since its development in the early 19th century. Originally designed for telegraphy purposes, it has been found to be used in telecommunications, power systems, automation, and computing. A brief elaboration on the history of relay technology:

- **Mechanical Relays of Early Periods (19th century)**

The early relays were mechanical; physical contacts would either open or close circuits in response to the changing states of input signals. These mainly found application with the immediate development in telegraphy and early telecommunication systems [18].

- **Electromechanical Relays (Late 19th to mid-20th century)**

Electro-mechanical relays were invented by the introduction of electromagnets. Their action was based on electromagnetic coils that controlled movement of mechanical contacts. Normally, these appear to be applied in telephone exchanges, early generation computers, and industrial control [19].

- **Solid-State Relays (Mid-20th century to present)**

Many applications replaced the electromechanical relay with the solid-state relay because it has faster response, longer life, and less sensitivity toward mechanical wear and tear. This switching function is accomplished using semiconductor devices of thyristors, transistors, or integrated circuits rather than electromechanical switching devices. They find wide applications in electronic devices, power electronics, and automation systems [20].

- **Microprocessor-Controlled Relays (Late 20th Century to present)**

The combination of microprocessors with digital electronics has led to creating so-called microprocessor-based relays, which have digital logic and programmable functionality that makes them more flexible, more controllable, and supports advanced functions like time-delayed operations, sequence control, and communication networking. Their fields of application are very broad in modern industrial control systems, smart grid applications, and IoT devices [21].

- **Intelligent Electronic Devices (IEDs) and Smart Relays:**

The intelligent relays and integrated electronic devices represent a new trend in the area of monitoring, control, and protection of power systems. The devices cover advanced sensor, communication, and computing abilities that can realize real-time monitoring, fault detection, and adaptive control in distribution and transmission networks [22].

- **Emerging Technologies:**

More recently, the development of the relays has been with the advances in material science, nanotechnology, and quantum computing. The most probable innovations in this field will be driven by recent technologies such as memristors, Nanoelectromechanical Systems (NEMS), and quantum relays to achieve better speed, lower power consumption, and novel functionalities [23]. These technologies have developed mainly forth the improvements in speed, reliability, and adaptability of the switching systems. Therefore, the improvement from mechanical to solid-state and digital relays has been spurred by a development to adapt to changing needs in an advanced modern application.

1.5 Challenges and Considerations in IDMT Deployment

IDMT protection is a protective relay designed to be used in any power system to detect and segregate faults quickly. Moreover, it provides the advantages of speed and choice; however, there arise some difficulties and considerations related to its deployment. The major ones are discussed here.

- **Coordination with Other Protective Devices**

The IDMT protection devices must be coordinated with the other protective relays in the power system so that proper selectivity is observed. This can be achieved by setting time delays and current thresholds so that there is no tripping of the circuit for irrelevant reasons, and isolation of a fault can be done as fast as possible [24].

- **Delicate Sensitivity**

There is a requirement that proper sensitivity versus stability must be achieved, where the protection relay should be sensitive enough to detect a fault quickly while being stable enough not to cause false tripping because of transient conditions or system disturbances [25].

- **Discrimination by type of fault**

IDMT protection should be able to discriminate among the several types of faults, whether it is phase-to-phase or phase-to-ground, so that it will properly respond. Incorrect discrimination might lead to unnecessary tripping or failure in isolating the fault [26].

- **Communication and Human Integration**

The need for current power systems is becoming increasingly important in devices to have communication and sharing of information. The integration of IDMT protection into a global communication network has to be considered to increase the coordination and monitoring of the system [27].

- **Reliability and Maintenance**

Regular maintenance and testing to ensure reliability of IDMT protection hold prime importance. Attention should be according to the method of testing, availability of spare parts, and consequences on system down-time due to undertaken maintenance actions [28].

- **Environmental Conditions**

IDMT protection devices usually respond in the different types of environments. The surrounding temperature, humidity, and inhalant should be considered to make these devices operate effectively.

- **Cybersecurity**

With the emergence of digital technologies that are integrated into power systems, cybersecurity becomes a major concern. It is, therefore, very important to secure the IDMT relays by protecting them against any cyber offense, unauthorized access, or malevolent attack toward them.

- **Standard Compliance**

Validate the IDMT protection system according to regulations and standards of the industry. In addition, compliance results in interoperability, reliability, and conformance with best practices [29].

- **Training and Documentation**

One has to be properly trained in operation and maintenance for IDMT protection. Support services in the form of troubleshooting, testing, and configuration change should be supported with comprehensive documentation facilities.

- **System Enhancement and Upgrades**

Scalability and compatibility with future changes or upgrades in the IDMT protection devices should be considered. The ability of the protection scheme to accommodate changes in the configuration of the power system may be very important [30].

Chapter 2

Related Work

2.1 Overview

The Simulation paradigm of the IDMT Protection Design of numerical relay is the important development in the power system protection technology. The combined model presented in this research with respect to advanced numerical relays is based on the IDMT scheme. It will offer a practical solution for detection and response to faults. Numerical relays have proved to be well equipped with modern approaches that involve complex algorithms and the possibility of digital signal processing for taking correct measurements of electrical quantities. Furthermore, they are ennobled with programmable configurations based on the system requirements. Such peculiar characteristics of the model, such as the inverse-time characteristic curve, makes it utilize an IDMT protection scheme for quick response to varying scenarios of faults. The model combines the precision of numerical relays and the reliability of IDMT protection for optimum performance, stability, and robustness of power distribution and transmission systems, showcasing a technological breakthrough in grid protection.

Kadhem et al. (2024) [31] analyzed the TSM and PSM values for an earth-fault and overcurrent, respectively, on a 33/11 kV power distribution substation where the setting elements of Basra are inherently instantaneous. Overcurrent relays simulated and earth fault relays were used in order to get immediate and time delay scenarios respectively. This was utilized by the Nathran substation to draw TCC curves for each Circuit Breaker (CB) relay, of twice 31.5 MVA against an operating voltage magnitude level as above. Substation included in that Basrah distribution network was the small substation. The recommended short circuit current at each CB was utilized to model the protection coordination for the Nathran substation in DigSilent Power Factory software. Actual data collection on the farthest point regarding the short-circuit current of the longest feeders. A reduction of the relay tripping operation time with 20% relative to that offered in the case study supplied had led to results that the proposed coordination mechanism was effective yet preserving coordination between backup protection and primary protection.

The actual results data was analyzed by **Mohammad et al. (2024) [32]** for the OCR installed in the power distribution board for both high and low voltage descending at a commercial building. Prior to measurement and testing with the MICROTEST 860 set, all parameters need to be clearly defined. However, the study proves that it can be technically recognizable for the operating time (s) of the existing curve set to IEC Standard of 0.10 TMS. Other than that, results show that the SS gained from incoming setting in an actual commercial site is not as precise as the standard inverse curve from human calculation results. By utilizing its algorithm, the setting relay of the OC case meets the IEC 60255-3 standard using the criteria of current injection and time tripping. This model used to extract the curve characteristics given that.

Khan et al., in 2023 [33], approach via machine learning applications. The effectiveness of most of the commonly used machine learning models was tested in the context of relay coordination. Among models used were Gradient Boosting, Decision Trees, Linear Regression, Random Forests, and Support Vector Regression. Quite ahead of the rest, the most propitious model was Gradient Boosting, with much reduced MSE and MAE (R2-score over 97%). The Cross-Validation Score of 86.2% showed that the discovery model was well fit, with high capacity in applying it over new data. Research has shown one powerful method for relay coordination in the smart grid: Gradient Boosting is accurate, efficient, and dependable while offering a promising substitute for traditional approaches based on calculations.

Reda et al. (2023) [34] proposed the REF 615 type, equipped with both earth fault relay and overcurrent protection, designed to be employed in the real radial feeder protection scheme in the Egyptian substation. As the network was constructed on a radial layout, the current of the fault was analyzed for cases with issues as well as under medium and heavy loading at the location. In the envisioned method of operation of the REF 615 OC relay, it was subjected to three settings all at the same time, together with NI, VI, and DMT settings. The relay's setting was divided into two halves for effortless operation. It was now that in the first area, the VI curve supports the NI curve, while in the second area, it was just the opposite. This was a novelty feature of the suggested model. The self-protection would be achieved once the relay became faulty. Such innovation reduces the operation time of the relay—decreases by 41.07%, hence better network security and reduced response time for faults. Including the self-backup protection, the CTI primary-secondary can be decreased by approximately 77-98%. Analysis of the protective coordination and study of the real radial system were both conducted in the ETAP software application.

Kamal and Anower., (2023) [35] gave a detailed explanation of preparation, simulation, and numerical relay implementation for undervoltage and overcurrent protection in electricity transmission and distribution networks. Some of the advantages are that such protections are offered at lowered expenses. The Coordinated Control and Protection procedure was assessed for its effectiveness through MATLAB/Simulink tests using the simulations of diversified operating scenarios. The voltage sensor (CT) and current sensor (PT) were both interfaced on the Raspberry Pi and programmed to activate the Standard Inverse-SI relay and two activation settings for the Extreme inverse-EI and Standard Inverse-VI, respectively, IDMT relays. Following are the IEEE/ANSI Codes taken into consideration and applied by IEC 60255 upon fault conditions: 50 for Instantaneous Overcurrent Relays, 51 for AC Inverse Time Overcurrent Relays, 27 for Undervoltage Relays, and 59 for Overvoltage Relays.

Viet and Xuan., (2023) [36] came up with a solution that offline simulation in the ETAP software can be coupled with. The maximum performance of an over current relay with a high degree of discriminative tripping was then guaranteed through utilization of Gurobi-Optimizer algorithm in designing of Inverse Time characteristic/IDMT characteristic constructed via a method for identification of TMS. This approach was finally assessed upon on the Quang Ninh province of Vietnam using the ETAP software platform and a sample skeletal distribution network of 6kV. More definitively, results included a reduction of OCR false trips and an extension of OCR operating time.

Tyagi et al., 2022 [37] showed an example of the MATLAB/SIMULINK modeling and simulating of inverse-type overcurrent relays. Several types of overcurrent relays are employed for the protection of transmission lines against such collapses in most substations. If a breakdown occurs in a particular transmission line, the remaining part of the line will promptly get disconnected by the activation of the overcurrent relays. Also, when trouble exists, overcurrent relays provide warning to the operator of the transmission line and serve to protect the transmission line as promptly as possible. Simulation results have been used in finding the right overcurrent characteristics for the distinct kinds of failure and then a relaying choice is made.

Mahmood and Ali created a laboratory platform that was programmable to operate three different experimental setups simultaneously, with a personal computer interfacing a programmable logic controller; one setup was for Direct-On-Line and star/delta starting, one for single-phase AC line controller, and one for IDMT overcurrent protective relay—all with three-phase induction motors. The first of these allows us to view and take down the current history of the three-phase induction motor when using the DOL and star/delta starting methods. In item two, one learns how to use the AC line controller in three modes: ON/OFF, phase angle, and integral cycle; thus, one also gets introduced to the simplest concept of operation in soft starters. The difference between solid-state and magnetic relays has also been explained. Characteristic curves of the IDMT overcurrent relay were used specifically for the third setup that was experimented within this experiment. This third configuration included one PLC, and the peripherals used for this setup were two desktop PCs. The central PLC was interfaced with both PCs using the Wxpython's Graphical UI Toolkit and Python's PyModbus communication utility.

Uwho et al., (2022) [39] discussed the relay coordination of Nigerian Ports Authority that was ineffective as it does not allow them to work in coordination. Further, the voltage rating for the distribution substation that supplied NPA at Marine was 2 X 15MVA, 33kV. If finally, it sought the relay and the circuit breakers to respond faster than it could use IDMT in combination with short circuit analysis. Initial information for the model and simulation of the network, based on the ETAP 19.0.1 Electrical Transient Analyzer, is gathered from the Port-Harcourt Electricity Distribution Company and Transmission Company of Nigeria. The results indicate an explanation of how the main feeder relays tripped in the wrong sequence with respect to their backups in the present situation. The current NPA Feeder in response to 3-phase failure recorded the following timings: 82.9 ms, 137 ms, 213 ms, and 110 ms in that order from the 33 kV feeder breaker to the line breaker; from the 33 kV control panel breaker to the 11 kV incomer control breaker. From the modified case, the times were 226 ms, 343 ms, 411 ms, and 420 ms. Of 4.20 milliseconds. From the modified case, the order in which the faults occurred was 1, 4, 3, 2. This is entirely contrary to the correct order of 1, 2, 3, 4. The relay coordination should be as quick as possible in ensuring safety to the devices connected to the network and for the end-user.

Hussain et al. (2021) [40] have proposed a flexible scheme for the coordinated use of directional overcurrent (DOCR) relay to protect AC microgrids. It is observed that the protection schemes for AC MGs are complex and very cumbersome since the network is dynamic in nature. Some critical areas of application regarding these are the transition between grid-connected and islanded modes, bi-directional power transfer, and integration of renewable energy resources that are intermittent with real-time variations in availability. As a consequence, the contribution in fault currents should vary importantly between network event circumstances. Their dynamic conditions often make traditional tripping schemes fail or perform abysmally. In this paper, an adaptive operation method of the ICPU is implemented in a case study of a modified IEEE 9-bus system using DigSilent Power Factory. The proposed scheme is compared against several scenarios and the static scheme to assess its effectiveness: grid-connected operation, islanding operation, and distributed generation in different modes that can form.

Thote et al., (2021) [41] analyzed the application of MATrix LABoratory (MATLAB) and Simulink for modeling and simulation overcurrent relays. The proposed project consists of two distinct phases. It is in this regard that the model simulation of an IDMT overcurrent relay within a MATLAB/Simulink environment was done in Section 1. Section 2 investigates the validation of results of such a simulation by utilizing an AVR microcontroller with advanced current sensing and control techniques to come up with an IDMT type of overcurrent relay. Several IDMT fault types, as well as their characteristics, have been based upon the testing of the developed model. Compare all these results with the ones obtained from the Simulink model and it would be quite evident that they were highly consistent.

All the other features of the system, as communicated to the students by Radhi **Mahmood et al. (2021) [42]**, have been developed in practice and implemented through firsthand experimentation using a PLC and HMI. The activity enabled students to develop enhanced IDMT protection relays for use in differential current, over voltage, under-voltage, overcurrent, and choices of settings. Success was plentiful with the use of the platform and its HMI to learn and apply protective relays—especially those designed specifically for use with this platform. In addition to being able to observe the real-time reaction that corresponds to how long a protective relay has been in operation under different settings, the kinesthetic learning aspect of the project expedited the understanding of what goes into updating these relays substantially.

Optimization Problem in Power System: **Muhammad et al. (2021) [43]** proposed a new optimization methodology known as FPSOGSA, in which canonical particle swarm optimization is mathematically formulated as a combination of both the classic gravitational search algorithm and fractional calculus; it goes on to further test the optimizer under a typical power system optimization problem requiring DOCR coordination in IEEE3,8, 15 bus networks. The frequency converter and the particle swarm and gravitational search algorithm have been integrated in order to make optimizations smoother. In this, certain features of each optimizer have been used and the best global workability solution has been identified and integrated even further. These have also been further substantiated from the results obtained through the proposed methodology through the comparisons that have been made with other best-known algorithms which had been implemented recently only. All the tools, including minimum fitness evolution, histograms, boxplot presentations, quantile-quantile plots, and empirical cumulative distribution functions, were used to achieve results from wide statistical analyses that assured the consistency, stability, and dependability of FPSOGSA in every simulation.

Eid et al., (2021) [44] studied the influence of the size of the FCL by relaying with user specific characteristics. Can resolve the protection problems in looping networks due to the addition of Distributed Generation (DG), integrating FCL with utility. The protection coordination scheme has, other than the configuration variables bulk like IP and TDS, also the facility to fine tune things with arbitrary user-defined characteristics, including things like the B inverse time type and the A directional overcurrent constants for relay characteristics. The found settings led to four optimal relay settings and FCL. The problem was formulated as a constrained NLP problem and was aimed to minimize the total running time of relays. An IEEE 30-bus mesh power distribution network was taken in order to show the proposed approach. The proposed approach minimized the overall operation time of the relay and the minimum value of FCL.

Sulimann and Ghazal., (2020) [45] used the technique of an FPAA-based over current protection relay. An improvement in performance over current numerical relays mightbe achieved with the recent technology that integrates digital technologies with field-programmable analog arrays (FPAAs). Overcurrent relays developed and realized using FPAAs were investigated. This research paper described how to model and simulate a protected system using MATLAB. The hardware implementation that made use of FPAAs has been described in detail. In this section, the author has presented the practical testing by simulating several fault conditions. It was observed from different simulation results that the new protection scheme is capable of learning several time-current characteristics and responding quickly to steady-state fault conditions. The developed protection system was simulated for line-to-line fault conditions, and it has been observed that it can cope with the faulty condition through appropriate identification of the faulted portion and allows the rest of the network to operate safe. Two other types of characteristics used are the IDMT type and the very-inverse type.

Bougouffa and Chaghi., (2020) [46] opted to study a dual simplex optimization technique in order to determine the coordination between DOCRs in a distribution system and the impact of the integration of RES on this coordination. A bit later, integration of renewable energy sources into this coordination is also examined. The efficacy of the IEEE 33-bus model can be assessed using such a system. The research is modeled in MATLAB. It was shown that the linear programming technique used was very effective for optimizing the design needed to provide the best protection for the radial distribution system.

Chapter 3

Methodology

3.1 Overview

The issue in the context of power system protection, leads to a critical void in design and implementation of mechanisms for protection from overcurrent under IDMT (Inverse Definite Minimum Time) settings. The above identified problem reveals a crucial gap in designs for tools overseeing the IDMT overcurrent protection of power systems. Lack of systematic prescription of design steps and procedural development in numerical IDMT overcurrent relay characteristics is lacking in spite of the research and education activities carried out pertaining to power system protection. Absence of standardized methodologies and tools incurs challenge toward the reliability and the effectiveness of protection schemes. This research tends to fill this gap with the design and validation of the IDMT overcurrent relay characteristics based on IEC 60255 standards. Other activities that are followed are a systematic methodology development, MATLAB/Simulink simulation of the designed characteristic, its implementation and performance with respect to selectivity, speed and reliability. This chapter details the software implementation to a great extent by taking an example of a Simulink model of an electrical system with an IDMT protection scheme. The most important highlight of this research is the scope for a proper methodology, which would act as a tool for understanding efforts to get the maximum benefits from IDMT overcurrent protection in electric power systems.

3.2 Problem Statement

Over the past years, the design from many laboratories for teaching and exploring power system protection has been noted and implemented. Among the many schemes used in the protection of electrical power systems, overcurrent IDMT protection is used prominently. As such, this project tries to design and implement, based on the recommendations of IEC 60255, the numerical features of an IDMT overcurrent relay for a specific electrical system according to appropriate standards. The characteristics are developed in MATLAB/Simulink and gotten at the simulation environment after implementation.

3.3 Objectives

- Prepare a step-by-step methodology to design a feature of numeric IDMT overcurrent relays to be in compliance with IEC 60255 standards.
- Implement an electrical system MATLAB/Simulink simulation model that is specific to the electrical system, for the purpose of verifying the functionality of the designed IDMT overcurrent relay.
- Discuss the performance of the IDMT overcurrent protection scheme in speed, selectivity, and dependability.
- Learn how the IDMT Overcurrent Protection has been optimized for superior performance and efficiency.

3.4 Software Implementation

The MATLAB Sim Power System suite of tools is used for modelling of the relay. An overcurrent relay using IDMT capabilities is included in Simulink's extensive model.

A three-phase electrical system delivering electricity to a load is shown in Figure 1 of the Simulink data. Table 3.1 shows the different system parameters.

Fig.3.1. of Simulink model shows three-phase IDMT overcurrent protection tripping mechanism. The output of the control mechanism is a logic 0 trip signal in the non-fault state and a logic 1 signal in the fault condition. The Trip signal is sent to CB after processing all the phase-specific trip signals.

Fig.3.2. shows that one of the phases is controlled by the input current during the relevant time. The current is converted to an RMS value over a 20-millisecond period by using the root-mean-square (RMS) block. Fixed threshold/pickup value is one of the two inputs of relational operator.

Table 3. 1 System Parameters.

Sr. No.	Parameters	Values
1.	Source Voltage (V)	440 V
2.	Source resistance (Ω)	0.0008929
3.	Source Inductance (μH)	18.63
4.	X/R Ratio	5

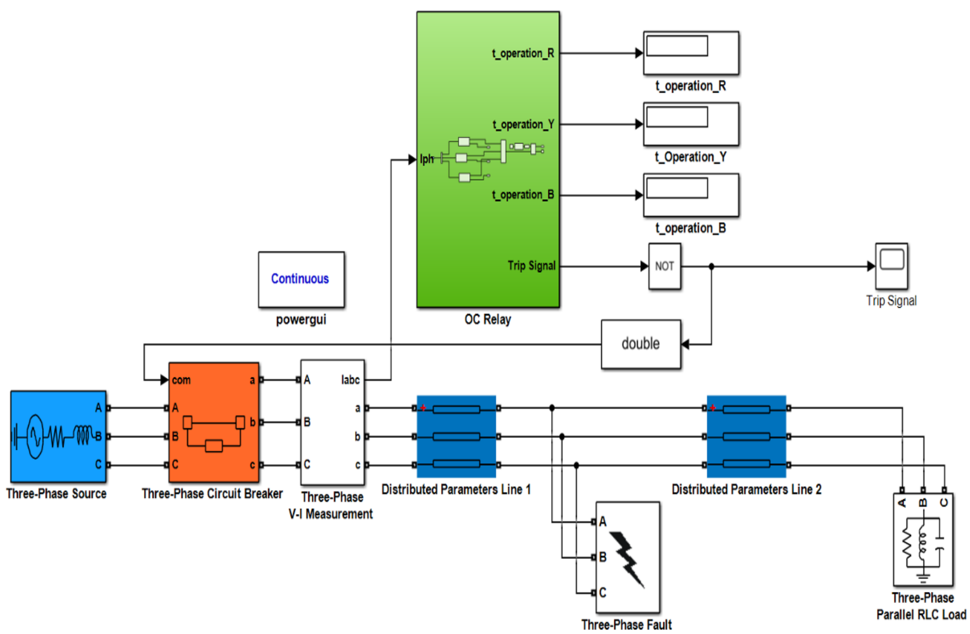

Fig.3. 1. Simulink model for IDMT protection

Ip is 2.6 A under these conditions.

1. An error situation occurs when the line current exceeds Ipu, and the relational operator's output is 1. The IDMT characteristics' typical operating time might be determined via

$$t = \frac{K}{\left(\frac{I_f}{I_p}\right)^{\alpha} - 1} \times TMS \tag{1}$$

2. Since this is not an interconnected system, hence Time Multiplier Setting (TMS) is set to 1 for the purpose of analysis of characteristics.
3. 2. The function $\left(\frac{I_f}{I_p}\right)^{\alpha} - 1$ is executed by a function block that is provided the ratio $\frac{I_f}{I_{pu}}$. The IDMT features are implemented via the dividing block.

$$t = \frac{K}{\left(\frac{I_f}{I_p}\right)^{\alpha} - 1} \tag{2}$$

Where.

- Standard Inverse Time Characteristics, K=0.14 and α = 0.02.
- Very Inverse Time Characteristics, K = 13.5 and α = 1.
- Extreme Inverse Time Characteristics, K = 80 and α = 2.
- Long Inverse Time Characteristics, K = 120 and α = 1.

The IDMT Overcurrent relay is guaranteed to operate after operating time 't' according to the IDMT characteristics that have been specified by relational operator 2. For other lines, it uses a tripping mechanism that is rather similar. An OR block receives the output from all three control mechanisms and, in the event of a malfunction on any of the three lines, sends out a trip signal. Full Load current has been calculated and based on it the CT ratio is selected. Other parameters like plug setting for phase real is kept higher than full load current and the line capacitance is neglected.

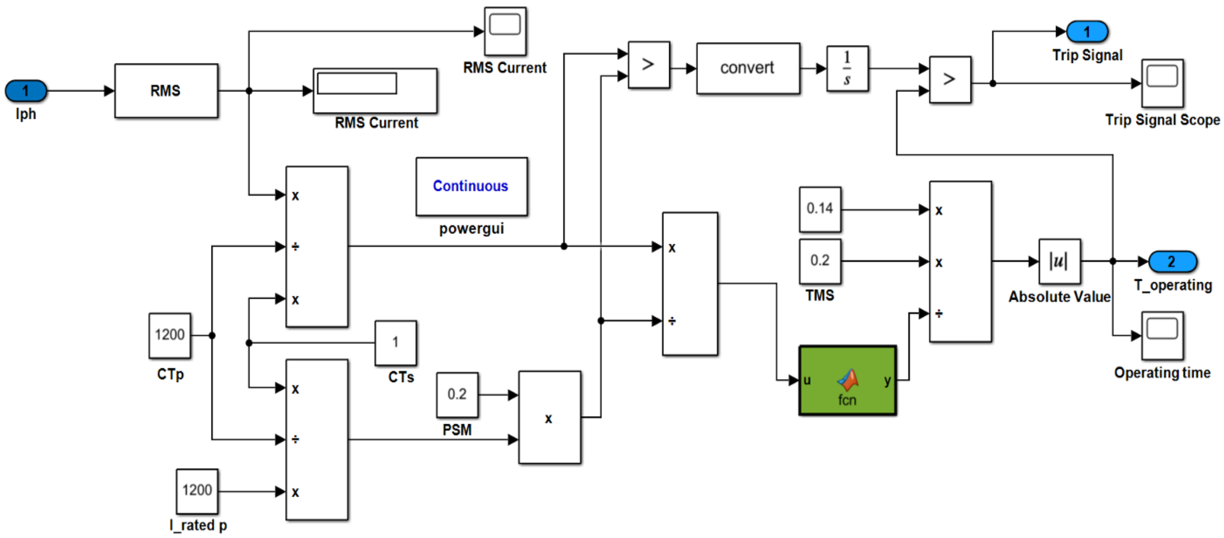

Fig.3. 2. Simulink model of control mechanism

The IDMT relay's arrangement block, seen in Fig.3.2, is present inside each phase, makes use of function block which is the exponential operation shown in (1). This block is created using the equation of operating time of IDMT relay. The value of PSM is selected to be 0.2 which is similar to the TMS. CT ratio for this arrangement is described in Table 3.2. The line length is 100 km and with negligible line capacitance. The tripping of this IDMT relay will take place when fault current is detected in any of the phase. Here the fault condition which is used to conduct the simulation work is Line-to-ground fault. The block diagram shown in Fig.3.3 demonstrates the methodology used to conduct the analysis and control of IDMT relay.

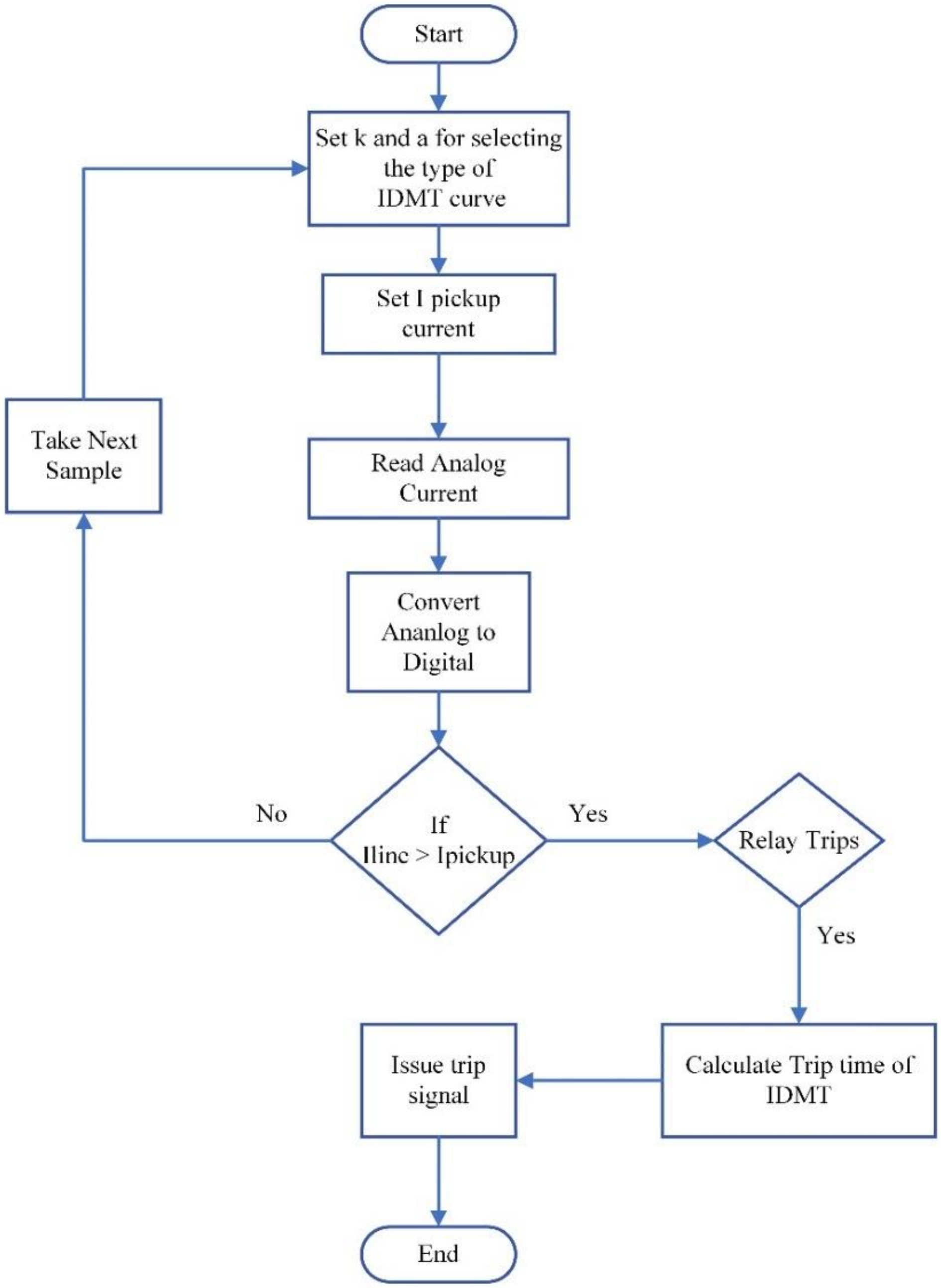

Fig.3. 3. Schematic of IDMT Relay

3.5 Application: Fault Analysis using IDMT relay network

The IDMT relay block chosen here is modelled with a transmission line, a three-phase source block of Simulink at the beginning end and three phase load (RL) at the other end. The parameters of the source, load, and line along with the relay specifications is shown in Table 3.2. Relay is operated in Standard Inverse mode, and each phase consists of a subsystem developed with the equation of operating time (1), as shown in Fig.3.2. Operation time is calculated based on the curves of each individual phases and when fault is detected, trip signal is sent.

Table 3. 2 Attributes of IDMT relay network.

Parameters	Values
Source Phase Voltage (KV)	76.21
CT Ratio	1200/1
X/R Ratio	5
Frequency (Hz)	50
Length of Line (Km)	100
Positive Sequence Resistance of Line, R1 (Ω/Km)	0.04558271
Zero Sequence Resistance of Line, R0 (Ω/Km)	0.15173259
Positive Sequence Inductance of Line, L1 (H/Km)	0.0006178532
Zero Sequence Inductance of Line, L0 (Ω/Km)	0.0015327239
PSM	1.25
TMS	0.35/1/1.5
Type of Curve	SI
Active Power (MW)	175
Switching Time of Fault (sec)	0.5
Fault Resistance, Rf (Ω)	2/20/40/50
Source Short Circuit level (MVA)	500

In this research, two types of faults, Single Line to Ground fault (SLG) and Line to Line Fault (LL) are taken into consideration as their frequency of occurrence is more as compared to other type of faults. These faults are simulated by varying fault resistances (R_f) so that to obtain variation in fault current which can be seen in Table 4.2. Plug Setting for phase relays are set at 1.25, whereas TMS is set at 0.35. The fault initiation takes place at 0.5s after the simulation initiates. The second form of results were obtained by varying TMS by keeping R_f fixed at 2Ω. These observations can be seen in Table 4.3. Table 3.2 contains the system parameters which were used in this work to model the circuit as shown in Fig.3.4, which briefly describes the attributes taken into consideration for the implementation of the work.

In the first mode of operation, fault resistance, R_f is kept at 2Ω, and the value of Fault Current, I_f is obtained for RG and RY faults along with their operation time T_{op} is noted. Then R_f is increased to 20Ω, 40Ω and 50Ω and same process is repeated for both the faults.

In second mode of operation, R_f is fixed at 2Ω and then TMS is changed from 3.5 to 1 and lastly 1.5, and again the process is repeated to obtain fault current and operation time.

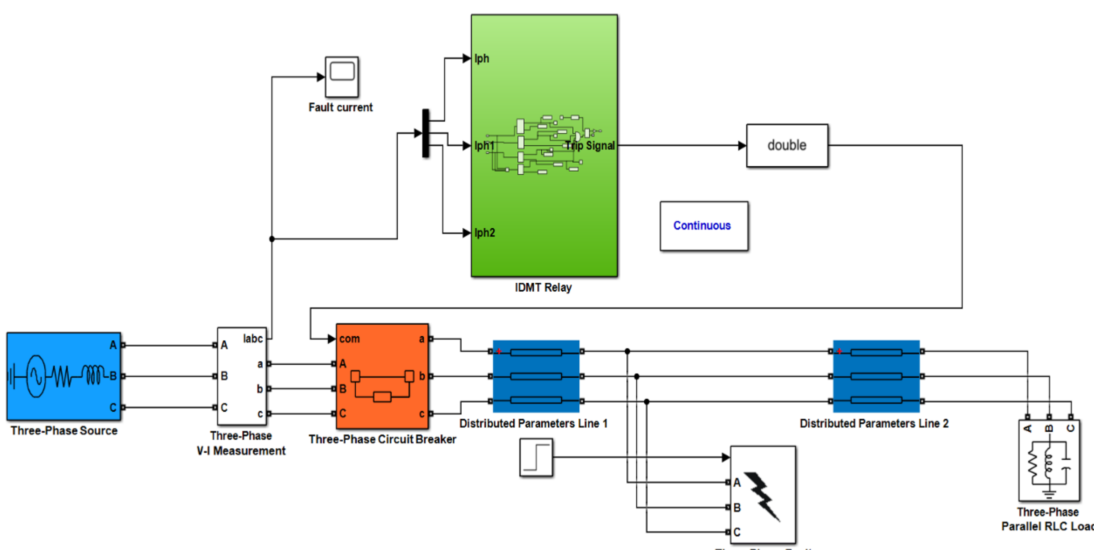

Fig.3. 4. Fault and Operating Time Analysis network

Chapter 4

Result and Discussion

4.1 Simulation Result

The output waveforms for different relays and the results for all the IDMT attributes in the Simulink model are shown in Figures 5 to 12. The signal for the circuit breaker to trigger is logic 1. Different TMS values and resistances of faults were used to alter the fault current value. The findings centered on the relay's operational duration.

I. Normal Inverse Time Characteristics

Case-1: The result for NI Time Characteristics; fault current I_f is obtained. Furthermore, 3.54 A and 11.05 s were determined to be the fault current and operational times, successively.

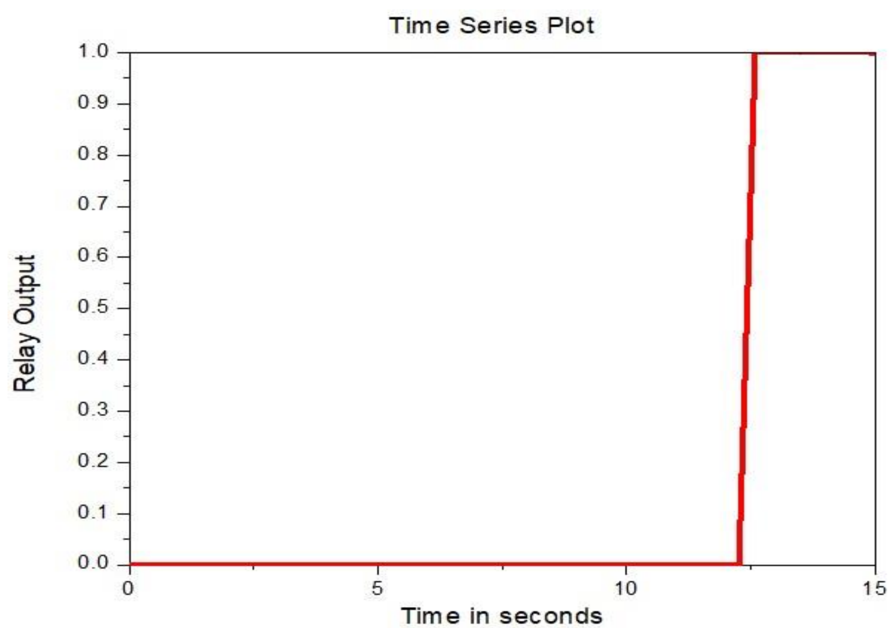

Fig.4. 1. Output for normal time inverse characteristics (case 1)

Case-2: The results for this Time Characteristics in second case, fault current I_f and operating time T_{OP} are shown in Fig.4.2. The relevant values are 8.14 A and 5.94 s.

Relay trips to 1.0 form 0.0 as shown in Fig.4.1. and Fig.4.2. in the time frame of 11.05s and 5.94s respectively.

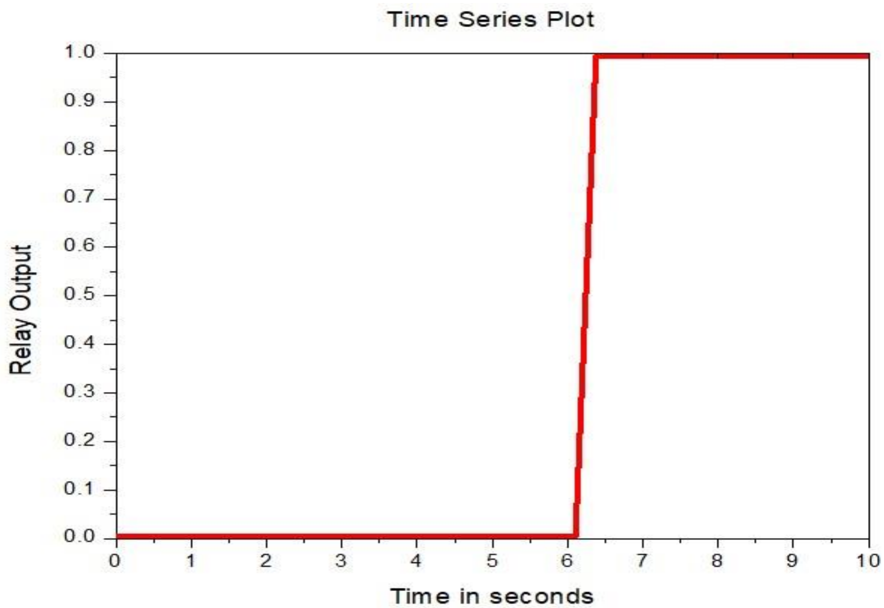

Fig.4. 2. Output for normal time inverse characteristics (Case 2)

II. Very Inverse Time Characteristics

Case-1: Fault current, I_f was determined to be 5.01A and operating time T_{OP} to be 16.25 s, as shown in Fig.4.3.

Case-2: For Very Inverse Time Characteristics, the Operating time T_{OP} is shown in the Fig.4.4. which is 5.68s and the fault current I_f is 9.01 A for the second case.

Relay trips to 1.0 form 0.0 as shown in Fig.4.3. and Fig.4.4. with operating time being 16.25s and 5.68s respectively.

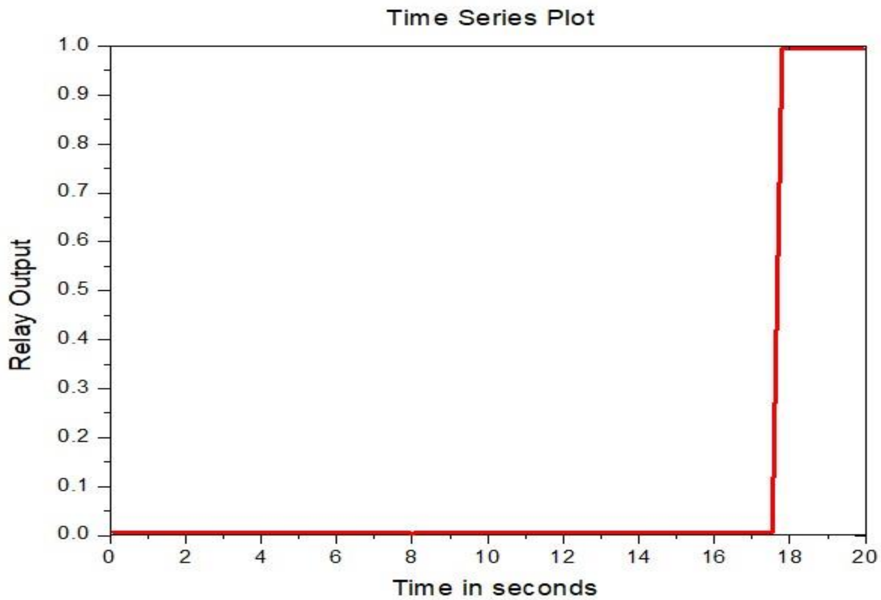

Fig.4. 3. Output for very inverse time characteristics (Case 1)

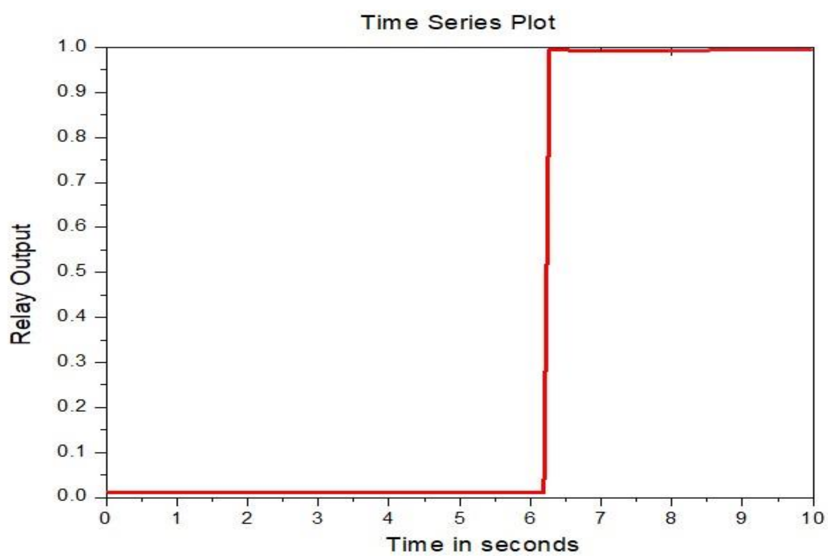

Fig.4. 4. Output for very inverse time characteristics (Case 2)

III. Extreme Inverse Time Characteristics

Case-1: Fig.4.5. displays the results for EI Time Characteristics, which were 5.45 A for fault current I_f and 40.67 s for operating time T_{OP}.

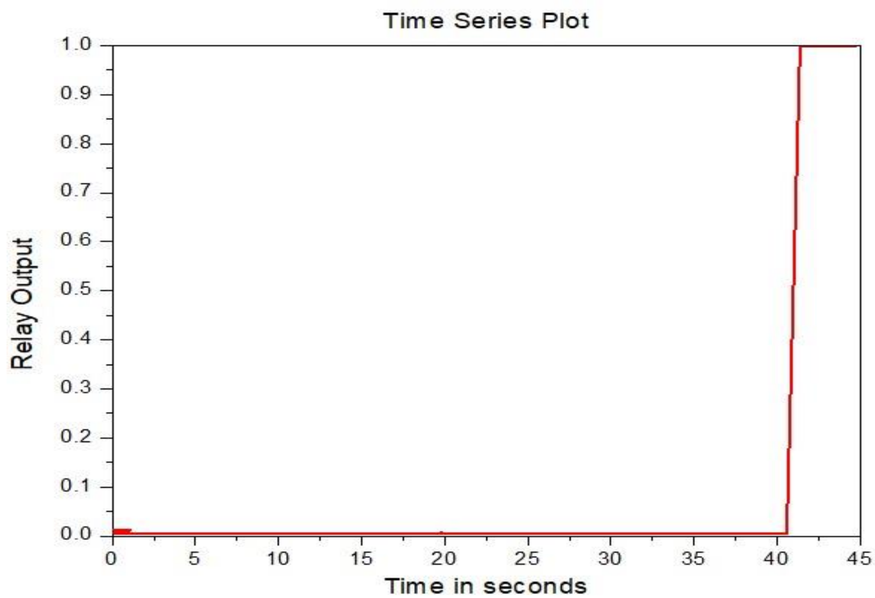

Fig.4. 5. Output for extreme inverse time characteristics (Case 1)

Case-2: The operating T_{OP} is 7.98 s as shown in the Fig.4.6. in second case of EI Time Characteristics, whereas fault current I_f for this operating time is 9.21 A.

Here also, Relay trips to 1.0 form 0.0 with operating time being 40.67s and 7.98s as shown in Fig.4.5. and Fig.4.6. respectively.

IV. Long Inverse Time Characteristics

Case-1: In case of Long Inverse Time Characteristics, T_{OP} or operating time obtained was 140 s, for which the fault current, comes out to be 5.98 A. The same is shown in Fig.4.7.

Case-2: A fault current of 8.56 A and an operating duration of 56.16 s were determined, as shown in Fig.4.8., for the Long Inverse duration Characteristics.

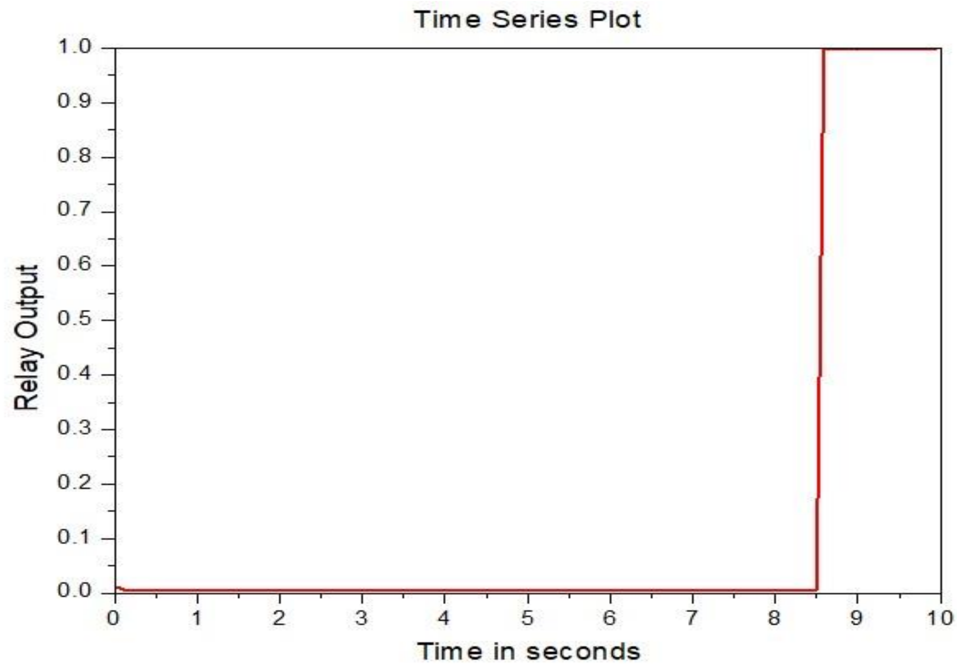

Fig.4. 6. Output for extreme inverse time characteristics (Case 2)

Tripping of the relay is obtained as shown in Fig.4.7. and Fig.4.8. for Long Inverse Time Characteristics where plot goes from 0.0 to 1.0 in the operating time of 140s and 56.16s respectively.

The graphical representation of the simulation data obtained is shown below in the Fig.4.13. which depicts the behaviour of the relay model as per the IEC standard of the protection scheme, which is trip time will be shorter for higher value of current multiplier. This proves out to be very helpful while designing the protection equipment for sever overloading conditions.

O

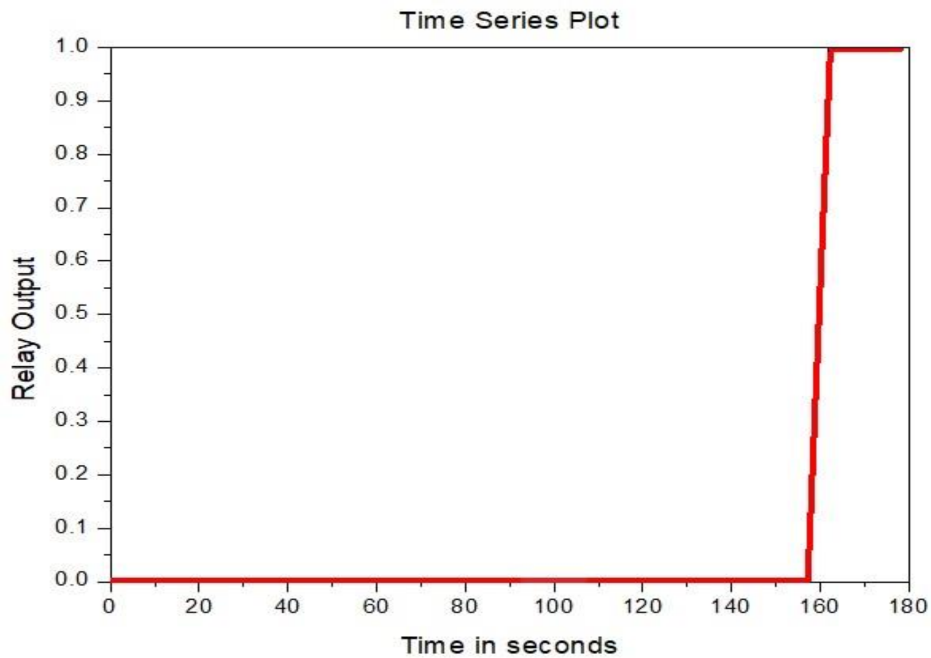

Fig.4. 7. Output for long inverse time characteristics (Case 1)

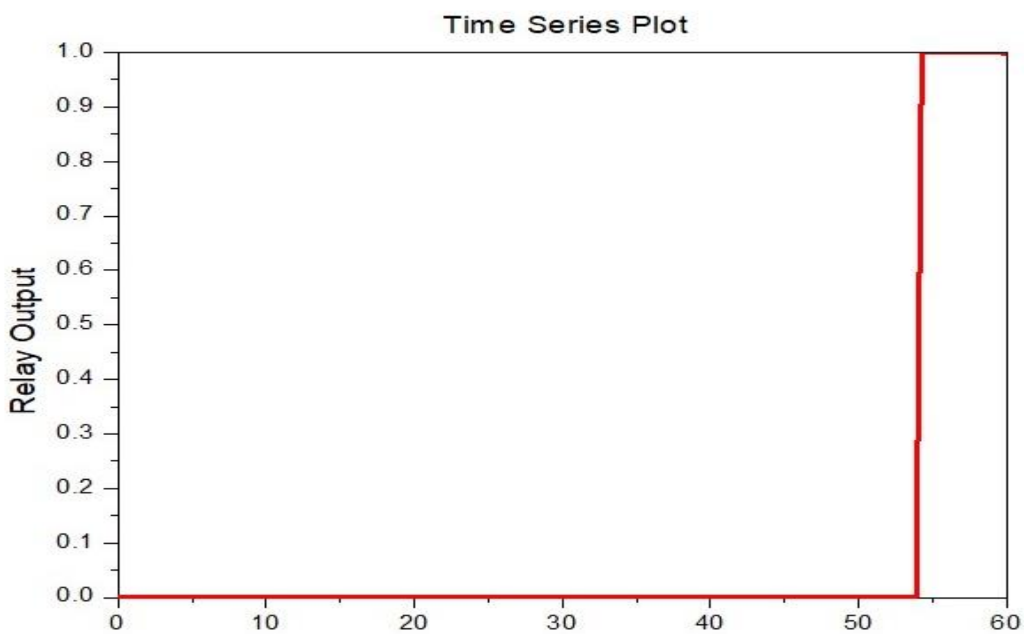

Fig.4. 8. Output for long inverse time characteristics (Case 2)

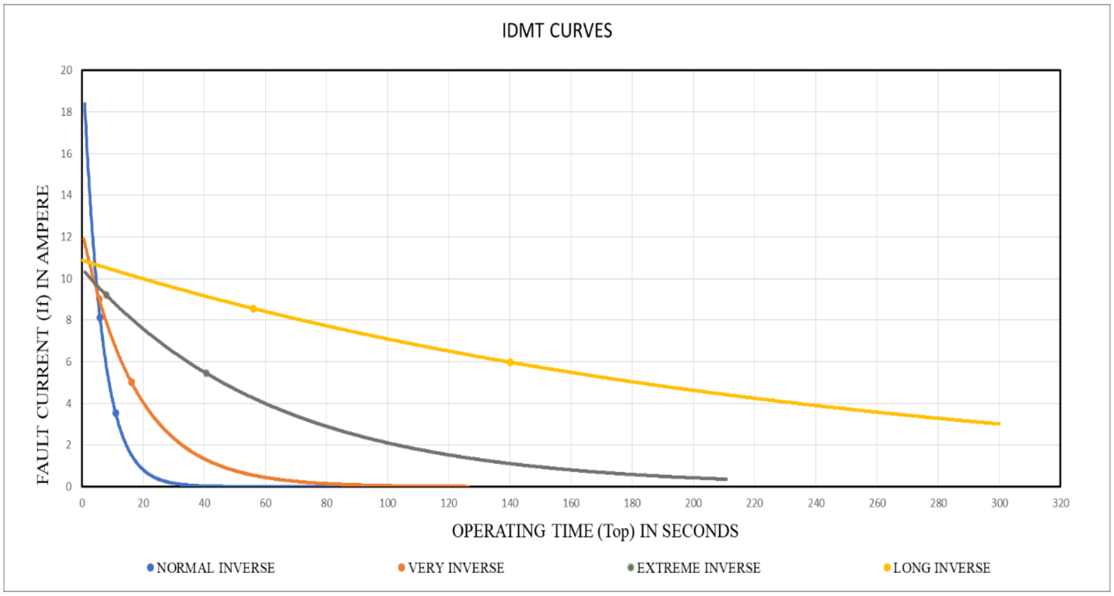

Fig.4. 9.IDMT curve characteristics

Table 4. 1 Obtained simulation results for tripping of IDMT relay.

Sr. No	**Name of the characteristics**	**Fault Current (I_f) in ampere**	**Operating Time (T_{op}) in seconds**
1	Normal Inverse	3.54 A 8.14 A	11.05 s 5.94 s
2	Very Inverse	5.01 A 9.01 A	16.25 s 5.68 s
3	Extreme Inverse	5.45 A 9.21 A	40.67 s 7.98 s
4	Long Inverse	5.98 A 8.56 A	140 s 56.16 s

4.2 Fault Analysis Results

For the case of variation of Fault resistance R_f, Table 4.2 shows the obtained fault current and the respective operation time for RG (Phase R to Ground) and RY (LL) faults. In case of Line-to-line Fault, fault currents in each of the faulted phases are shown and their corresponding time of operation of relay is mentioned. It was observed that, as the R_f is increased, I_f decreases and time of operation of the relay increases, which depicts inverse relation.

Table 4. 2 Fault Current and Operation Time obtained by varying Rf.

Sr. No	Type of Fault	Fault Resistance, R_f (Ω)	Fault Current, I_f (A)		Operation Time, T_{op} (s)	
1	RG	2	3019		0.204	
2	RG	20	1960		0.263	
3	RG	40	1614		0.443	
4	RG	50	1528		0.778	
5	RY	2	R: 3102	Y: 2978	R: 0.194	Y: 0.192
6	RY	20	R: 1808	Y: 1884	R: 0.262	Y: 0.270
7	RY	40	R: 1478	Y: 1605	R: 0.441	Y: 0.402
8	RY	50	R: 1400	Y: 1530	R: 1.223	Y: 1.218

Table 4.3 shows the changes in fault current, I_f and operating time of relay when TMS is varied and R_f is kept fixed. As TMS is increased consecutively from 0.35 to 1 and finally to 1.5, there is sudden increase in T_{op} was observed for same RG and RY faults for same fault currents level. Relay starts its operation from 0.5 seconds and clear the fault in the subsequent amount of time which is listed.

Table 4. 3 Fault Current and Operation Time obtained by varying TMS.

<table>
<tr><th>Sr. No</th><th>TMS</th><th>Type of Fault</th><th colspan="2">Fault Current, I_f (A)</th><th colspan="2">Operation Time, T_{op} (s)</th></tr>
<tr><td>1</td><td rowspan="2">0.35</td><td>RG</td><td colspan="2">3019</td><td colspan="2">0.204</td></tr>
<tr><td>2</td><td>RY</td><td>R: 3102</td><td>Y: 2987</td><td>R: 0.262</td><td>Y: 0.270</td></tr>
<tr><td>3</td><td rowspan="2">1</td><td>RG</td><td colspan="2">3019</td><td colspan="2">0.514</td></tr>
<tr><td>4</td><td>RY</td><td>R: 3109</td><td>Y: 2880</td><td>R: 0.594</td><td>Y: 0.532</td></tr>
<tr><td>5</td><td rowspan="2">1.5</td><td>RG</td><td colspan="2">3019</td><td colspan="2">0.584</td></tr>
<tr><td>6</td><td>RY</td><td>R: 3109</td><td>Y: 2880</td><td>R: 0.753</td><td>Y: 0.760</td></tr>
</table>

Chapter 5

Conclusion

5.1 Overview

The IDMT protection scheme is, therefore a very important tool in the stability and reliability of power systems. Based relatively on an inverse functioning of the trip time against the magnitude of fault current, together with using state-of-art numerical relays, modern relaying provides for a very quick and precise response to various fault scenarios. The fact that IDMT protection can be varied in time and current-dependent operation, with characteristic curves, PSM, and TMS, among others, in a bid to protect versatile and reliable power systems in distribution and transmission, is what drives the relay industry into innovation and commitment. From the olden mechanical relays and smart relays and IEDs to smart relays and IEDs and to the presently called-for more adaptable switching solutions, evolving while meeting the changing demands for faster and more reliable switching. Numerical relays will improve overall power system security, if they incorporate IDMT protection.

However, the successful deployment of the IDMT protection scheme is challenged by issues such as coordination with other devices, sensitivity-stability balance, type of fault discrimination, integration into a communication network, reliability and maintenance, cybersecurity, standard compliance, personnel training, flexibility to accommodate changes in the system, and system upgrades. In this regard, therefore, the maximum benefit should be realized from the IDMT protection system to ensure uninterrupted power supply and, therefore, great contributions toward grid stability. In this context, simulation results and hardware experimentation are shown to validate the effectiveness of the IDMT protection scheme in various fault scenarios. It therefore appears that the flexibility and reliability in the application of a scheme response to the different fault currents with the correct operating times. As a result, this paper proves that overall IDMT Protection Scheme, when carefully applied and maintained, is of the essence to enhance the power systems' resilience and performance with little or no disturbance to the electrical network.

5.2 Future Scope

Several promising avenues in power system reliability should be there in the future scope of the IDMT Protection Scheme. Integration of AI is one of the applications that will render it flexible enough to take decisions that would make the protection system adaptive and self-learning at the same time. Cybersecurity measures should be developed, such that the IDMT relays are fully protected from the emerging digital environment. Any development in sensor technology towards better fault detection and isolation would increase the sensitivity and responsiveness of the scheme. This can help in realizing the potential of quick, coordinated responses over wide-area protection and communication, besides machine learning for fault pattern recognition at large spatially distributed power systems. Other advantages include that of scalability and centralized management through smart grid integration and cloud-based solutions: all coming with the promise of a quantum revolution in the domain, probed further by interoperability of standards in realization and assimilation in the power system landscape. Such a development is being embraced further to make the IDMT protection schemes more robust, adaptive, and efficient in view of contributing from the standpoint of continued enhancement of reliability and resilience of the power system.

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LIST OF PUBLICATION

Sr. No	PAPER TITLE	PUBLICATION	SCOPUS	AUTHORS	STATUS
1.	Simulation-Based Evaluation of IDMT Characteristics for Overcurrent Relay Protection	IEEE - 4th International Conference for Intelligent Technologies (CONIT), 2024	**YES**	1. Utkarsh Rishu 2. Dr. Anup Kumar Mandpura 3. Prof. Rohan Pillai	**Accepted**