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Title:

Design and Implementation of Laboratory Experiments of Protective Relays for Master Program

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Abstract

Power systems are fundamental to modern society, providing the energy necessary for everyday activities and industrial operations. The reliability and stability of these systems are paramount, requiring robust protection mechanisms to safeguard against various faults, including short circuits, overloads, and earthing faults. Protective relays play a crucial role in detecting these faults and isolating affected parts of the system to prevent widespread outages and equipment damage.

This project begins by establishing the foundational principles of electrical system protection. It emphasizes the importance of safeguarding power networks and explores the complexities of different types of faults, with a particular focus on earthing faults. Understanding these principles is essential for appreciating the critical functions of protective relays.

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Introduction

In the rapidly evolving field of electrical engineering, protective relays play a crucial role in ensuring the stability, safety, and reliability of power systems. These essential devices detect abnormal conditions and initiate control actions to isolate faults, preventing equipment damage and maintaining system integrity. This memoir project, titled "Design and Implementation Laboratory Papers of Protective Relays for Master Students," provides a comprehensive and practical guide for graduate-level students embarking on the study and application of protective relay systems.

The primary objective of this project is to bridge the gap between theoretical knowledge and practical skills through meticulously crafted laboratory experiments and papers. The project is structured into three core chapters, each focusing on a different aspect of power system protection and relay technology.

Chapter One provides an in-depth exploration of electrical power system protection, covering the fundamental principles and concepts necessary for understanding the importance of protection systems in maintaining the stability and reliability of power grids. It delves into the various types of faults that can occur in power systems, the mechanisms for detecting these faults, and the strategies for mitigating their impacts. This chapter sets the stage for more advanced studies by providing a solid theoretical foundation in power system protection.

Chapter Two focuses on protective relays, the critical components at the heart of power system protection. It discusses the various types of protective relays, their operating principles, and their roles in safeguarding electrical systems. Topics include the evolution of protective relays from electromechanical to digital devices, the functions of different types of relays, and the criteria for selecting appropriate relays for specific applications. This comprehensive overview equips students with the knowledge needed to understand the functionality and importance of protective relays in power systems.

Chapter Three provides detailed information about the specific types of relays used in the laboratory experiments conducted as part of this project. The chapter covers thermal relays, differential relays, and numerical relays, explaining their unique characteristics, applications, and advantages. Each type of relay is discussed in the context of its practical use in protecting electrical systems. This chapter also includes the design and implementation of various experiments that demonstrate the operation and effectiveness of these relays in real-world scenarios.

Following the detailed discussion of different types of relays, this section presents the experiments conducted to test and analyze their performance. Each experiment is described in detail, including the setup, procedure, and observed results. These experiments are designed to provide students with hands-on experience in configuring and testing protective relays, reinforcing the theoretical knowledge gained in the earlier chapters. The results of these experiments are analyzed and discussed, providing insights into the practical applications and limitations of different types of relays.

Through this project, master students will not only acquire technical knowledge but also develop essential skills such as critical thinking, problem-solving, and effective communication. The laboratory papers serve as a valuable resource, providing a step-by-step approach to mastering the design and implementation of protective relays. By completing these laboratory experiments, students will be well-prepared to contribute effectively to the field of power system protection, addressing the challenges of modern power systems and enhancing their reliability and resilience.

This comprehensive guide aims to equip master students with the knowledge and skills necessary to excel in the field of protective relays, ultimately preparing them for successful careers in electrical engineering. By combining theoretical understanding with practical experience, this memoir project ensures that students are capable of designing, implementing, and maintaining protective relay systems that meet the demands of contemporary power systems.

CHAPTER 1

ELECTRICAL SYSTEM PROTECTION

1.1. Introduction to Electrical System Protection

The use of protective devices in an electrical system is essential to ensure minimum interruptions of service caused by faults. These protective devices detect specific fault conditions and respond by isolating the affected circuit or equipment from the rest of the system. The protective devices are designed to respond to a specific input and to develop an output that will effect rapid interruption of the electrical circuit associated with the input. The response time of a protective device is very short, usually in the milliseconds range. An overcurrent relay, for example, may trip an associated circuit breaker in a time period as short as 8 to 12 milliseconds. A fault condition that develops in an electrical power system may have several associated fault effects. It is the selective operation of the protection devices that isolates the faulted circuit. [1]

The primary objective in the design of an electrical power system is to ensure electrical continuity, that is, to supply electrical energy to the various circuits in a plant with the required degree of reliability. To achieve this, means must be provided to prevent damage from abnormal system conditions, such as short circuits, overloads, mechanical faults, lightning strikes, and other similar problems. These means take the form of protective devices and systems installed at various points in the power system. [2]

1.2. Importance of Electrical System Protection

Electric power system protection is primarily concerned with the generation of relay operations that initiate circuit breaker trips to de-energize faulted parts of the system and isolate them from the rest of the system. Generally, relays respond to specific changes in electrical quantities associated with power system faults or abnormal conditions, and initiate circuit breaker trips to disconnect the affected part of the system.

Relaying operations usually initiate breaker trips to isolate faulted parts of the system when damage is about to occur to components which make performance of the system impossible, or if the continued presence of voltage at the fault location represents a danger to personnel in the vicinity. The ultimate purpose of system protection is to minimize the affected area and the duration of interruptions of service supporting life and property. This requires sensitivity and reliability of protection systems in operating only for genuine system faults while avoiding unnecessary operations for non-dangerous disturbances. [3]

1.3 Fundamental Concepts

Faults in electricall; systems are mainly of two types: short circuits and earth faults. Short circuits are connections of very low impedance between the conductors of the system - the phase conductors in the case of a single-phase or polyphase circuit - while earth faults are connections of low impedance between one of the conductors and the general mass of earth. In the case of an earth fault, current flows from the faulty conductor into the ground. Short circuits and earth faults can occur in electrical systems for several reasons, the most important of which are faults in the insulation of electrical equipment and conductors and human errors during installation, maintenance, and testing of electrical equipment. [3]

Protection of electrical equipment is about safe isolation of faulty equipment from the rest of the electrical system and minimizing damage to the equipment and the system that can result from the flow of excessive fault current. These tasks must be accomplished very quickly - usually within a few milliseconds - to prevent accidents and limit the extent of damage. The devices that carry out these protective tasks are known as protection devices. Protection devices can be associated with a specific piece of equipment to provide protection for that equipment or can be installed in the system's wiring to protect an entire system or part of a system. Specific equipment protection is usually provided by overcurrent devices in combination with some type of fault-sensing device, while more general system protection is provided by devices that can sense various system faults such as overvoltages, undervoltages, or reverse power situations in addition to overcurrents. [1]

1.3.1Types of Electrical Faults

Adequate protection for faults is therefore needed to limit the effects of faults. Overcurrent protection responds to the current associated with the fault. For example, if a short circuit fault occurs, the current is limited only by the impedance between the source and the fault. The short circuit protection operates and opens the circuit breaker (or isolates the fuse) before the fault current can reach a value that causes heavy damage to power system equipment. [1]

Several types of faults may occur in an electrical system. An open circuit fault occurs when a wire is broken, resulting in an interruption of the circuit. A short circuit fault occurs when the insulation between conductors is lost or the conductor is melted, resulting in a low resistance connection between the conductors. A ground fault occurs when one of the power conductors inadvertently makes contact with ground, resulting in a flow of current from the power system into the ground. This can happen if the conductor is installed in a metallic conduit, the insulation degrades, and the conductor contacts the conduit. Ground faults also occur in power equipment when insulation breaks down between live parts and the equipment enclosure, which is supposed to be at ground potential. The relative severity of faults in a power system is usually assessed in terms of the magnitude of the fault current, with the understanding that a large fault current can damage equipment, overheat conductors, and present a shock hazard. [4]

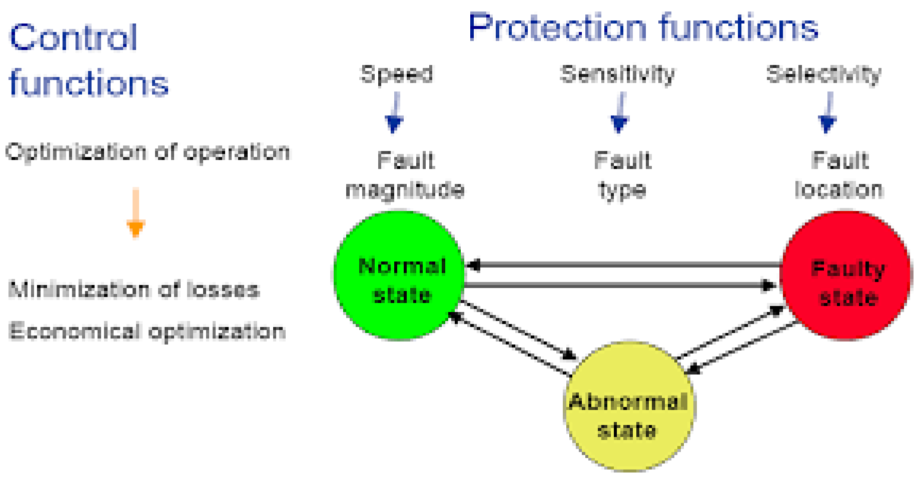


Figure 1.1: fault in electrical system.

1.3.2Basic Protection Principles

The most basic protection principle is that of overcurrent protection. Overcurrent protection is designed to operate when the current reaches a value that is greater than the rated current for the electrical wiring or for the equipment connected to the wiring. It will also operate if a short circuit occurs between the conductors. It is the most common type of fault in electrical distribution systems and is the major reason for protection. Overcurrent protection is provided for two general reasons. First, it is a protection designed to prevent damage to conductors and electrical equipment due to overloads. Second, it is a system protection designed to clear a fault quickly and remove the affected equipment from service. Upon removal of service, the faulted equipment can be either repaired or replaced. [4]

Each interconnected power system requires protection against possible electrical and mechanical failures due to internal and external causes. The basic protection principle is to isolate faulted parts from the rest of the electrical system as quickly as possible. If this is done, motors, generators, transformers, and other critical equipment will be protected from being damaged. There are many basic protection principles, but the most essential include overcurrent protection, differential protection, and distance protection. These three protection principles are found in most switchgear protective devices. Other more advanced protective principles are restricted earth fault or ground fault protection, directional protection, under-voltage protection, and under-frequency protection, to name just a few. These are typically found in more sophisticated solid-state protective devices. [4]

1.4 Components of Electrical Protection Systems

Circuit breakers are the most common protective devices in power distribution and transmission networks. Other protective devices include fuses and protective relays. A fuse is a simple overcurrent protection device and has no provision to open from its closed position without replacing it. Fuses are often used in distribution circuits and control circuits. Protective relays are designed to sense the fault and send a trip signal to the circuit breaker to open the contacts. Unlike fuses, relays can be reset and reused. For higher electrical systems, a combination of several relays is used to provide protective functions. The main components of an electrical protection system include circuit breakers, fuses, relays, and current transformers. [4]

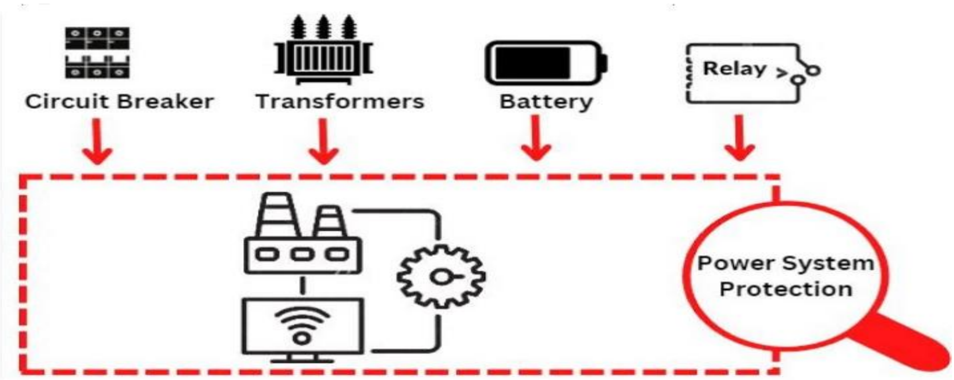


Figure1.2: Some of power system protection components.

1.4.1 Circuit Breakers

4.1.1 Introduction

At some time during our life, whether in our own home, in an office block, in an industrial plant, or in a substation, we will have heard the unmistakable sound made by a high-voltage circuit breaker when it 'opens' or 'closes'. In the case of the high-voltage circuit breaker, this operation takes place in a fraction of a second and in so doing, it either connects or disconnects a very large amount of electrical power. This power could be the source of light and heat in a residence, or it could be feeding a large industrial plant, creating the risk of considerable financial loss should the supply be interrupted for more than a very short time. Circuit breakers are employed to perform two functions, either the switching of an electrical circuit when no current is flowing, a feat performed by the isolating switch, or the switching of the circuit while carrying current. Over the years, circuit breakers have evolved to perform the current-switching function at all voltage levels. [4]

4.1.2 Isolator (Disconnecting Switch)

The isolating switch, or more appropriately named, the isolator, is used to provide a visible and reliable means of disconnecting the equipment from the electrical supply for servicing, maintenance, and repair. When the isolator is in the open position, the equipment is de-energized. The isolator should be locked in the open position by personnel performing any work on the equipment, to prevent an operator elsewhere closing the isolator and inadvertently re-energizing the equipment while work is in progress. [4]

Figure1.3 : Different types of circuit breaker

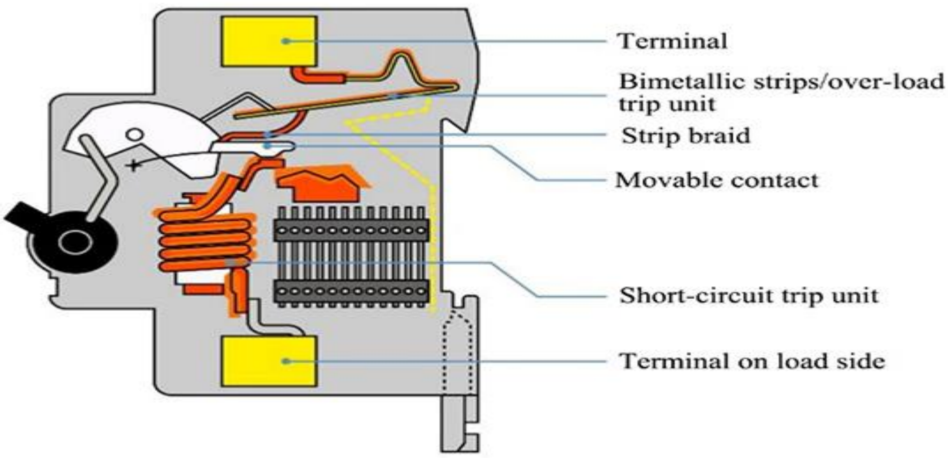


Figure 1.4: circuit breaker’s components

1.4.2Relays

4.2.1Introduction

Relays are electrical devices that utilize electric power for their operation. These are used to open or close the contacts from a remote place with the use of an electric control signal. The power to operate the contacts of a relay is provided by the control signal itself. The control signals are also electrical but can be obtained from the non-electrical signals with the help of sensors. Control of the working of loads with heavy currents or voltages like electrical motors, transformers, or heating devices is, therefore, made possible with the help of a relay. [5]

4.2.2Relay Application

There are some important basics to remember in the application of relays. Every relay employed in the power system must have a definite, specific function that is intended to avert a particular type of fault. A relay must not only initiate the protective function, but also prevent the interruption of service when a permanent fault occurs. Therefore, it must be highly selective in its operation and respond only to those faults for which its protective function has been assigned. Probability of operation is as important as sensitivity. For example, in feeder protection, a relay should operate rapidly for high fault currents and should not operate for load currents. It should also show a certain amount of time delay for fault clearing of fault currents, just to discriminate in favor of other parallel feeders. Optimal operation would involve the fault current clearing capabilities of the CB. We speak of "relaying coordinated with CB" to achieve this objective. [4]

1.4.3Fuses

Fuses are the simplest, least expensive, and provide the oldest method of overcurrent protection. They consist of a short piece of wire or thin strip of metal designed to carry normal current without deterioration but to melt and open the circuit if excessive current passes through. The melting time of a fuse element is a function of the square of the current flowing through it and is inversely proportional to the magnitude of the current. Fuses have the advantage, from a protection coordination point of view, of being inherently fast clearing. They are easily coordinated with other overcurrent protective devices to provide selectivity in clearing only the circuit portion of the device immediately ahead of the fault, thus selectively isolating the faulted circuit. [4]

Fuses have some significant disadvantages, however. With few exceptions, they are not reloadable. Any attempt to replace a blown fuse by a new one may result in loss of production. Fuses require frequent testing to ensure that the circuit is operable. Because fuse blowing is attributed to their melting due to excessive current flow, they are not considered very reliable as protective devices. Furthermore, fuses are notorious for their lack of discrimination. It is difficult, especially in industrial systems, to ensure that feeder circuits always have sufficient load current to prevent blowing of protection fuses that are maintained down the line despite presence of short circuits. [4]

Figure 1.5: fuses types

1.5 Types of Protection Schemes (In power system)

These levels of protections are generally achieved by implementing a variety of protection and relaying schemes, thereby allowing malfunctions to be cleared as quickly as possible while also maintaining the power systems' integrity. [4]

Most power networks implement a very wide variety of protection schemes because power systems have many different components. In fact, in addition to the types of protection identified above, many other protective functions must be produced to protect the power systems' constituents. However, the protection of the power system itself also requires further considerations because the system's behavior during fault conditions is as important as the protection of its components. Several different levels of protection can be identified in a power system:

(1) Busbar protection that is used to protect the common busbar of a station or a substation.

(2) Transformer protection that is applied to protect transformers from faults. In such schemes, both primary and secondary faults are considered, and different schemes are

applied for each type.
(3) Feeder protection that is used to protect long and short electrical feeders from faults. For long electrical feeders, pilot wires are employed to transmit tripping signals between relays, while for short feeders, overcurrent and directional relays can be used.
(4) Motor protection that is used to protect motors from short circuits, overloads, and single-phasing.
(5) Generator protection that is applied to protect generators from various types of faults. Generators have to be protected from internal faults, loss of prime mover, loss of synchronism, and overloads. Different types of relays are used for these different protection functions.
(6) Transmission line protection that is used to protect transmission lines from various types of faults, and is usually realized using distance relays. [4]

Protection schemes are selected and applied to provide adequate protective functions for all types of power system components. The principal protective schemes used in electrical networks are:

1.5.1Overcurrent Protection

Overcurrent protective devices associated with adjustable frequency drives and solid-state motor controllers must be properly selected for the application. Fast-acting fuses must be used to adequately protect the drive or controller. Other fuses or circuit breakers in the circuit may not provide adequate protection for the drive or controller since these devices may not operate quickly enough to prevent damage when an overcurrent condition exists. The drive or controller must also have its internal protection enabled for all applicable conditions. This often requires that the drive or controller be properly programmed to enable its internal thermal overload protection model for the type of motor driving and the application. The drive or controller must also be properly installed. [4]

Many types of devices are used to provide protection against excessive currents. These protective devices generally function to open one or more electrical circuits when an overcurrent condition exists. Overcurrent conditions are generally categorized as either overloads or faults. An overload condition exists when a load draws excessive current for an abnormal length of time. Fault conditions exist when a power conductor inadvertently comes in contact with ground or another conductor of a different phase.

Fault currents are generally several times larger than the normal full load currents. It is essential that some form of overcurrent protection be provided with all electrical circuits, to prevent excessive damage due to heat generated by the flow of large amounts of current. [4]

1.5.2 Differential Protection

In the case of circulating current differential protection used commonly for transformers, coils are connected in the secondary circuit on opposite sides of the relay. When the relay operates, the secondary current of the transformer does not flow through the coils of the relay, which effectively protects the relay from overloads. The relay must, however, be properly supervised, which commonly involves sending a signal from the primary side of the transformer. Various checks have to be carried out to ensure the integrity of the differential protection scheme. [4]

Differential Protection. Two types of differential protection are in common use. One is current differential or simply pilot-wire protection, and the other is percentage differential or circulating current protection. This second method is commonly used for transformer protection. Differential current protection is favored for the protection of very long transmission lines. Busbar protection is also very often employed by differential current relays. Both percentage differential and current differential relay schemes operate on the principle of comparing the current entering a circuit with the current leaving, or with the current at another point in the same circuit. [4]

1.5.3 Distance Protection

Distance protection was originally electro-mechanical in operation, and with these relays, very little time delays could be tolerated for sensitivity settings. As a consequence, many transmission lines have operation envelopes that insert capacitors at quite short distances from the receiving end. Upon fault occurrence, the capacitors present heavy charging currents and as a result, the line relay sensitivity is reduced. In the absence of a fault, the transmission of a heavy current charging signal to the line protection relay now entails a non-trivial relay operating time, and selective tripping of the more remote line section is more likely. The problem is, however, exacerbated by the fact that the faulted line is no longer protecting the relay setting points, and that malicious attacks may exploit this vulnerability to trip the line by injecting a signal from the capacitor installed for the power-factor-correction function. [4]

Distance protection is one of the most important developments in the protection area and is widely used for the protection of transmission lines. The unique advantage of this scheme is that it is able not only to protect the equipment but also to clear line faults without unnecessary tripping of healthy sections. In other words, it is more selective. This protection works on the principle that the apparent impedance measured from the relays to the point of fault generally changes when a fault occurs. The protection is normally provided at both ends of the protected line and is called bi-directional protection. It can, however, be provided at one end only, operating in one direction, called uni-directional (or one zone) protection. [4]

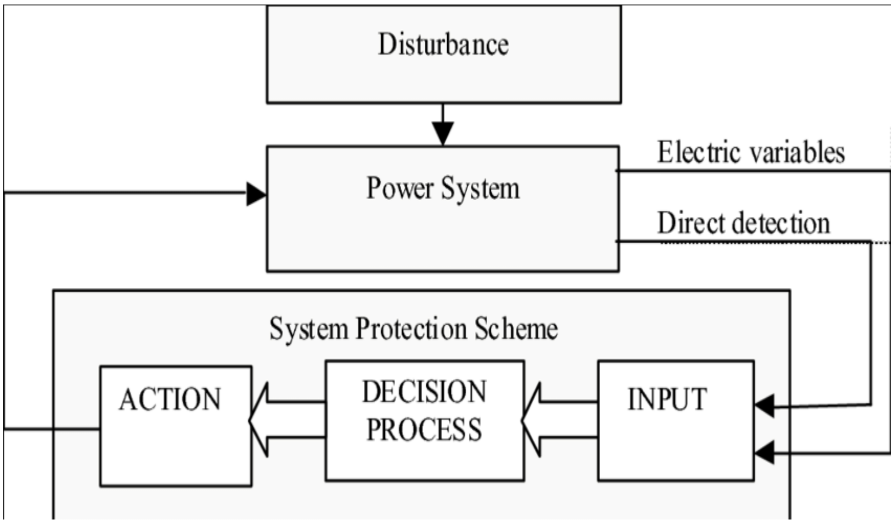


Figure1.6: General structure of a system protection schemes.

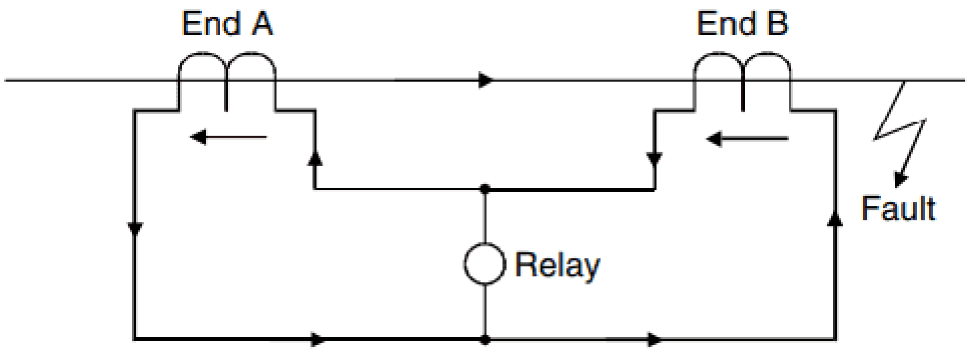


Figure 1.7: protection scheme for electrical system protection using relay.

1.6Different Types of Earthing Systems

1.6.1Introduction to Earthing Systems

The earthing system must withstand discharge phenomena such as lightning, which are statistical in nature and can deposit a number of coulombs on the earth at a spark front of the order of milliseconds. With the introduction of independent power systems and metal running equipment, substantial lightning can be expected to appear within the electrical earthing systems. Regarding equipment earthing, it must be pointed out that sometimes they can be a part of device insulation monitoring and fault monitoring systems and contribute to the necessary reliability demands. Sister systems of telecommunication networks can put the essential operational equipment very near to the electrical earthing system and require the control of touch and transferred potentials to the switching equipment. [4]

Electrical earthing is defined as grounding, which is done to divert unwanted or unnecessary current directly to the earth instead of passing through machines and instruments. The different types of earthing systems generally followed are pipe or rod earthing, plate earthing or use of earth electrode, strip or wire earthing, and other types of earthing systems. Electrical earthing has various applications in power supply and systems, including computation of current and potential distribution in layered soil, performance of piping and earthing system in substations, risk factors associated with earthing systems, surveys of substation grounding systems, measures to improve the quality and reliability of earthing systems in substations, retrofitting and reconstruction of earthing systems, computer-aided analysis of overhead line grounding, lightning protection, and computer-aided simulation of grounding systems. [4]

1.6.2 Importance of Earthing in Electrical Systems

In practical situations, an earthing system draws a current closer to line frequency, which might travel through the earth. This is possible in an earthing system due to the existence of stray capacitances and capacitive charging. The stray capacitance is an inherent quantity that comes along with any two conductors that are separated by an insulator; the presence of an earthing system makes the system line-fault resistant and the purpose of the system is obtained. The earthing of a system, thus, helps to minimize the damage to a system. [4]

Earthing or grounding of an electrical system is very important, as it ensures the safety of a person and the protection of the equipment operated on the system. The earth is considered as the infinite sink for an electrical system, where current is drawn or sunk without any opposition. An electricity system is rarely at zero magnitude, and over a period of time, it may become unsafe. Since there is always a chance of a human error in a system, it is necessary to take care of the fault by providing an alternative path for the current. The main reason for the existence of an earthing system is to absorb these hazardous currents that are liable to damage the system and people who come in contact with it. Shocks that cannot cause severe damage to the person can lead to serious body damage as well as long-term injury. To prevent any possible shock hazards from unknown or unidentified currents, it is necessary to have an effective earthing design. All these safety concerns can be mitigated by the proper engineering design of the earthing system. [4]

1.6.3 Earthing SystemsTypes

Earthing-Grid:

All non-current carrying metallic parts connected together then to earth using copper bars, strips, or a conductor. This is mostly used in substations, buildings, large plants, HV equipment, etc.

The resistance value is directly proportional to grid length and inversely proportional to the width of the grid, which should be maximum. Depth should be large depending on ion movement towards soil to dissipate the fault currents effectively. Grids are sometimes covered with limestone to detect saltwater movement towards the earth grid. [4]

Solid-Earthing:

Single rod earth connected to the equipment. This is mostly used in telecommunication for the reliable and conservative behavior of small loads. It is not preferable for larger systems or in highly earthed systems. Care shall be taken with about toe and step voltage concern. Its impedance varies as per soil structure and composition with temperature, moisture, and humidity. [4]

To cater to the requirements of the various electrical systems, there is a wide range of earthing systems that can be used. The selection of the earthing system will depend on accuracy and performance required for the various parameters like R, X, voltage, R-X ratio, continuous current, short time current, temporary current and default current. The common types of systems are:

6.3.1 TT System

A TT system is normally less expensive than a TN system for cases up to about 1000 KVA, especially if the neutral earth-fault protection for a TN system is taken into account. For higher powers, a TT system can be a little more expensive due to the costs of investing in more efficient electrodes. The TT system has the advantage that the customer's life can continue without interruption in case of disconnection of the neutral, and the electrician's work is made easier because it does not need to keep symmetry when substituting lamps and switches. Indeed, the electrician can be less qualified as he does not need to concern himself with correct neutral connections. Finally, since the supply lines to the customers are shorter in a TT system, there are fewer losses in case of an earth fault and the voltage variations (with lightning) will be lower. [4]

In the TT system, a separate electrode is provided for each electrical installation for its earthing. With an earth electrode for each installation, there are no earth currents flowing as a result of other earth faults. There are reduced dangers in regard to indirect contact and the problems associated with inductive interferences and in-circuit monitoring. A TT system is properly designed; it is as safe and creates as few problems as a TN or IT system. However, the requirement of separate electrodes for each installation is a potential possibility of reduced safety due to mistakes – it is human nature to cut corners. A single building like a factory might have 2000 electric points, 2000 separate earth electrodes for all these installations can pose a serious problem and the results can be dangerous. [4]

6.3.2. TN System

A typical TN system is shown in Fig. 2.1. This type of system is used in countries such as the United States of America, Canada, Mexico, Brazil, Japan, and some regions of India. Be aware that, in the example shown in Fig. 2.1, the connections at the customer are interchanged, so a TN-S system is shown. The earth cable may be interrupted at the meter, this interruption not violating sectorial standards. [4]

TN systems may be implemented in three commonly used configurations. The T-T system, in which the star-point of the transformer is connected to ground using a rod or pipe electrode at the transformer, the T-N system, in which, in addition, the exposed conductive parts of the transformer and the installation are earthed, and the N system where consumer units have a protective conductor that is also the neutral conductor. [4]

TN systems have a direct electrical connection between earth and the low-voltage consumer's installation, but the remainder of the system is isolated. These systems have either a direct or very low-interrupt current path to ground. The purpose of this grounded or earth of the low voltage side is to protect humans and animals from electric shock, to protect the insulation of the electrical installation, and to ensure a stable voltage (via the consumer's installation). [4]

6.3.3. IT System

Normally grounding is done either through a grounding transformer or by a grounding resistance. The grounding resistance offered should be less than 10 ohms so that the earth fault current flows and the protective relays operate to detect the respective fault. The whole of the earth fault current flows through the grounding, whether it is a resistance or a grounding transformer. In the case of a resistance, by Ohm's law, If is the current flowing and R is the resistance, the voltage drop will be If taking the current value from equation, If = V/R. Also, in the case of a transformer, the voltage and the current are inter-related as per the relation Z = V/I so that I = V/Z. The neutral voltage of the transformer is zero so that the value of V is minimum and Z consists of only magnitudes. This is the insight of an earth fault in the system. [4]

The IT system stands for Impedance Grounding Transformer system. In order to understand the IT system properly, the meaning of the term impedance grounding transformer is understood first. The normal distribution system is normally grounded. It is done to have a reference for the system. The system is thus a balanced system. In case any one of the three phases becomes faulty and in turn becomes ungrounded, the entire system becomes unbalanced. If proper protection does not exist other than a fault occurring on the phase, the number of other phase faults also will take place. This can, in turn, lead to serious thermal damage leading it to catch fire. [4]

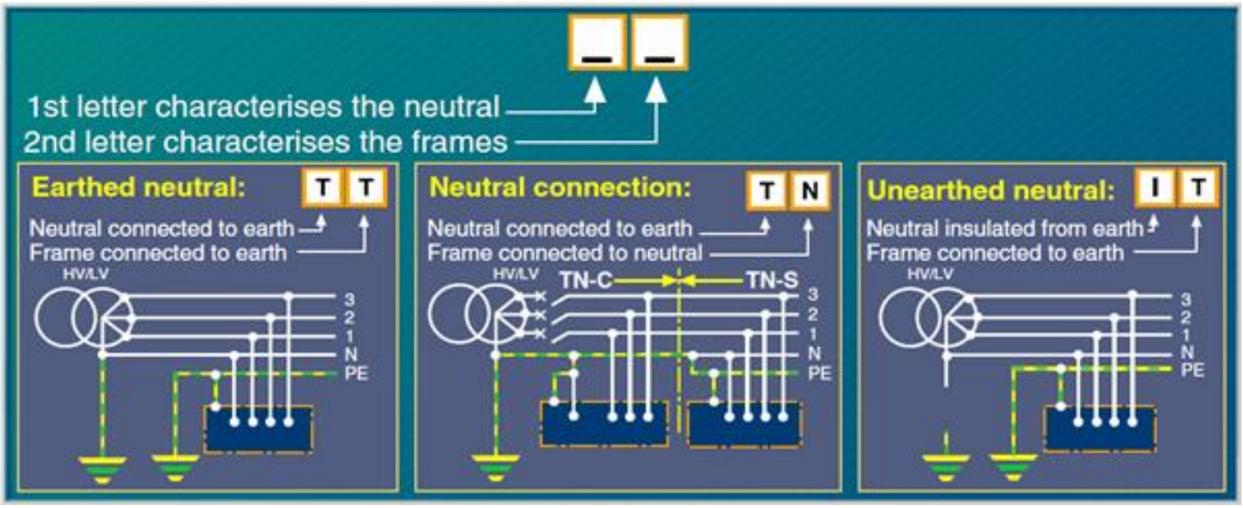


Figure 1.8:different types of earthing system.

1.6.4Comparison of Earthing Systems

The subject of electrical safety in design, operation and maintenance has always been an important subject because personnel working near electrical equipment are exposed to the risk of injury or death. Everyone knows, despite progress in terms of protection against accidents and development of safety standards, the serious consequences of electrical accidents. The purpose of earthing an AC power supply system is to provide a secure point on the system that the earth can, in all possible circumstances, including a failure in the system, touch without side effect. It also aims to restrict the voltage and all associated phenomena between that point and the extraneous-conductive-part to a value that does not risk the safety of human beings, animals, and property with a high probability, and allows the correct functioning of electrical equipment. In other words, the aim of the earthing is to allow current to take a safe route to earth should a fault occur which establishes, or could establish, a current path from any accessible object (appliance enclosure) to the earth. [4]

The different types of earthing systems that are used in practice are compared based on different parameters. It is an important issue to compare the performance of such systems in terms of safety and reliability. The criteria for the comparison includes the operating earth resistance value, required conductor size for implementation, earthing conductor length and type, touch voltage during a short circuit, economic aspects, structure of the system etc. Besides these, the evaluation whether a unique system or a different one can satisfy the safety limits depends on national code standards. Countries have different practices according to national standards. The comparison is very useful for understanding, evaluating and selecting the type of earthing that is to be applied. Therefore, the comparison may provide a valuable tool to decide the best solution for the appropriate application or project with advantages and disadvantages for each earthing implementation. [4]

Table 1.1gives the difference between different types of earthing systems.

Table 1.1: the difference between earthing system types .

Parameter	TT	TN-S	TN-C	TN-C-S	IT
Definition	Both the source and the consumer's installation have their own earth connections.	Separate protective earth (PE) and neutral (N) conductors from the source to the consumer.	Combined PE and conductors throughout the system.	Combined PE and N conductors in part of the system separate in others.	Source is unearthed or earthed through a high impedance .
Safety risk	High loop impedance can cause higher voltages on equipment .	Risk of broken PE conductor causing unsafe conditions.	Risk of broken neutral conductor causing unsafe.	Similar to TN-C with additional complexity.	Double faults can cause over-voltage requires specialized protection.
Instalation cost	Moderate	High	Low	Moderate	High
Continuity of service	Low (faults require disconnection)	High	High	High	High
Common use cases	Residential installation in rural ereas.	Commercial and industrial installations	Rarely used due to safety concerns.	Common in residential andcommercial buildings.	Specialized industrial and medical installations.

1.6.5Advantages and Disadvantages of earthing system types

Table 1.2: the ADVANTAGES and DISADVANTAGES of each earthing system type

Parameter	TT	TN-C	TN-S	TN-C-S	IT
Advantages	Simple installation	High reliability	Low installation cost	Combines benefits of TN-S and TN-C	High continuity of service
	Independent earth connections	Low fault loop impedance	Reduced conductor cost	Effective protection against faults	Best for cricial applications
	Easy to locate faults	Effective fault detection	Simplified wiring	Lower EMI problem than TN-C	Minimal touch voltage risks
	Suitable for areas with poor grounding	Safe for sensitive equipement	Economical for short distances	Widely used in residentiel setup	High safety in fault conditions
Disadvantages	Higher earth fault loop impedance	Higher installation cost	Risk of neutral and earth conductor	Complexity inimplementation	Complex and expensive installation
	Requires regular maintenance	Requires separate PE and N conductors	Combined PE and N can cause safety issues	Risk of broken neutral conductors	Requires instalation monitoring devices
	Prone thehight voltages	More susceptible to EMI than TT	Note recommended for EMC sensitive areas	Potential issues in case of neutral break	Requiers specialized fault detection

CHAPTER 2

PROTECTIVE RELAYS

2.1 Introduction to Protective Relays

Protective relays are the essential tools of the protection engineer in the field of electrical power systems. These devices are the prime interface between the control and protective equipment used in power systems. They detect fault conditions in the power system, generate a trip signal to circuit breakers, and simultaneously can be used for control, monitoring, testing, and data collection functions in the power system. It is crucial that these devices are accurately and reliably operated since power systems contain costly and essential equipment such as synchronous generators, transformers, transmission lines, and motors. [6]

2.1.1Definition and Purpose of Protective Relays

Numerous types of relays are used in power systems as main protection. The type to be used for a particular purpose is selected depending on operating parameters such as short circuit currents, temperature rise characteristics, and time-current characteristics. In short, a relay is a control device which, in service, supervises the system, while at the same time it is always ready, in case of an impending or actual failure, to initiate the protective operation that will interrupt the supply before the fault threatens the integrity of the installation. [1] [5]

The basic purpose of protective relays is to supervise the electrical system and to initiate disconnecting devices or circuit breakers, which isolate or disconnect circuit parts in the event of a fault. As an overcurrent relay informs that its protection system and devices are guarding the circuits, it can also be called the bus protection relay. A relay that provides protection for the whole power station is a main protection relay. In a power system that is broken down in terms of divisions, plants, main busses, Geneva buses, and station buses, relays that serve this special purpose are called bus protection relays. [1] [5]

2.1.2 Historical Development of Protective Relays

The origin and evolution of Protective Relays comes from the eleventh century with the use of primitive lightning conductors. The credit goes to Stephenson in 1961 for the introduction of measuring relays to sense the current through an iron sample and close a circuit to send a warning signal. This later led to the introduction of the Electromagnetic Comparator of F.B. Espies. S.Z. de Ferranti and Willans introduced a high-speed overcurrent relay for protecting turboalternator armature up to a capacity of 150 KW. Pneumatic differential relays were introduced by C.P. Steinmetz. M. Dubanton brought out the first numerical relay in 1925. This development was closely associated with the 50 Hz power of the public network. Signal processing was introduced due to the growing computational requirements of algorithms in both power system software; widespread deployment of fast processors and communication facilities has made possible a new generation of numerical relays. These relays can handle numerous technical functions and thus ensure efficient and multipurpose protections for the power system components. [7]

The problem of protection of generators, lines, and transformers in multi-generator, multi-area and interconnected power systems has always been a major consideration. This problem has been complex and has increased due to growth and expansion of these systems. This has, however, led to a development of new ideas and concepts. The increasing cost of power system components as well as the transmission of all higher power has increased the considerations given to the problem of system protection. Since the early days, where electromechanical relays were used, there has been tremendous progress in the design as well as application of relays to fit the growing challenges. [1] [5]

2.2 Fundamentals of Protective Relaying

Any protective-relaying system functions on the basic principle that there is an associated relationship between some input quantity and the condition to be predicted or detected. Each complete protective circuit may be divided into two functional units:

sensing, forward-driving, and enough control equipment to operate a single tripping relay, together with its own current and voltage necessary to perform the work. The basic proper time-energy requirements must be satisfied: high speed, axial, symmetry, equilibrium, current grading, voltage grading, and damping. Upon detection of an abnormal operating condition, the protective system must proceed through a number of sequential steps before tripping a circuit breaker. [5]

A fundamental requirement for the successful application of protective relaying to power systems is the understanding of the basic principles involved. The objective of any electric system protection scheme should be to minimize damage resulting from failures at a minimum cost. The protection must be reliable, fast, economic, sensitive, selective, and it must provide complete coverage. The reliable protection of an electrical system against abnormal operating conditions requires the establishment of dependable alarm signals and/or the automatic and secure disconnection of the faulty section of the system. Protective relays are the alarm or operating element that performs this protective function. [5]

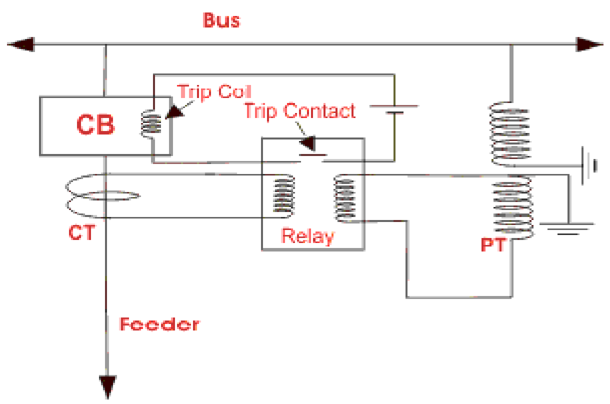


Figure 2.1: Basic connection diagram of protection relay.

2.2.1Basic Operating Principles

The relay output activates a tripping circuit for the associated circuit breaker(s). Non-speed-governing unit protection provides generator field failure back-up protection and generally activates the unit protection relay when the other relay schemes do not operate to protect the generator from overloads (generally large negative sequence currents) greater than the gas cooling limits regardless of the generator's load angle. These types of relays are often used for transmission-line protection and transformer winding fault protection (specifically for low-magnetizing-inrush demands). When air-core current transformers (CTs) sense the energy of the fault point, if the relay operates properly because of the relay input, they provide a quick response that reduces the amount of damage to equipment located close to the fault. Salary. Maintaining these protective devices in a state of readiness to operate is an important and crucial task. [8]

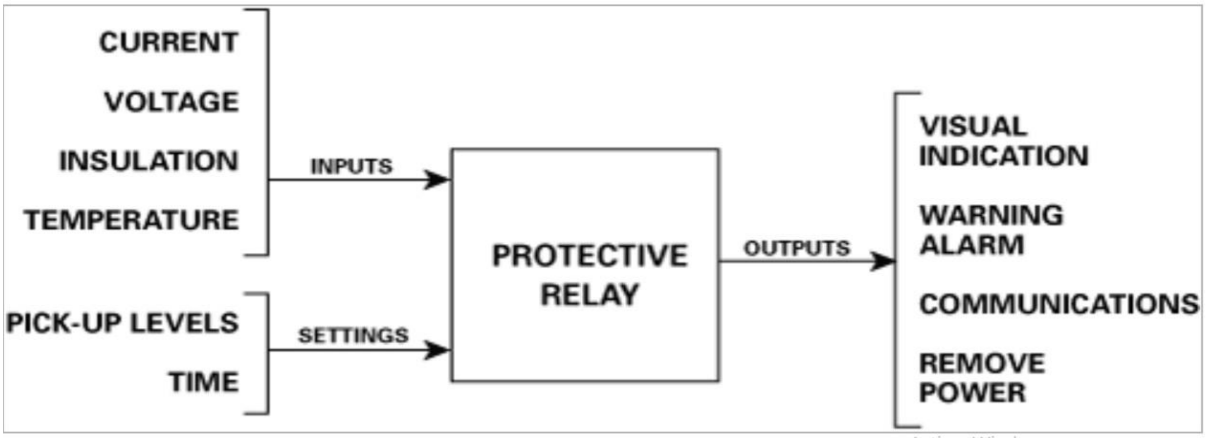


Figure 2.3: Basic operating principles of Protective relay.

2.2.2Types of Protective Relays

Relays in power system can be classified as follows depending upon the type of actuating quantities that is whether the relay operates depending upon current of voltage or both.

- Electrical relays
- Magnetic relays
- Electromagnetic relays
- Induction relays
- Impedance relays
- Resonant relays
- Directional relays
- Electromechanical relays
- Thermal relays
- Static relays
- Solid state relays

- Numerical relays
- Microprocessor based relays

The above mentioned relays may also be classified as attracted armature relays, induction relays, differential comparison relays, balanced beam relays and biased relays. There are also directional, distance, over current, definite time, inverse time, differential, rate of change of frequency, impedance, over voltage and under voltage, frequency, loss of synchronism, reverse power and other protective associated relays. [5]

The most important function of the protective relay is to detect a fault and discriminate between internal and external faults. The relay should initiate the appropriate action for the switching off of the faulty element from the rest power system. The protective relays are classified in different ways depending on the type of application. The relays in power systems based on functions are denoted as follows:

- Overcurrent protection relay
- Distance protection relay
- Restricted earth fault protection relay
- Directional overcurrent protection relay
- Differential protection relay
- Rate of rise of voltage protection relay
- Breaker failure protection relay

These functions are not provided usually by a single relay but they may consist of these functions in association with other electrical equipments or may be in single use of microprocessor based relays. [9]

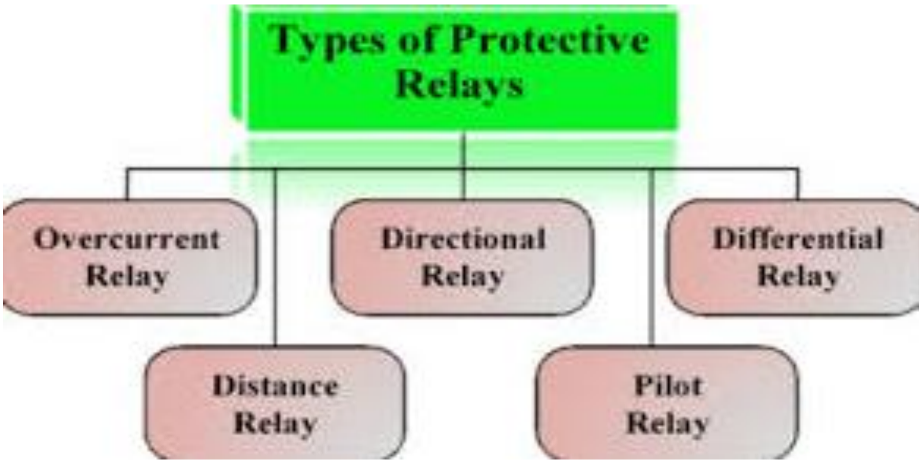


Figure 2.4: different types of protective relays

2.3Key Components of Protective Relays

Power system protection is a very important consideration in the electric power system, since the reliability of electrical generation, transmission, distribution, and utilization is very important to any modern society. Electric power systems operate with relatively narrow tolerances of voltage and frequency and can usually carry large amounts of power over long distances. To avoid widespread outages and system stability issues, the aim is to provide the highest availability of power with the most cost-effective practical protection methods. The protective relay is an intelligent electronic device that constantly monitors all these parameters and will automatically initiate a control action when any of the underlying parameters are outside of predetermined safe limits. [5]

2.3.1 Current Transformers

In a current transformer, a secondary short circuit is often used as a way to confirm whether it operates within its intended range, particularly if the counter is based on a current transformer. Through measuring the open-circuited voltage at the CT output terminals, saturation under fault conditions may be detected. As long as the connecting burden resistance still remains across their secondary winding, CTs are typically protected from damage by a short circuit by allowing them to endure a slight number of turns of secondary current without harm. [10]

2.3.2 Voltage Transformers

The voltage transformers serve to transform the relatively high voltage at the bus-bars to the safe voltage in the measuring elements of protective relays and meters. They also isolate the measuring elements from the high potential to which they would otherwise be permanently subjected. In addition, under relay operations, these voltages attain extremely high values, which are often unable to bring the relay into operation but may inadvertently damage them. The voltage transmittance characteristic must be envelope-shaped, as shown in Fig. of specially-grated paper, so that the relay can be made to operate irrespective of whether overvoltage is due to faulty relay, opening of circuits or ground asynchronous and incoming power operations. [11]

2.3.3 Relay Contacts

There are two sets of contacts in the digital relay. One set is called the input or control contacts. These contacts are used to supply energy to the relay. In a DC relay, the contacts may be wired directly from the battery terminals. In an AC relay, they must be connected to an AC source of the same voltage range as the sensing circuit's voltage range. These contacts are shown in the circuit of the monitor relay on Figure. The relay is de-energized and the energization current does not flow through the coil contacts. [12]

The other set of contacts is the coil contacts. These are connected to the relay coil and are operated simultaneously with the relay by the impedance relay's energy. When the relay picks up, the coil contacts short the coil terminals for slow speed dynamic response suppression. When the relay is in the release mode, the coil contacts are open. Before the relay contacts are considered to be true outputs of the relay, the relay should have a time setting delay that is intended to serve as a dynamic braking zone for the supervised breakers. The breaker is tripped if the impedance relay does not de-energize during the dynamic braking time for the monitored breaker. The contacts' input and output capability of the relay help to speed up the relay programming process. [13]

CHAPTER 3

Different Type of Relays Used in the Proposed Experiments

3.1Introduction

The principal task of the protection and automation systems in electrical systems consists of detecting, locating, and removing from service, in the shortest possible time, those elements affected by an abnormality. But if this task is essential, in modern installations protection is required to ensure the reliability and selectivity of electrical circuits, so that any anomaly results in the least inconvenience for the entire electrical system. [1]

The majority of interruptions are caused by a fault. Faults are mainly caused by insulation problems (pollution, moisture, root intrusion, partial discharges, corona phenomena, aging, thermal stress, or mechanical impact), commonly referred to as temperature faults. The first consequence of these failures is mechanical stress on the conductors and insulating elements in the short circuit or the reversible fault. These effects can lead to secondary mechanical damage, which is usually the cause of permanent damage to the electrical system, the obsolescence of key elements, and the fire hazard. This chapter provides a detailed overview of Thermal-Current Relays, Differential Relays, Numerical Relays, and protection. [5] [1]

3.1.1Importance

Protective relays may be defined as an intelligent switchgear. This device is not continuous in operation and does not carry current in normal time. It contains a detector which, in the presence of faults, sets an operating mechanism into motion that ultimately actuates the trip-coil of a circuit breaker to open the faulty line and hence isolates the rest of the system from the fault. The importance of the protective relay in power systems is so vital that any defect in the relay is not acceptable. It is equally required that the proper functioning of each relay is verified continuously. Each protective relay, in fact, must be truly selective in its operation, so that it is operated, i.e. initiates breaker trips, only for the passage of fault current resulting from a fault on the portion of the power network which it is designed to protect, while it remains insensitive to system fluctuations and to extraneous disturbances. [1] [6]

In addition, the response of the relay must be as rapid as possible since, during the presence of a fault and after the relay detects its existence, the power system is submitted to transient overcurrents or other conditions whose continuance for just fractions of a second may result in unacceptable damage to the system components and/or in dangerous conditions of network operation. On the other hand, the relay duration must be sufficiently long to allow discrimination of transient from permanent disturbances and prevent sensitive equipment from unnecessary de-energization. In many cases, the relay should initiate the maximum number of breaker operations consistent with system clearings and re-energizations. The necessity to operate quickly and selectively represents the relay sensitivity, while the requirement of operating only in the instance of a fault and refraining from operating whennon-damaging fluctuations or disturbances are present is called selectivity. The fusion of speed, sensitivity, and selectivity is a primary characteristic of each protective relay. [6] [1]

3.2 Types of Protective Relays used

Electromechanical relays (EMRs) are widely used in protection schemes. They operate by transforming electrical signals to mechanical outputs. EMRs are further categorized into thermal overcurrent relays, differential relays, and numerical relays.

3.3 Fundamentals of Thermal Relays

Thermal overload relays provide protection for electric motors against overheating. They are often connected in an "inverse time curve" where the trip time becomes shorter with increasing current. Usually, two different operating elements are used to activate the trip mechanism: an inverse time relay and a latch relay. These relays have different short-circuit withstand capabilities due to their independent design. This allows for a differentiation in trip time for different types of faults, improving the system's protection against short-circuit currents [14]

The trip characteristics of the thermal overload section of the relay are usually determined by the design of the thermal overload relay and the ratio of time constants. Overload relays are often designed for standard starter sizes, and the standard current settings can be adjusted over a certain range using a dial(s). In the past, thermal overload relays used extensive areas of bimetallic strips. More recently, a hybrid use of current for the magnet system and a part of the bimetallic strip for the thermal overload section has been used more frequently. This is usually done with magnet systems that are dependent on design for the trip mechanism. [15]

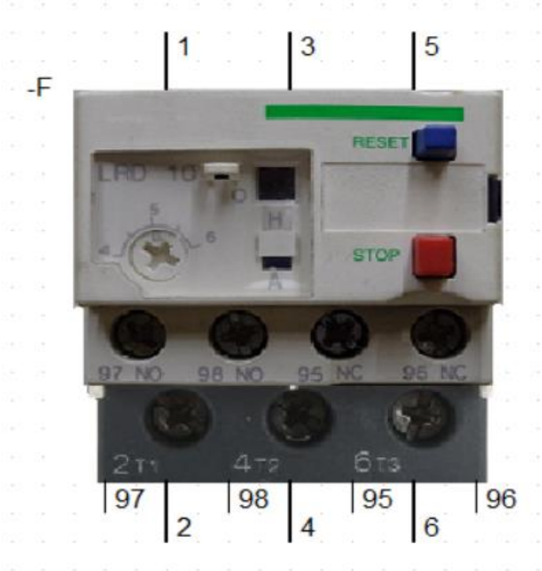


Figure 3.1: Thermal relay used in our experiments.

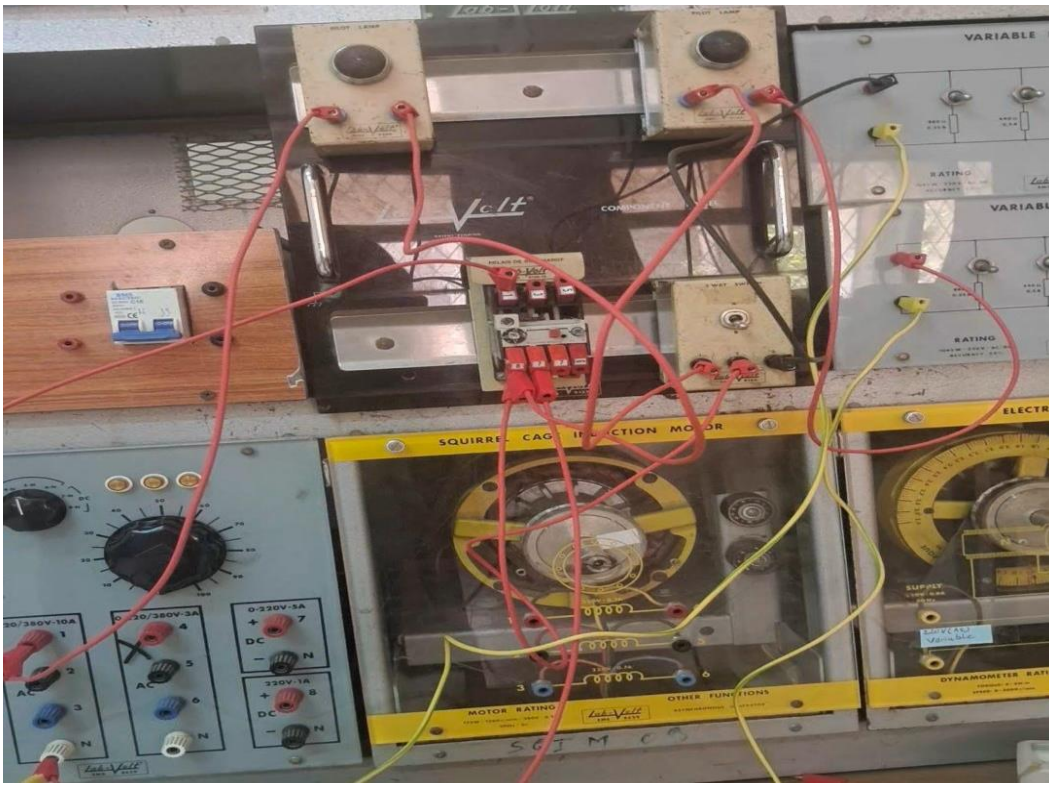


Figure 3.2: The experiment setup of thermal relay in IGEE lab.

3.3.1Operating Principle

In the thermal relay, the tripping solenoid is enabled by the expansion of a bimetal connected to a heating resistance. This resistance is fed by a current proportional to the current in the protected circuit. If the value of the current is equal to the thermal setting (rating plug or bimetallic element (EM)), the heating of the bimetal produces tripping, opening the protected circuit. The operational time is affected by the preliminary regulations of the thermal relay that depend essentially on the length of the regulator. Overload and short-circuit protection is obtained due to the fact that the heat produced by overcurrent is a function of the square of the current, assuming that the thermal setting is chosen according to the recommendations of regulation. [16]

When the current increases, the operating time of the thermal relay decreases significantly. The technique of protection that consists of choosing a nominal trip current at least equal to 1.6 times the value of the permissible current according to the cable factor is called inverse time characteristic. The largest operating times guarantee protection against high values of short-circuit currents. For other types of overloads, the protection cannot be less than the quick function that guarantees for high overcurrents, an almost instant tripping. Overcurrent protection is based on the specific characteristics of components subject to overcurrents. The nature of the protective function is characterized by the kinetic principle of these components. [17]

1. **Heat Generated by Current (Joule Heating):**

$$Q = I^2Rt \quad (3.1)$$

Where:

- Q is the heat energy generated (in joules).
- I is the current (in amperes).
- R is the resistance (in ohms).
- t is the time duration (in seconds).

2. **Temperature Rise:**

$$\Delta T = \frac{Q}{mc} \quad (3.2)$$

Where:

- ΔT is the temperature rise (in degrees Celsius).
- Q is the heat energy generated (in joules).
- m is the mass of the conductor (in kilograms).
- c is the specific heat capacity of the material (in joules per kilogram per degree Celsius).

3. **Thermal Time Constant:**

$$t = \frac{mc}{hA} \quad (3.3)$$

Where:

- τ is the thermal time constant (in seconds).
- m is the mass of the conductor (in kilograms).
- c is the specific heat capacity (in joules per kilogram per degree Celsius).
- h is the heat transfer coefficient (in watts per square meter per degree Celsius).
- A is the surface area (in square meters).

Table 3 : Thermal Relay Characteristics

Parameter	Typical Value	Description
Trip Time	5-20 seconds (at 600% load)	Time taken to trip under overload
Reset Time	60-300 seconds	Time taken to reset after tripping
Current Rating	Up to 1000A	Maximum current the relay can handle
Temperature Range	-20°C to 60°C	Operating temperature range
Thermal Time Constant	10-300 seconds	Time constant for temperature rise

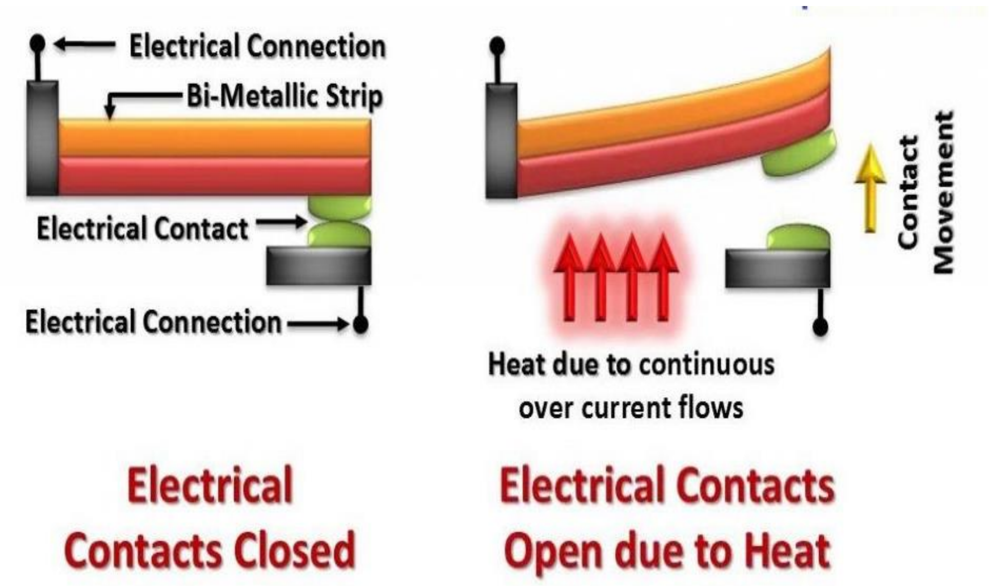


Figure 3.3: Thermal relay basic operating principle

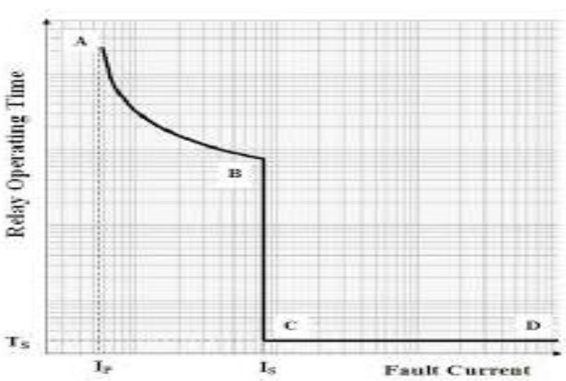


Figure3.4: Time versus current curve for thermal relay

3.2.2 Applications

The differential principle of protection is based on the simple application of Kirchhoff's current law in the protection of the equipment by ensuring that the algebraic sum of the currents entering and leaving at any given point is zero. This means that a balance is to be maintained between the currents flowing into the protected zone and those leaving it. As mentioned, this protection can be used for protection at any voltage level in virtually all types of electrical equipment such as generators, transformers, cables, busbars, etc. This type of protection is the direct consequence of spreading the installed protection devices evenly throughout the submitted equipment, as thoroughly as possible, analyzing the voltages through the submitted protection locations. The security criterion used in the implementation of this scheme is that the unprotected faults are those that occur inside the signals and conditioned by them. [18]

3.2.3 Advantages and Limitations

Overcurrent relays, in general, have many advantages which make them the best relay for a vast majority of system protection applications. These advantages include their relatively low cost, necessary dependability, speed of operation (which is extremely important for coordination purposes), inherent familiarity, the wide range of current-time characteristics available, simplicity of application and settings calculation, etc

However, there are inherent limitations of overcurrent relays for specific types of applications. For example, on long lines, overcurrent relays have difficulty in discriminating between normal load current and abnormal (incipiently fault) current values. For transformer primary fault protection, overcurrent relays must be selective against magnetizing inrush values on the order of 8-10 times the normal full load current values and must tolerate operation below typically high inrush multiples. For bus protection, the overcurrent relay has no directional characteristic to make a decision for fault current that cannot be read during concurrent oppositely offset fault conditions. Lastly, the zones of protection used in overcurrent relays are bounded, and certain connection conflicts may develop, as will be discussed.

.3.3 Fundamentals of Differential Relays

A brief treatment of some theoretical aspects of the differential relay is provided in this section. In contrast with the thermal and electromagnetic relays about which many older texts are available, the literature pertinent to this type of relay is relatively small. As a result, our prejudiced assertions are made in an attempt to fill this gap for the busy designer of electric power systems and engineers. The signal which the differential relay responds is the product of the fault current I and the resistance R in ohms. We treat I for our purposes as the primary quantity of interest whereas R is of secondary importance. Our discussion is outlined as follows: 1) The basic principles of operation are considered. 2) Various strategies for phase comparison are outlined and differences among them are illustrated. 3) Emphasis is put on the influence of fault resistance. 4) Models of the power system incorporating relay dynamics needed for computer studies are described.

The differential relay is based on the assumption that the difference of currents at the two ends of any protected section of the power system bus simple, coupled circuits carrying fault as well as power currents still yields a positive result. It can readily be demonstrated from Kirchhoff's law that ring or circular chains of in-phase connected simple resistive and inductive loads surrounding the current source on the power system bus essentially agree with this assumption. In conclusion, the fundamental function of the differential relay is to detect a sufficiently large electrical quantity difference on the monitored section of the power system during fault conditions in order to take appropriate protective steps.

3.3.1 Operating Principle

From the thermal relay, the minimum number of touches in moving contacts must be required when reaching the required temperature of operation. The cause of delayed trips is the excess power of the control circuit. The differential relay must have the highest requirement in terms of stability, a minimum number of false operations caused by a short circuit.

Traditional differential protection uses two elements: one, usually quite sensitive, in each line, transmitting movement between them through electromagnetic or mechanical means. This difficulty was only overcome with the use of electronic regulation, available in analyzing relays or in some digital protection, which allows channeling a small portion of the power to one, the most sensitive, and only sends the information to the relay as a whole when the protection reaches the second element, the one most inert.

Thermal, differential, and numerical relays have the same operating principle: they verify the relationship between two variables: power and time. The thermal or biomagnetic relay turns when a certain temperature is reached on the helical bimetallic strip that actuates a microswitch, linking a signal or a coil through a delayed centrifuge. To enhance relay sensitivity, water delay may be used. This uses the delay caused by the boiling of a water bubble immersed in an oil capsule, whose pressure increases in the same way with the water temperature, or the toggle principle, or the instantaneous opening of two or more contacts in series

When the relay detects an overload, a warning or alarm signal is triggered; and if the overload persists, a disconnector connected in series with the relay contacts is actuated, cutting the circuit.

Differential relays measure the difference between the incoming and outgoing currents in a protected zone. Under normal operating conditions, these currents should be equal. If a fault occurs within the protected zone, the difference exceeds a preset threshold, triggering the relay to trip and isolate the fault.

1. **Differential Current:**

$$I_{diff} = | \ I_L - I_R \ | \qquad (3.4)$$

Where:

- I_{diff} is the differential current (in amperes).
- $I_L$theentering current (in amperes).
- I_R is the leaving current (in amperes).

2. **Operate and Restraint Currents:**

$$I_{operate} = I_{diff} \qquad (3.5a)$$

$$I_{restraint} = \frac{I_R + I_L}{2} \quad (3.5b)$$

3. **Operating Condition:**

$$I_{operate} > k * I_{restraint} \quad (3.6)$$

Where k is a constant typically set between 0.2 and 0.5.

4. **Percentage Differential (Bias) Characteristic:**

$$I_{operate} = K1 + K2 * I_{restraint} \quad (3.7)$$

Where:

- K1 and K2 are constants.

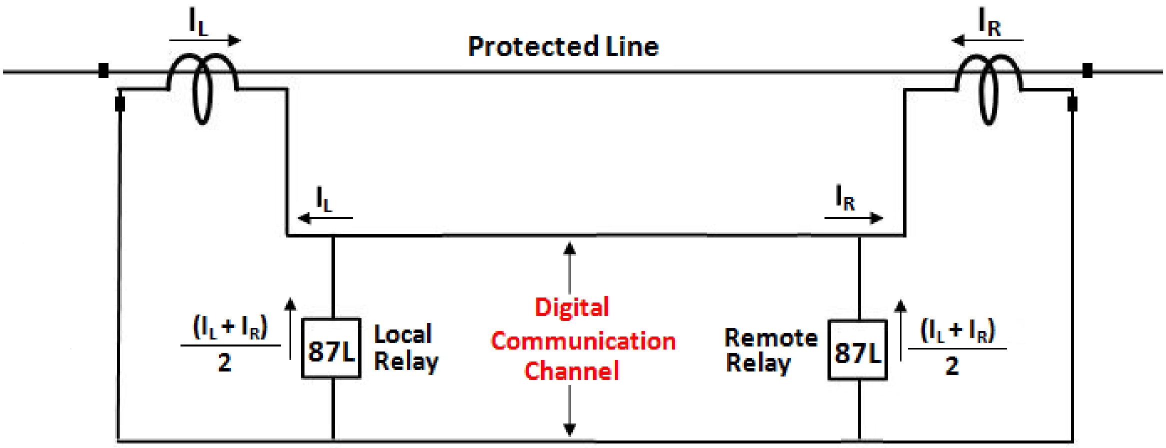


Figure 3.5: Differential relay working principle.

Table 4 : Differential Relay Settings

Setting	**Typical Range**	**Description**
Pickup Current	10-50% of full load current	Minimum current to activate the relay
Restraint Current Factor	0.2-0.5	Factor to prevent false tripping
Operating Time	20-50 ms	Time taken to operate after fault

		detection
Slope 1	20-40%	Slope for lower differential currents
Slope 2	40-70%	Slope for higher differential currents

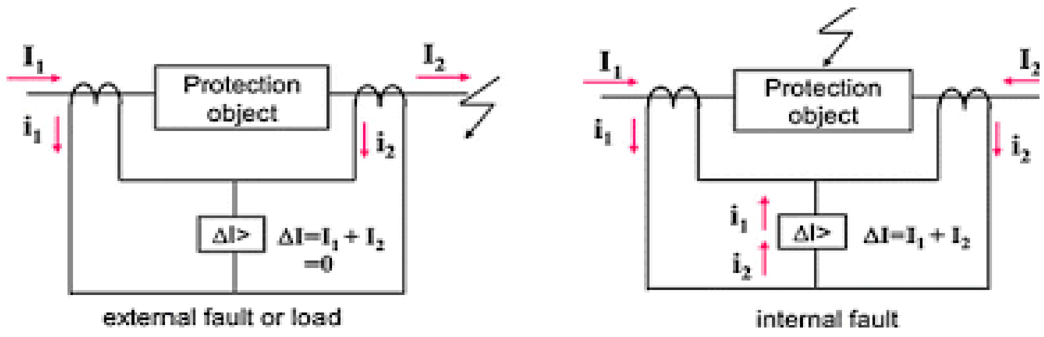


Figure 3.6: The external and internal fault of differential relay.

3.3.2 Applications

The development of electronic and microprocessor-based relays is moving at a brisk pace as a result of the progress in electronic components, combined with the carryover of numerous applications from other electronic fields. Even though the cost of this new technology is still relatively high to justify its application without regard for cost, the various benefits derived from using it usually justify the investment. On the other hand, many relay applications used in the past should now be made more secure and selective by making use of some of the features present in the most new electronic and microprocessor-based relays available today. These features are derived from the processing capability of microprocessors and digital signal processors. It is also increasingly possible to obtain a much lower setting level for these new relays, thus making them much more sensitive to a variety of circuit faults.

3.3 Advantages and Limitations

Thermal and differential relays offer good selectivity due to their ability to respond to fault currents. In addition, relay coordination is facilitated because the selectivity of these relays is largely independent of the values of the currents that they measure. It is interesting to note that the most sensitive relays with regard to current shape have discrete-time meters with a rather crude uniform sampling technique. The fact that relays can be set to intentionally ignore the effects of noise by using polarization techniques can be regarded as a distinct advantage. As with any advantage, polarization has a distinctive disadvantage in that it limits the sensitivity of the relay.

The application of electromechanical devices has been mostly supplanted by solid-state relays because the programming of solid-state relays is much simpler and they offer a wider range of features including self-adjustment, protection against erroneous signals, can include diagnostics, and have a greater ability to be customized to provide fast and predictable trip times for complex power system requirements. The basic limitations of the solid-state relays are cost, robustness, and the limited ability of protective devices that has been described earlier.

Some protective systems use only a very limited selection of operation characteristics and settings. Such systems may not be dependable over longer periods of operation. It is important that researchers in the area of power system protection.

3.4 Fundamentals of Numerical Relays

A numerical relay is another advanced digital protection relay. Though the relay does not have an electromechanical mechanism at the output, it uses a signal-processing unit to receive processed electrical analog signals and produces a trip output. The relay performs three primary functions: current measurement, protection algorithm, and tripping. Digitization occurs as soon as the protection input reaches the actual relay. Signal processing involves sampling, filtering, and computations, typically at very high speeds (in milliseconds). In addition to traditional protection elements, numerical relays provide communication ports for remote access, fault data recording, event/sequence-of-event recording, flexible applications and settings, self-diagnostic, condition monitoring, etc., with high accuracy and reliability. [19]

While these sophisticated relays are advancing with features, they can only be installed and operated by skilled manpower. The relay and protection design engineer need to have significant knowledge of computational algorithms, accuracy issues, communication protocols, network engineering, testing, and commissioning, etc., while the relay and field engineers need to specialize in signal processing, resource management, and maintenance. In general, for any protection system to work effectively and provide acceptable levels of reliability and protection, a thorough analysis and selection needs to be conducted based on available technology, the potential application and associated interfaces, and proper protective device coordination. With fast advancement in technology and significant reduction in prices for digital and microprocessor-based relays, these relays are taking over the electrical protection systems in most utility and industrial zones. [20]

Figure 3.7: Numerical relays.

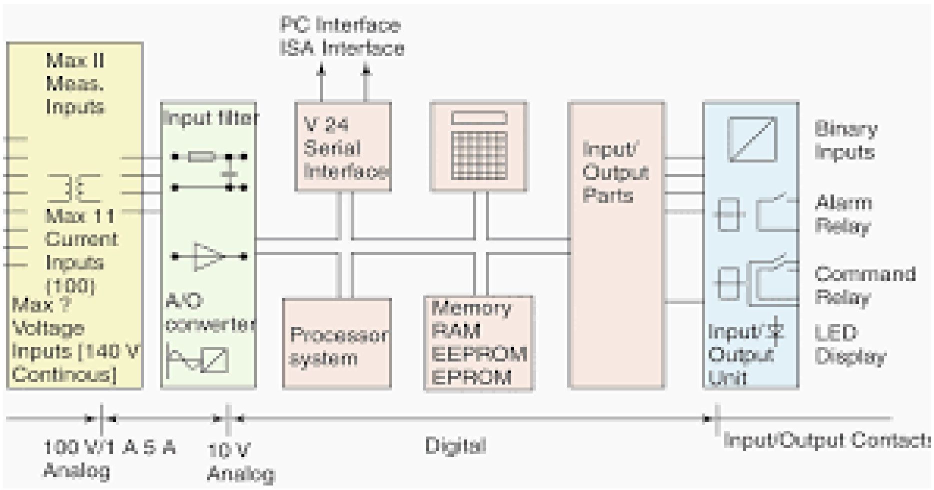


Figure 3.8: Numerical relay block diagram

3.4.1 Operating Principle

Numerical relays utilize various equations and algorithms, such as additive equations, rate of change equations, and others, which constitute their protection functions in a program to monitor the electrical system. These equations or algorithms are written for performing this function. The advantages of using numerical relays over mechanical or static ones include undisturbed protection setting changes; reduced installation and maintenance costs via universal hardware and modular software; application versatility and compatibility; extended operation; parameter recording for fault analysis, sequence of action, and protection testing; the ability to perform additional functions such as measurement, monitoring, and recording in order to detect and avoid critical operating states. Numerical relays are capable of performing a considerable number of functions. For example, they can take into account various protection principles (overcurrent, overvoltage, torque-free operation, second zone, frequency, etc.) and can conduct special protection tests, such as the control of blinding contacts, local reconnection, trip circuit supervision (TCS), control of pre-insertion resistors, directional short circuit protection, etc. [21]

This technology has the capacity for adaptation into new generations of relays. Numerical relays also have the ability to provide comprehensive protection scheme coordination by adapting time-current tripping characteristics, as well as thermal overload and instantaneous trips. They can also adapt these characteristics to the protection requirements imposed on elements. These relays can also be installed with a combined functionality that includes protection, automation, measurement, analysis, monitoring, and communication. After the disappearance of a fault, numerical relays are able to perform automatic disarmament by incorporating virtual supervision and preset delay times. Time-resettable functions adapted for such relays are another aspect that must be taken into account since they can detect the onset of problems, provide signals, receive signals, and communicate with other slave devices that, in turn, can provide user control. Whenever necessary, numerical relays can be adjusted for integrating the available facility bus communications. [21]

Numerical relays sample and digitize electrical signals. These digital signals are processed using numerical algorithms to detect faults. The relay compares measured values with set thresholds to make decisions. Numerical relays can perform multiple protection functions simultaneously, such as overcurrent, differential, and distance protection.

1. **Sampling and Digitization:**

$$V[n]=V(t)\ |_{t=nTs} \quad (3.8)$$

Where:

- V[n] is the sampled voltage at the nnn-th sample.
- V(t) is the continuous voltage signal.
- Ts is the sampling interval.

2. **Discrete Fourier Transform (DFT):**

$$X(k) = \sum_{n=0}^{N-1} x(n)e^{-j\frac{2\pi}{N}kn} \quad (3.9)$$

Where:

- X(k) is the DFT coefficient.
- x(n) is the sampled signal.
- N is the total number of samples.
- j is the imaginary unit.

3. **Phasor Calculation:**

$$\hat{V} = \frac{2}{N}\sum_{n=0}^{N-1} v[n]\ e^{-j\frac{2\pi}{N}n} \ (3.10)$$

Where:

- $\hat{V}$ is the phasor representation of the voltage.
- V[n] is the sampled voltage.
- N is the number of samples.

4. **Protection Algorithm:**

$$\text{Trip} = \{ \quad 1 \quad if\ \mid Imeasured \mid > Iset 0 \quad otherwise \ (3.1)$$

Where:

- Trip is the tripping decision (1 for trip, 0 for no trip).
- ImeasuredI is the measured current.
- Iset is the set threshold current

Table 5 : Numerical Relay Features

Feature	Description
Sampling Rate	16-32 samples per cycle
Communication Protocols	IEC 61850, Modbus, DNP3
Protection Functions	Overcurrent, Differential, Distance
Accuracy	High (typically within 1% error)
Self-Diagnosis	Built-in diagnostics and health checks
Disturbance Recording	Captures and logs fault data
Remote Communication	Allows for remote monitoring and control
Firmware Upgrades	Can be updated for improved performance

3.4.2Types of Numerical Relays

The types of numerical relays correspond to typical existing electromechanical, static, and microprocessor relay applications. Towards a total relay protection solution, through a platform approach, it is worth mentioning the new technology of multi-application numerical relays, which along with central units are already available. Compared with the electromagnetic and static relays, the numerical relay is responsible for protecting the electrical power systems, from the generation to the load, effectively and innovatively. The thermal, differential, and numerical relays are presented briefly in this chapter. Subsequently, case studies of these relays are shown and analyzed. Therefore, this chapter has as its objective the presentation of fundamentals of the application of commercial numerical relays in electrical power systems. [21]

3.4.3 Advantages and Limitations

In recent years, a number of numerical relays have been developed. These relays use microprocessor-based technology for the protection purpose. In these relays, different relays and protections can be programmed according to the requirement. However, all relays do have some advantages and limitations. The advantages and limitations of the thermal, differential, and numerical relays are presented.

A low inrush current is the major advantage of the thermal protection. It is cheap and simple in construction and can be accommodated in a small and compact space. It is suitable for long-life device protection against overcurrent. Its operation does not depend upon line voltage, and the principle of fault protection is entirely different than that of circuit breakers. ZFC (zero flux current), the timer, and instantaneous (unit time and inverse time) tripping are particularly good in reducing the total operating time of the relay.

Digital relays are used in different modes such as high imp, high slope, sensitive, restrained, etc. Such a relay is more protected when it is used in a redundant system. However, the application becomes very complex. The cost of the relay will be high and will not be competitive with any of the other types of relays used in the power system protection. The differential protection is slow and less sensitive to harmonics and DC components. Corrosion of CT tubes is common in these relays as they are oil-filled. The solid-state relay brings the microprocessor-based numerical relay into luxury and can operate quickly compared to conventional relays.

3.5 Comparison of Thermal, Differential, and Numerical Relays

The purpose of this study is to compare the thermal, differential, and numerical functions of these three relay types (as mentioned above) for different loads and apparatus found in electrical systems in everyday use. Several suggestions are made, and a conclusion is developed according to the comparisons and calculations made.

Although the ultimate decision is made on the basis of user requirements, the characteristics, features, and limitations of these types of relays differ. As of today, most relays complete protection tasks, such as overcurrent, Zero Sequence Overcurrent (ZSO), differential, distance, and measurement tasks. Using numerical technology, several other functions, such as Autoreclosing, Synchrocheck, and Breaker Failure Protection, can also be achieved using this relay type. Trip commands for breakers, which make up a portion of the provided functions, are made using various communication protocols. Due to its low price and high reliability at high currents, the electromagnetically operating thermal relay is the most common protection device used for the protection of simple current-dependent devices and loads, such as the power lines of single-phase, three-phase, and transformer motors. As indicated in the previous section, the differential relay will trip the switch when the relevant control area current rises and creation of the indirect stabilizing control loop is obligatory. Additionally, using graphical methods, it is possible to calculate some important protection functions.

a) Electromechanical relays b) Solid-state relays c) Microprocessor relays d) Static relays e) Distance relays f) Simple distance relays g) Impedance relays

The choice of relay types for various functions often depends on the specific characteristics needed. Various relay devices are available, such as:

3.5.1 Performance

A characteristic of the relay is its operating time, which is the time from the occurrence of a fault to the relay operation. Another important characteristic of the relay is its selectivity, which is the ability to be operated under desired operating conditions and not under other conditions. The sensitivity of the relay is characterized by the minimum value of the measured quantity at the input of the relay at which the relay can operate. This minimum value is very important for the relay because in distribution networks, it is necessary to respond to low and very low fault currents to provide well-timed fault clearing. High selectivity, response to low and very low fault current levels, and a fast operating time are conflicting demands for the relay. The principle measures of performance are operating time, operating characteristic, and the probabilities of fault detection and discrimination.

The error in determination of operating time and the action taken due to this error have significant influence on the protection performance. If the relay sensitivity is adjusted too high or if the relay characteristic has a low slope, the relay might operate without the presence of a fault. To prevent a false operation of the relay, overreaching characteristics may be employed, but that may make the relay slow to respond to faults. As a compromise between these conflicting requirements, inverse-time and definite-time characteristics are adopted. The typical characteristic for a current relay is shown in Figure. As seen from this figure, the relay must be very sensitive to detect a fault between two distant current transformers and must be highly selective to detect faults on your line only. A typical current protection tolerance time and the IT characteristic are also depicted in this figure. The operating time of the relay must be adapted to the time interval in which the maximum risk for life and the maximum risk for equipment is expected to exist. Therefore, the risk level, the characteristics of the faults, and the protection objectives must be carefully analyzed before implementing the protection scheme.

3.5.2 Cost

The thermal overload relay is generally the lowest-cost form of overload relay and is accordingly the most widely employed type. In the case of the induction type, it is the only practical means of protection and is therefore invariably used for this purpose. Differential relays have only a limited application and are, because of their construction, more expensive than the overload relay. This cost increases if a high degree of discrimination and stability, and accuracy, is required. However, a reduction in cost is often possible if a testing means for the differentially connected core of the transformer is eliminated.

The numerical relay per se is not expensive but when associated with a measuring device capable of interfacing directly with the current transformer of the circuit-breaker, the cost is high. To be cost-effective, the measuring relay should serve at least two protection purposes. Apart from the direct application of the numerical relay for protection, the cost may be high when applied together with, for example, current-to-time or current-to-definite minimum-time units. If the number of connections required is high then the cost can become excessive in view of its intended use. The deciding factor will, however, be long term dependability and especially inherent security. The latter attribute is frequently of very minor significance as it is not possible to differentiate between an inherent and an auxiliary type of delay. If the latter delay depends on circuit impedances then it is indirect and cannot be considered as a reliability index.

3.5.3Maintenance

Maintenance of relays is generally confined to visual inspection and functional tests. In addition to the annual ultrasonic cleaning and visual inspection of all relays and their components, it is very desirable to test them with automatic test apparatus after the external protective system has been tripped by the safety block system on some pertinent abnormality. Nothing can be more misleading than the safe resetting of a voltage relay fractured during load rejection without checking its operativeness online after a load rejection. For this purpose, a timed 5% non-trip test under forced or volt-free conditions is essential. A load rejection causing busbar overvoltage provides the natural opportunity to test the better thermal differential, usually from 100% rated current down to around 40% lagging. Overspeed is also most conveniently tested under forced conditions in the same circumstances. Finally, only an emergency manual trip test can prove the continued absence of phantom transmission.

That many protection relays continue to operate in practice with visible defects such as fractured pointers is evident from our own limited experience. What is less clear is whether they continue to operate safely, and it is therefore desirable to minimize the risk of inappropriate or unsafe relay operation, to inspect the function of the local control tripod switches annually. The minimum amount of functional testing which relays receive is understandable given the consequences of deliberate or accidental unscheduled tripping. Whenever the relays in a power station were automatically or manually disconnected, they were subjected to a more or less rigorous pre-energization test program. If it did not pass, they were not energized. When all systems are satisfactorily checked, each isolated busbar system or the whole station is connected with the grid. If an abnormality occurred (any safety block relay tripped), the subsequent decision according to the pre-established protection plans determined either an autoreclosing operation or a trip. But if the situation worsened in the overall protection, the protective system dismantles down to the two cautions made at each failure. A better operational culture could ultimately be justified.

CHAPTER 4

EXPERIMENTS AND RESULTS

EXPERIMENT 1: Overcurrent Protection Using Different Types of Relay (Electromagnetic, Thermal Relayand Differential Relay)

Part 1:Electromagnetic Relay Principle of operation

Objectives

1. To safeguard electrical systems from damage due to the short circuit current.

2. To understand the working principle of electromagnetic relays.

3. To observe the response of an electromagnetic relay to the different overcurrent conditions.

Discussion

Overcurrent electromagnetic relay is critical in electrical engineering for protecting equipment from the damaging effects and person from excessive current flow. Electromagnetic relays are a fundamental element for overcurrent protection, operating on the principle of electromagneticforce produced from current flow through a coil. When the current exceeds a certain threshold, the produced electromagnetic relay force causes a relay to trip. The relay then disconnects the power circuit to prevent damage. Electromagnetic relays are simple, reliable, and cost-effective, making them suitable for various home and industrial applications. However, they have fast response times compared to other types (instantaneous).

Instruments and Components

- Pilot Lamp, Red

- Pilot Lamp, Green

- Electromagnetic relay

- AC Metering Module (5A)

- Power Supply Module (0-220V 3ϕ, 380V 3ϕ)

- Variable Resistive load module

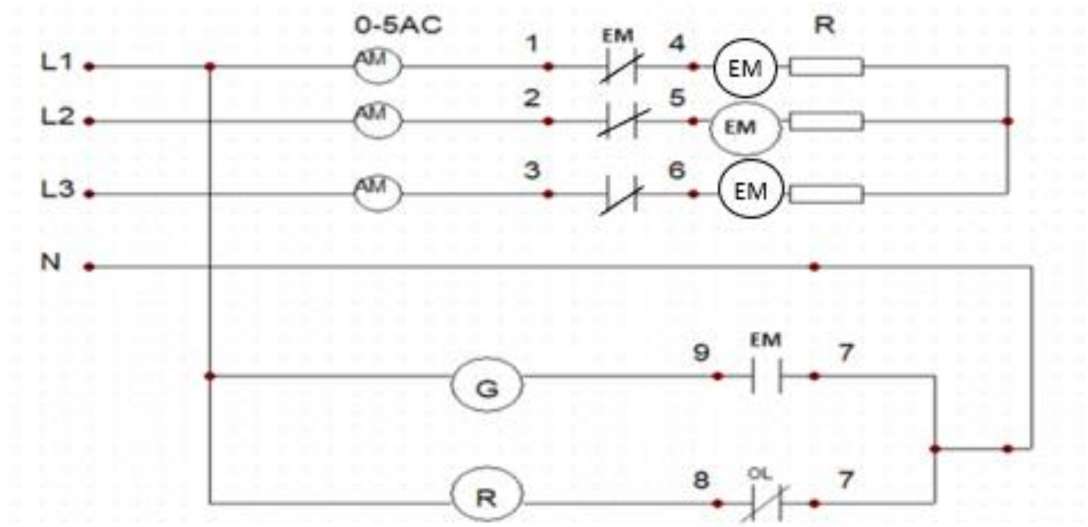


Fig. 4.1 Experimental setup for electromagnetic relay operation principle study

Procedure

1. Setup:

- Connect the power supply to the variable resistance via the electromagnetic relay as shown on the circuit diagram (see Fig.4.1).

- Monitor the current using the ammeter connected in series with the output of the electromagnetic relay and one terminal of resistance.

- Setting value theelectromagnetic relay is 5A. Ensure that all connections are secure and correct.

- Set the variable resistance to a high value to start with a low current.

2. Observations:

- Turn on the power supply. Observe the initial state of the system.

- Decrease the resistance of the load gradually to increase the current. Observe the behavior of the electromagnetic relay.

- Note the minimum current value at which the relay activates to disconnect the circuit.

- Record the response time of the relay and the current value at which it trips.

  - I = 5.5Aac

  - T = 1 s

4. Turn off the power supply.

6. Summary:

- Write a summary of the experiment, explaining how the electromagnetic relay functions based on observations and recorded data.

- The experiment demonstrates that the electromagnetic relay effectively protects the electrical system by disconnecting the circuit when the current exceeds the setting value(threshold). This is due to the electromagnetic force generated by the current, which trips the relay.

Questions and Answers

1. What is the principle behind the operation of an electromagnetic relay?

- An electromagnetic relay operates on the principle of electromagnetic force generated by current flowing through a coil. When the current exceeds a certain threshold (setting value =5 A), the electromagnetic force causes the relay to trip and disconnect the power circuit to prevent damage.

2. Why is it important to use an ammeter in this experiment?

- Using an ammeter is important to accurately monitor the current flowing through the circuit. This helps determine the current value at which the relay trips, ensuring the relay's correct operation and calibration.

3. What factors can affect the performance of an electromagnetic relay?

- Factors affecting the performance of an electromagnetic relay include ambient temperature, the condition of the contacts, the accuracy of the current setting, electromagnetic interference, and mechanical wear.

4. How can the reliability of electromagnetic relays be improved in practical applications?

- The reliability of electromagnetic relays can be improved through regular maintenance, proper calibration, using high-quality components, ensuring a clean operating environment, and implementing protective measures against electromagnetic interference.

Results

The results section includes the observed current at which the relay trips and the response time. These observations help in understanding the operational characteristics and effectiveness of the electromagnetic relay in protecting against overcurrent due to the short circuit abnormal conditions.

Part 2:Thermal Relay

Objectives

1. To safeguard electrical systems from excessive current due to overload.

2. To understand the working principle of thermal relays.

3. To observe the response of a thermal relay to the different overcurrent conditions.

Discussion

Overcurrent protection due to the overload is critical in electrical engineering for protecting equipment from the damaging effects from excessive current flow. Thermal relays are a fundamental element for overcurrent protection, operating on the principle of heat generation due to current flow through a conductor. When the current exceeds a certain threshold, the generated heat causes a temperature rise, which is detected by temperature-sensitive element of the relay such as bimetallic strips. The relay then disconnects the circuit to prevent damage. Thermal relays are simple, reliable, and cost-effective, making them suitable for various industrial applications. However, they have slower response times compared to electronic devices and require careful calibration to maintain accuracy.

Instruments and Components

- Pilot Lamp, Red

- Pilot Lamp, Green

- Thermal relay

- AC Metering Module (5A)

- Power Supply Module (0-220V 3ϕ, 380V 3ϕ)

- Variable Resistive load module

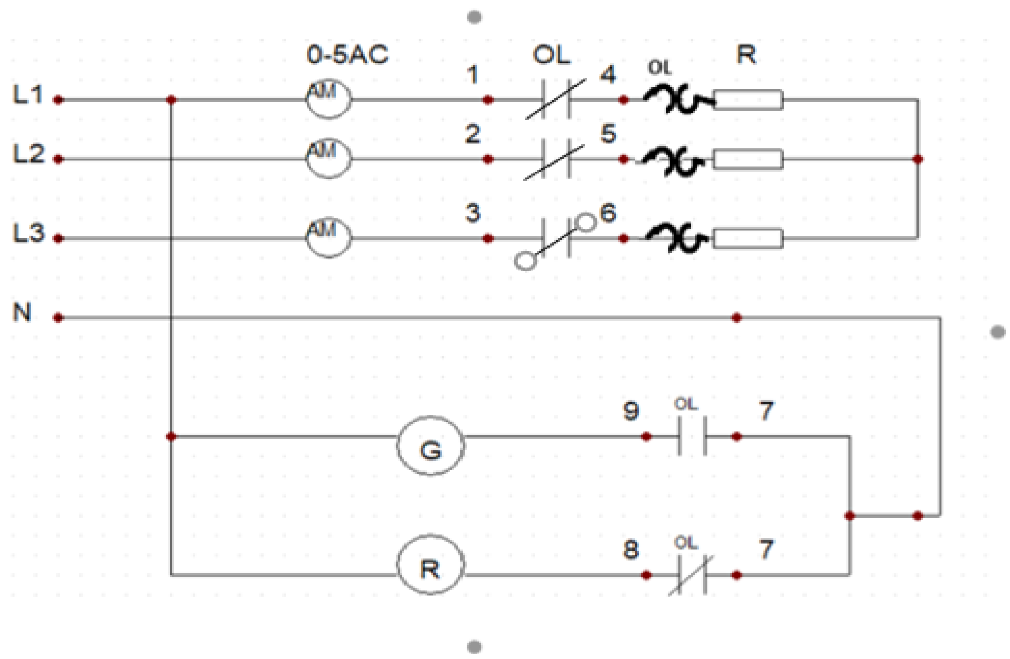


Fig. 4.2 Experimental setup for the thermal relay operation principle and characteristic study

Procedure

1. Setup:

- Connect the power supply to the variable resistance via the thermal relay as shown on the circuit diagram (Fig.4.2).

- Monitor the current using the ammeter connected in series with the output of the thermal relay and one terminal of resistance.

- Set the thermal relay at 0.5A. Ensure that all connections are secure and correct.

- Set the variable resistance to a high value to start with a low current.

2. Observations:

- Turn on the power supply. Observe the initial state of the system.

- Decrease the resistance of the load gradually to increase the current. Observe the behavior of the thermal relay.

- Note the minimum current value at which the relay activates to disconnect the circuit.

- Record the response time of the relay and the current value at which it trips.

- I1 = 0.6Aac

- T1 = 10 s

- <u>Increase the resistance</u> step by step until reaching the maximum current. Measure and record the response time of the relay from the time when this current is applied until the relay trips and its value for each step.

- In = _______ Aac

- Tn = _______ s

Table 4.1 Data

Current (Aac)	Response Time (s)
0.6	10
0.8	8
1.0	6
1.2	5
1.5	3

4. Turn off the power supply.

5. Plot a curve showing the relationship between the current value absorbed by resistance and the response time of the relay.

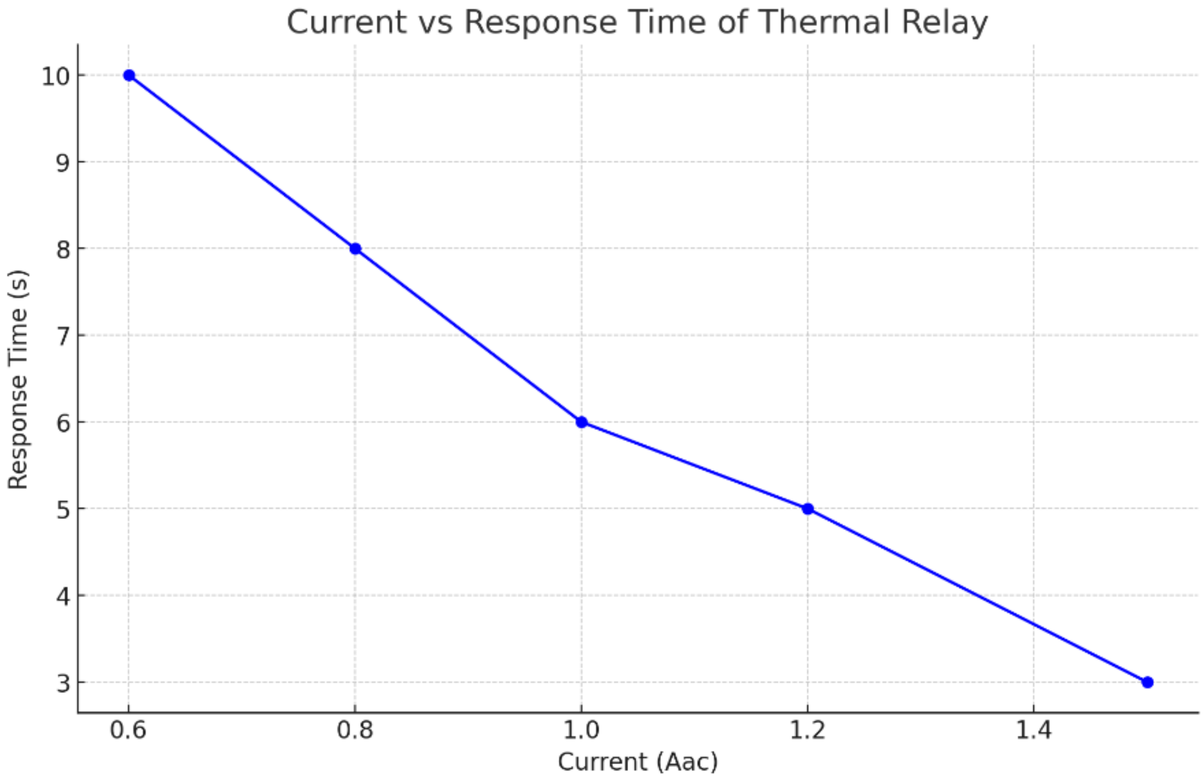


Fig. 4.3 Current vs Response Time Plot

Here is the plot showing the relationship between the current value absorbed by resistance and the response time of the thermal relay. The data indicates that as the current increases, the response time of the relay decreases, which is consistent with the behavior of thermal relays under overcurrent conditions.

6. Summary:

- Write a summary of the experiment, explaining how the thermal relay functions based on observations and recorded data.

Results

- <u>Normal Conditions:</u> The thermal relay remained closed, ensuring continuous operation without interruptions.

- <u>Overcurrent Conditions:</u> The relay tripped at 0.5A within 10 seconds, demonstrating sensitivity and responsiveness. It reset after 30 seconds, confirming its ability to cool down and return to its protective state automatically.

Questions

1. What is the principle behind the operation of a thermal relay?

- The principle behind the operation of a thermal relay is that current flow through a conductor generates heat due to resistance. This heat causes a temperature rise, which is detected by temperature-sensitive elements like bimetallic strips. When the temperature exceeds a certain threshold, the relay disconnects the circuit to prevent damage.

2. Why is it important to use an ammeter in this experiment?

- It is important to use an ammeter to monitor the current flowing through the circuit accurately. This helps in determining the current value at which the thermal relay trips, ensuring the relay's correct operation and calibration.

3. What factors can affect the performance of a thermal relay?

- Factors affecting the performance of a thermal relay include ambient temperature, load characteristics, environmental conditions, calibration accuracy, and the thermal properties of the materials used in the relay.

4. How can the reliability of thermal relays be improved in practical applications?

- The reliability of thermal relays can be improved by regular calibration, proper installation in suitable environments, periodic maintenance, and using high-quality materials with consistent thermal properties.

Part 3:USING DIFFERENTIAL RELAY

Objectives

1. To safeguard electrical systems from leakage currentdue to ground fault.

2. To understand the working principle of differential relays.

3. To observe the response of a differential relay to different ground faults.

Discussion

The differential relay is designed to monitor the difference in current between the live and neutral conductors. In a properly functioning system, the current flowing through the live conductor should equal the current returning through the neutral conductor. However, in the event of a ground fault, some of the current will find an alternate path to ground, creating an imbalance that the differential relay can detect.

To test the fault detection capability of the differential relay, the experiment involves introducing controlled ground faults using a variable resistance. This resistance allows for precise simulation of fault conditions, such as varying the magnitude and duration of the leakage fault current. By doing so, we can observe how the differential relay responds to different leakage currents.

For instance, a minor ground fault might produce a small imbalance that the relay needs to detect reliably. Conversely, a severe fault could result in a large imbalance, requiring the relay to react swiftly to prevent damage or hazards. By evaluating the relay's performance across a range of fault conditions, we can assess its sensitivity and reliability in real-world applications.

The response time of the differential relay is a key performance metric, indicating how quickly the relay can detect and respond to a fault condition. In electrical systems, the prompt isolation of faults is essential to minimize the duration of exposure to potentially hazardous conditions and to protect both people and equipment.

During the experiment, the response time is measured from the moment a fault is introduced using the switch to the point when the differential relay activates to isolate the fault. This time interval is critical for determining the relay's effectiveness in real-world scenarios. A fast response time ensures that faults are addressed before they can cause significant damage or pose a threat to safety.

Instruments and Components

- Pilot Lamp, Red

- Pilot Lamp, Green

- Differential relay

- Two AC Metering Modules (5A)

- Power Supply Module (0-220V 3ϕ, 380V 3ϕ)

- Resistive load module

- Resistance (<800Ω)

- Three ways Switch module

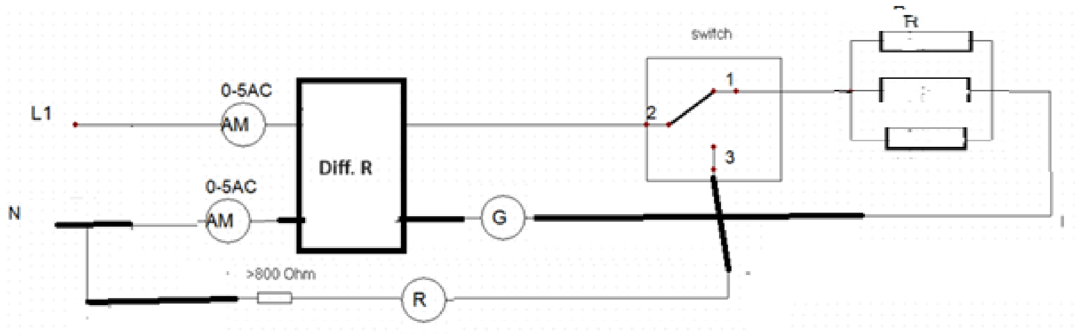


Fig. 4.4 Experimental setup for the differential relay operation principle and characteristic study

Procedure

1. Setup:

- Connect the power supply to the resistive load via the differential relay and a variable resistance to emulate the grounded insulator as shown in the circuit diagram.

- Monitor the current using two ammeters, each connected in series with the output of the differential relay and one terminal of resistance.

- Ensure that all connections are secure and correct.

- Set the variable resistance to a high value to start with a very low leakage current.

2. Observations:

- Turn on the power supply. Observe the initial state of the system.

- Measure I1 and I2, and calculate Delta I = 0.22Aac.

- Decrease the resistance of the variable resistance gradually to increase the current. Observe the behavior of the differential relay.

- Note the current value at which the relay activates to disconnect the circuit.

- Record the current value at which it trips: Delta I = 0.29Aac.

3. Turn off the power supply.

5. If the setting Delta I of the relay is 0.3 A, is the measured Delta I that has caused the relay to trip the same as the setting value?

Answer: If the setting Delta I of the relay is 0.3A, but the measured Delta I that caused the relay to trip is 0.29A, there is a small discrepancy. While the relay was set to trip at 0.3A, it tripped slightly earlier at 0.29A. This is very close to the set value, indicating that the relay is functioning properly, but with a slight deviation which is normal due to factors like calibration tolerances, sensitivity settings, or minor inaccuracies in measurement.

Summary:

- The experiment demonstrated how a differential relay functions to protect electrical systems from leakage currents. The relay monitors the difference in current between the live and neutral conductors, tripping when an imbalance is detected.
- Initially, the system showed a Delta I of 0.22 Aac. As the variable resistance was decreased, increasing the leakage current, the relay tripped at a Delta I of 0.29 Aac.
- The relay was set to trip at 0.3A, and the measured trip point was slightly lower at 0.29A. This small discrepancy is within acceptable limits and can be attributed to calibration tolerances or sensitivity settings.

Questions:

1. **What is the principle behind the operation of a differential relay?**
   A differential relay operates by monitoring the difference in current between the live and neutral conductors. If an imbalance is detected, indicating a leakage current or ground fault, the relay trips to disconnect the circuit and prevent damage or hazards.
2. **Why is it important to use two ammeters in this experiment?**

Two ammeters are used to measure the current in both the live and neutral conductors. This allows for the calculation of Delta I (the difference in current), which is crucial for determining if there is an imbalance that would cause the differential relay to trip.

3. **What factors can affect the performance of a differential relay?**
   Factors that can affect the performance of a differential relay include calibration accuracy, sensitivity settings, transient conditions, environmental factors (such as temperature and humidity), and electrical noise or harmonics in the system.
4. **How can the reliability of differential relays be improved in practical applications?**
   The reliability of differential relays can be improved by regular calibration, ensuring proper sensitivity settings, using high-quality components, protecting the relay from environmental factors, and implementing noise filters to reduce electrical interference.

Conclusions

In Part 1 and 2, the electromagnetic and thermal relay performed as expected, providing effective protection by, 1disconnecting the circuit during overcurrent conditions and resetting automatically after cooling. This enhances the safety and reliability of the electrical system, preventing potential damage and reducing downtime.

The relationship between the current value absorbed by resistance and the response time of the relay can be plotted as a curve, typically showing a decrease in response time with an increase in current.

This experiment demonstrates the effectiveness of electromagnetic and thermal relays in protecting electrical systems from overcurrent conditions, highlighting their advantages, limitations, and practical applications.

In part 3, the differential relay performed as expected, tripping slightly below the set point of 0.3A at 0.29A. This performance demonstrates the relay's ability to protect electrical systems by detecting and responding to leakage currents. Proper calibration and consideration of environmental factors are essential for maintaining the accuracy and reliability of differential relays in practical applications

4.2 EXPEREMENT 2:TT EARTHING SYSTEM PROTECTION CIRCUIT

Part 1: Using Thermal and Electromagnetic Relay

Objectives

1. Evaluate the effectiveness of thermal and electromagnetic relays in promptly detecting overcurrent due to overload and short circuit faults, but not leakage currents due to ground faults in the TT earthing system.

2. Measure the response time of the thermal relay from the moment a fault is applied.

Discussion

By emulating ground faults using the switch and variable resistances in our experiment, we can observe how accurately and swiftly the thermal relay detects overcurrent due to overload and short circuit faults. We aim to determine the sensitivity of the thermal relay in detecting faults of varying magnitudes and durations. This sensitivity is crucial for ensuring that even small fault currents are detected promptly to prevent potential hazards. Effective fault detection is paramount for the safety and reliability of electrical systems. By assessing the thermal relay's capability in detecting faults, we can identify any limitations or areas for improvement in the protection circuit. This information is essential for optimizing the performance of the circuit and enhancing overall system safety.

Instruments and Components

- Red Pilot Lamp

- Green Pilot Lamp (2)

- Thermal Relay

- AC Metering Module (5A)

- Power Supply Module (0-220V 3ϕ, 380V 3ϕ)

- Resistive Load Module

- Resistance (<800Ω)

- Three-Way Switch Module

Procedure

1. Setup:

a) Connect the circuit as done in Experiment 1, but operate for a single phase as shown in the diagram Fig.4.5.

b) Connect the control circuit as shown in the provided diagram.

c) Add a switch between the output of the relay and the resistive load:

- The input of the switch is connected to the relay output.

- First Position: One output of the switch is connected to the resistive load.

- Second Position: The other output is connected to the ground resistance.

2. Testing:

a) Set the switch to the first position to perform Experiment as Experiment 1.

b) Turn on the power supply and repeat the procedures from the previous experiment to ensure the relay works. Does it work?

Yes, it does.

c) Turn off the power supply.

d) Set the switch to the second position. What do you observe? Will the green lamp connected to the ground resistance indicate?

Yes, it does.

e) After a while, is there any change?

No, there is no change.

f) Does the relay trip?

Absolutely not.

- If YES, count the time from when the switch is turned on until the relay trips: t = s

- If NO, why? Because the relay cannot detect the small change in the ground current.

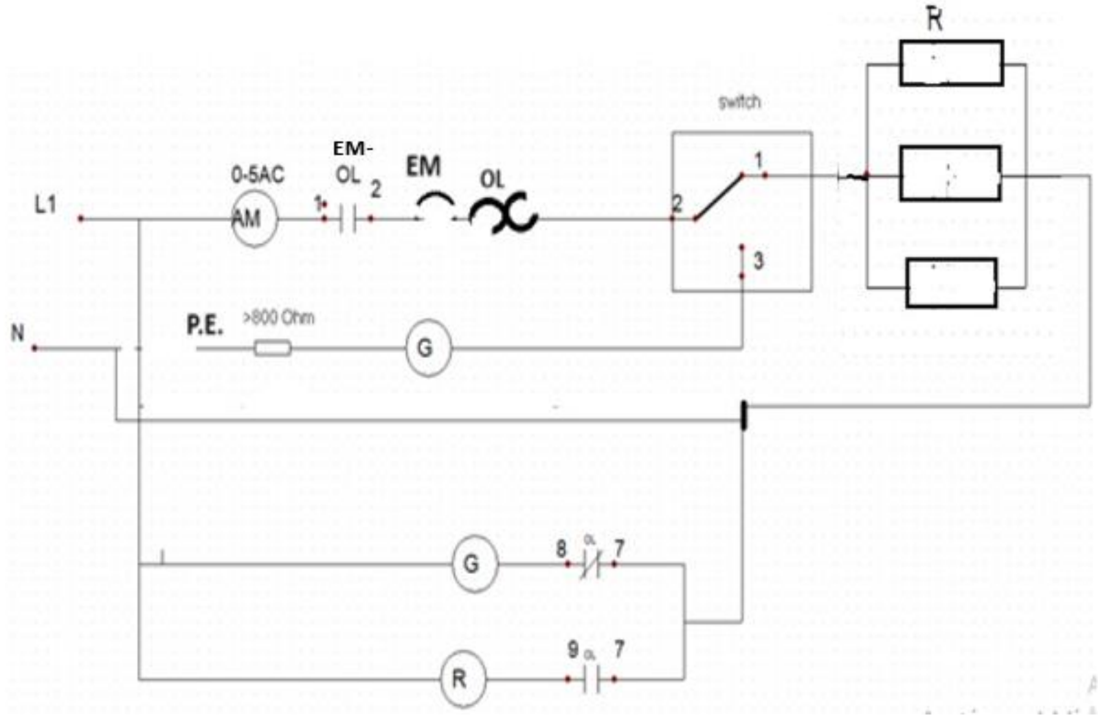


Figure 4.5: TT earthing system protection circuit diagram using thermal-electromagnetic relay.

Results:

When we set the switch to the first position, the relay behaves as it did in Experiment 1. Under normal conditions, the thermal relay does not react and simply passes the current to the load. Once we start decreasing the value of the resistive load and reach the threshold (setting value), the relay trips after 10 seconds. Then, when we change the switch to the second position and wait for a while, the relay does not react or trip, even if there is a ground fault.

Conclusion:

From this experiment, we can conclude that the thermal relay is less sensitive to small faults because the fault current that passes through the ground fault is too small. As a result, the thermal relay remains closed and does not react to the small fault.

Part2: USING DIFFERENTIAL RELAY

Objectives

1. Evaluate the differential relay's capability to detect ground faults in a TT earthing system.

2. Measure the response time of the differential relay upon fault detection.

Discussion

The differential relay monitors the difference in current between the live and neutral conductors. In a properly functioning system, the current flowing through the live conductor should equal the current returning through the neutral conductor. In the event of a ground fault, some current will find an alternate path to ground, creating an imbalance that the differential relay can detect.

In a TT earthing system, the local earthing of exposed conductive parts creates a direct connection to the ground. This arrangement means any fault current will flow through the earth, potentially bypassing the neutral conductor entirely or partially. The differential relay is sensitive to these imbalances and will trigger an alarm or disconnection if a significant difference is detected.

The experiment involves introducing controlled ground faults using a switch to test the differential relay's fault detection capability. This switch allows for precise simulation of fault conditions, such as varying the magnitude and duration of the fault current. By doing so, we can observe how the differential relay responds to different fault scenarios.

The response time of the differential relay is a key performance metric, indicating how quickly the relay can detect and respond to a fault condition. Prompt isolation of faults is essential to minimize the duration of exposure to potentially hazardous conditions and to protect both people and equipment.

Instruments and Components

- Red Pilot Lamp

- Green Pilot Lamp

- Differential relay

- AC Metering Module (5A)

- Power Supply Module (0-220V 3ϕ, 380V 3ϕ)

- Resistive load module

- Resistance (<800 Ω)

- Switch module

Procedure

1. Setup:

a. Replace the thermal relay (from the previous experiment) with the differential relay as shown in the circuit diagram (see Fig.4.6).

b. Configure the switch with two positions:

- FIRST POSITION: The relay is connected to the resistive load.
- SECOND POSITION: The relay is connected to the ground resistance.

2. Initial Testing:

a. Set the switch to the first position.

b. Ensure the resistive load is set to its maximum value.

c. Note: The differential relay's pickup current is 300 mA.

d. Turn on the power supply. The green lamp should indicate that the system is functioning normally, meaning the current entering the zone is equal to the current leaving the zone.

c. Measure I1=…………A, I2=…………., and IG==……………..

d-What is your observation?

3. Fault Emulation:

a. Change the switch to the second position. Observe any changes. The red pilot lamp should indicate briefly (for less than a second), then the relay should trip. This indicates an unbalanced current due to the earth fault, which the differential relay detects to initiate a trip signal.

b. Measure again I1=…………A, I2=…………., and IG==……………..

d-What is your observation?

c. Explain that the differential relay detects changes in current when the switch is changed, even if the current change is very small.

Results

Initially, under normal conditions, the relay does not react and remains closed. Once a ground fault occurs, the laboratory protection equipment trips, preventing us from seeing the relay's reaction because the relay's pickup current is 300 mA.

Conclusion

The differential relay responds instantaneously to only earth faults, ensuring rapid isolation of the fault; but not to overcurrent conditions. It accurately identified and responded to earth fault by detecting significant differences between incoming and outgoing currents. The relay promptly detected earth faults by identifying current differences, providing a crucial safety mechanism for preventing electric shocks and equipment damage.

The differential relay's instantaneous response time enhances system reliability by minimizing the duration of fault conditions. Quick recovery and reset capability allow for minimal disruption to operations, ensuring continuous and safe functioning of the system.

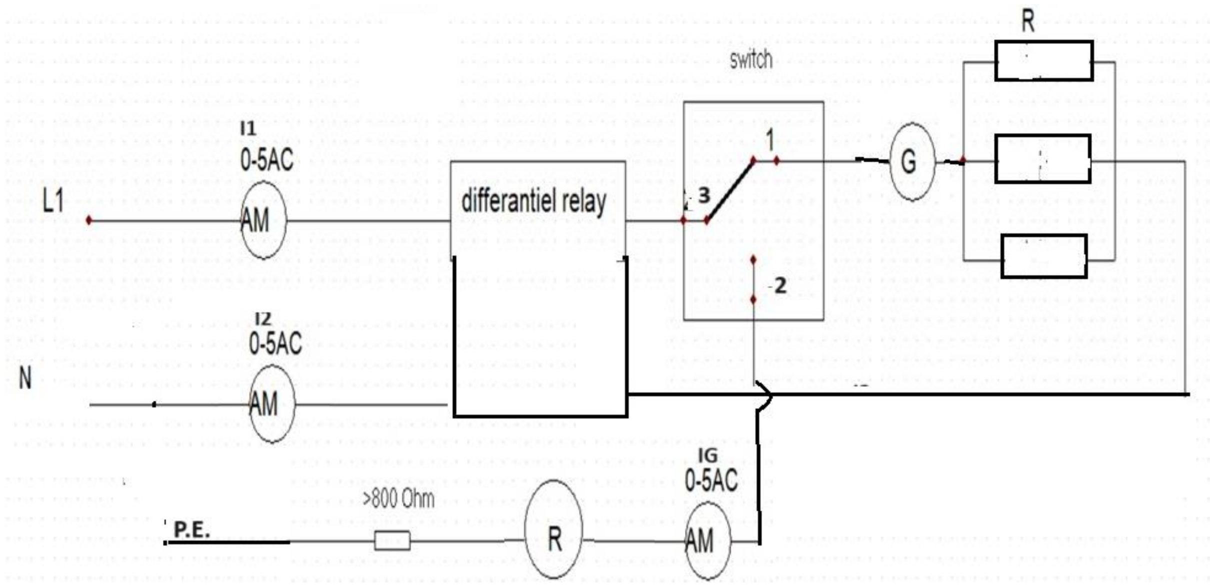


Figure 4.6: TT earthing system protection circuit diagram using differential relay.

4.2.3PART 3: USING BOTH ’’ THERMAL RELAY & DIFFERENTIAL RELAY ‘’

USING BOTH THERMAL RELAY & DIFFERENTIAL RELAY

Objectives

1. Evaluate the combined effectiveness of thermal and differential relays in detecting and isolating faults in a TT grounding system.

2. Measure the response times of both relays when detecting overcurrent and ground fault conditions.

Discussion

The thermal relay and differential relay play distinct but complementary roles in the protection circuit. The differential relay is designed to detect imbalances between the live and neutral conductors, indicating ground faults. It operates by comparing the current in both conductors and triggering an alarm or disconnection if a significant difference is detected. This makes the differential relay essential for identifying ground faults, where current bypasses the neutral conductor and flows through the ground instead.

The thermal relay, on the other hand, is designed to protect against overcurrent conditions. It operates based on the principle that excessive current flow generates heat. When the current exceeds a predetermined threshold, the thermal relay heats up and eventually trips, breaking the circuit to prevent overheating and potential damage.

In the experiment, the combined use of these relays allows for comprehensive fault detection. The differential relay provides protection against ground faults, while the thermal relay guards against overcurrent conditions. By introducing controlled faults through a switch, we can test the sensitivity and reliability of both relays. For instance, simulating a ground fault will primarily test the differential relay, while an overcurrent condition will test the thermal relay.

Effective fault detection is crucial for maintaining the safety and integrity of the electrical system. The combination of thermal and differential relays ensures comprehensive protection against a wide range of fault conditions. This dual-layer protection enhances overall system reliability and safety, reducing the risk of electric shock, equipment damage, and fire.

Instruments and Components

- Red Pilot Lamp
- Green Pilot Lamp
- Differential relay
- Thermal relay
- AC Metering Module (5A)
- Power Supply Module (0-220V 3ϕ, 380V 3ϕ)
- Resistive load module
- Resistance (<800 Ω)
- Switch module

Procedure

1. Setup:

   a. Connect the circuit as shown below.

   b. Connect the two relays in series, with the differential relay connected in series with the thermal relay.

c. Configure the switch with two positions (as in previous experiments).

2. Initial Testing:

a. Set the switch to the first position.

b. Repeat the steps of PART 1.

c. Note: The differential relay pickup current is 300 mA and Pickup of the thermal relay is 0.5.

3. Ground Fault Emulation:

a. Set the switch to the second position.

b. Repeat the steps of PART 2.

4. Analysis:

What can you conclude from this experiment?

Results

During normal operation with the switch in the first position, the circuit operated at a consistent 220V AC with a current draw of 4.8A. Both relays remained in their normal state, allowing uninterrupted operation of the load. The thermal relay stayed closed, and the differential relay did not detect any discrepancies, confirming that both relays do not interfere with normal motor operation. The thermal relay tripped at 5.5A after a delay of 10 seconds, effectively preventing prolonged overcurrent exposure.

Changing the switch to the second position, the differential relay detected a discrepancy immediately, providing an instant response. The thermal relay provided a delayed trip to avoid nuisance tripping, while the differential relay offered immediate protection by detecting the current imbalance, ensuring rapid isolation of the load.

The thermal relay required a 30-second cooling period before it could reset, ensuring the system stabilized before re-engagement. The differential relay could be reset immediately after clearing the fault condition, allowing for prompt resumption of normal operations.

After resetting both relays, the motor resumed normal operation, demonstrating the reliability of the protection system in restoring normalcy after fault conditions.

Conclusion

The combination of thermal-electromagnetic and differential relays in series provides a robust protection mechanism. The thermal-electromagnetic relay offers protection against sustained overcurrent due to overload and short circuit conditions, while the differential relay provides an immediate response to earth faults.

This protection schemesignificantly enhances the safety of the electrical system by ensuring rapid detection and isolation of different fault conditions, thereby reducing the risk of damage to the motor and other equipment. The differential relay's ability to detect discrepancies instantaneously ensures that ground faults are isolated swiftly, minimizing the duration of fault conditions. The quick reset capability of the differential relay, combined with the thermal relay's automatic reset after cooling, ensures minimal operational downtime, promoting continuous and safe functioning of the motor against the overload. The electromagnetic relay ensures the rapid detection and isolation of the protected equipment when a shirt circuit appears

The coordinated response of the thermal relay prevents unnecessary trips due to transient overcurrent conditions, ensuring the motor operates smoothly under normal conditions. The combined use of both relays provides comprehensive management of different fault scenarios, including both overcurrent due to overload and short circuit and earth faults, enhancing the overall protection of the electrical system.

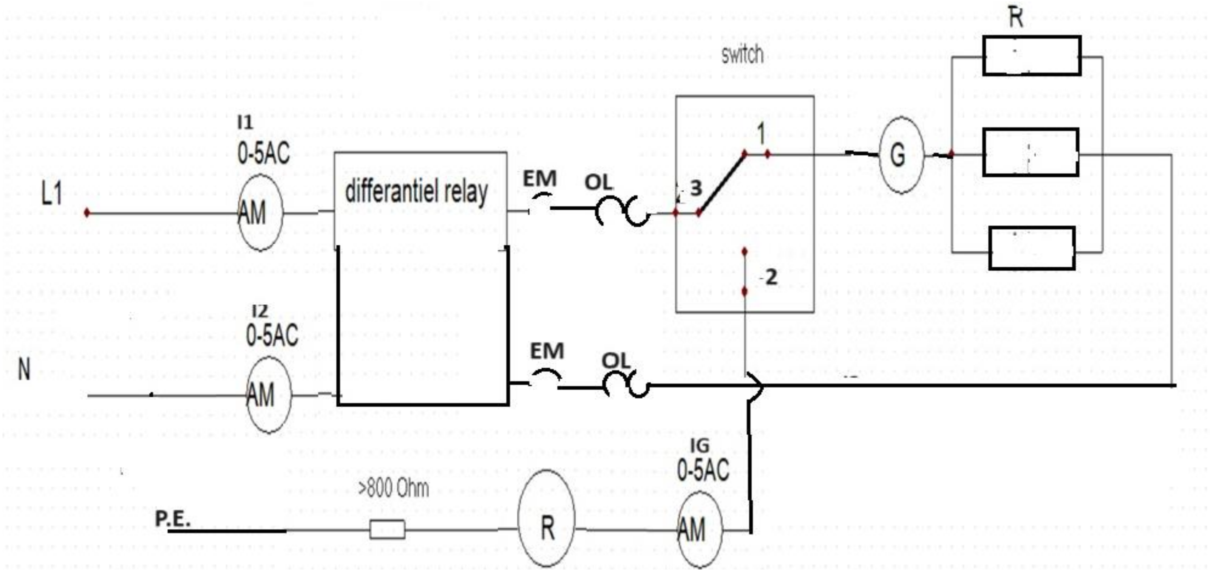


Figure 4.7: TT earthing system protection circuit diagram using both thermal-electromagnetic relay and differential relay.

4.3EXPEREMENT 3:TN-C-S EARTHIN SYSTEM PROTECTION CIRCUIT

4.3.1 PART 1: USING THERMAL-ELECTROMANETIC RELAY

Objectives

1. To design and test a protection circuit for a TNCS earthing system using a thermal6electromagnetic relay.
2. to detect and respond to both fault conditions such as overcurrent or short circuits.

Discussion

In modern electrical installations, ensuring the safety and reliability of the system is paramount. The TNCS (Terra Neutral Combined Separate) earthing system is a widely used configuration that offers a balance between effectiveness and efficiency. In a TNCS system, the neutral and protective earth (PE) conductors are combined into a single conductor (PEN) within the distribution network, simplifying the overall earthing arrangement and reducing wiring complexity.

However, despite its advantages, a TNCS earthing system is not immune to faults or overcurrent conditions that can pose risks to both people and equipment. Therefore, implementing effective protection mechanisms is essential to safeguard against potential hazards.

One such protective device commonly used is the thermal relay. Designed to detect overcurrent conditions, thermal relays play a crucial role in preventing overheating and damage to electrical circuits. By monitoring the current flow and reacting to deviations from normal operating conditions, thermal relays provide a vital layer of protection within TNCS earthing systems.

In this experiment, we will explore the design and testing of a protection circuit for a TNCS earthing system using a thermal relay. Through practical demonstration, we aim to understand the functionality of thermal relays in detecting and responding to overcurrent conditions, ensuring the safety and reliability of the electrical installation.

Instruments and components

Pilot Lamp, Red

Pilot Lamp, Green

Themal relay

AC Metering Module (5A)

Power Supply Module

(0-220V 3ϕ, 380V 3ϕ)

Resistive load module

Resistance(<800)

Switch module

Procedure

1.a) Connect the circuit shown in Fig.4.8.

b) Connect PE to the earth and N to the load and other components.

c) Install the differential relay around line and neutral conductors. The differential relay should be set to monitor the difference in current between these conductors.

c) Add a switch between the output of the relay and the resistive load which is :

- The input of the switch connected to the relay output .
- FIRST POSITION :One of the output switch connected to the resistive load
- SECOND POSITION : The other one connected the ground resistance.

2.a) Put the switch at the first position and set the resistive load at the maximum value.

b) Turn on the power supply. What happen? The green led indicates .

c) Decrease in the value of the resistive load , keep do it . what happen after a while ?

after 10 seconds the relay trip and the red lamp indicates after the green one turn off.

3.a) Change the position of the switch. What do you observe after a while ?their is no change even we wait for more than 30 seconds.

b) Increase the value of the resistive load then turn off the power supply .

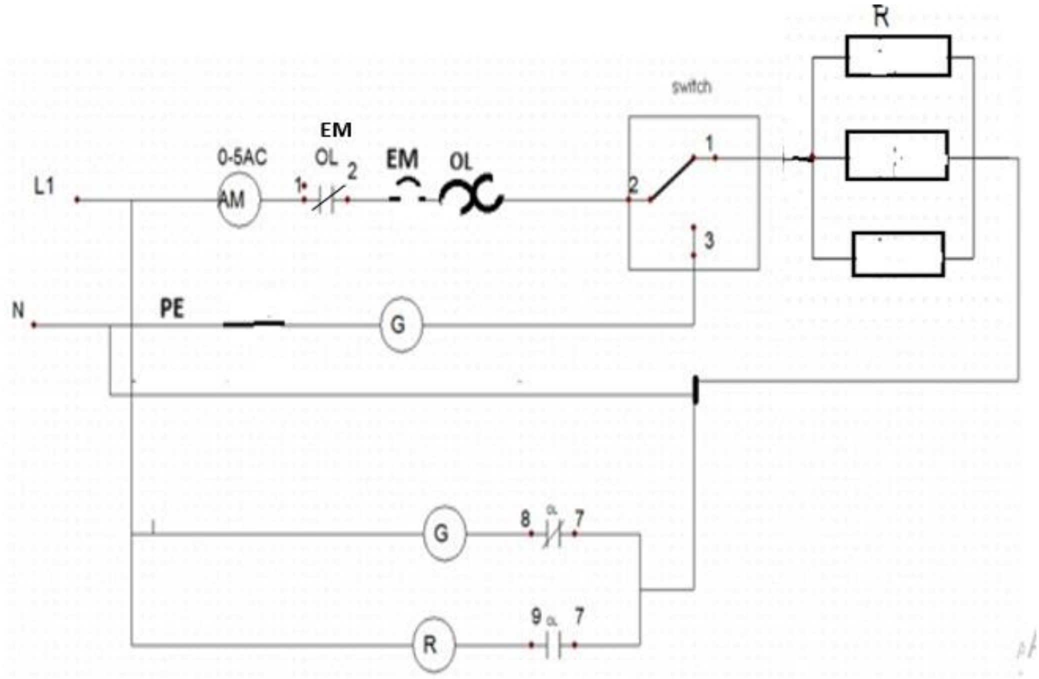


Figure 4.8: TN-Cearthing system protection circuit diagram using thermal-electromagnetic relay.

Results :

At first position , relay operate as his normal case which is closed when the fault accur and when we increase in the value of the resistive load it will trip at threshold after 10s. Theirfor, after changing the position of the switch after waiting for 30 seconds , the relay will close and back to its normal case of operating. We did not observe any change on the relay .

Conclusion :

The thermal relay is effective in detecting and responding to overcurrent conditions, it does not respond to earth faults as the PEN conductor does not cause significant current imbalance detectable by the relay.

The thermal relay did not detect the simulated earth fault since the TN-C system's combined neutral and earth path did not create a significant current imbalance..

4.3.2 PART 2: USING DIFFERENTIAL RELAY

Objectives

1. To design and test a protection circuit for a TNCS earthing system using a differential relay.

2. to detect and respond to fault conditions such as leakage currents or ground faults.

Discussion

In modern electrical systems, ensuring the safety and reliability of the earthing system is crucial to prevent potential hazards and damage to equipment. The TNCS (Terra Neutral Combined Separate) earthing system is widely employed for its efficiency and simplicity, combining the neutral and protective earth (PE) conductors into a single conductor within the distribution network.

However, despite its advantages, TNCS systems are susceptible to faults such as ground faults or leakage currents, which can pose serious risks if left undetected. Therefore, implementing effective protection mechanisms is essential to mitigate these risks and ensure the safety of the electrical installation.

One of the key protective devices used in TNCS earthing systems is the differential relay. Differential relays, also known as residual current devices (RCDs), are designed to detect imbalances between the live (line) and neutral currents. This makes them highly sensitive to ground faults or leakage currents, enabling them to provide rapid and reliable protection against electrical hazards.

In this experiment, we will explore the design and testing of a protection circuit for a TNCS earthing system using a differential relay. By simulating ground faults or leakage currents, we aim to observe the differential relay's response and evaluate its effectiveness in detecting and isolating fault conditions. Through practical demonstration, we seek to gain insights into the role of differential relays in enhancing the safety and reliability of TNCS earthing systems.

Instruments and components

Pilot Lamp, Red

Pilot Lamp, Green

Differential relay

AC Metering Module (5A)

Power Supply Module

(0-220V 3ϕ, 380V 3ϕ)

Resistive load module

Resistance(<800)

Switch module

Procedure

1.a) Repeat the same circuit at PART 1 by replacing the thermal relay with differential relay. as shown in the figure bellow.

b) Put the switch position at first position. Make sure that the resistive load at max.

Note: the differential relay pickup current is: 300 mA

c)Turn on the power supply. Is the green lamp indicate? yes, it indicates.

3.a)Change the position of the switch. What happen? explain
The red lamp indicates for less than a second then the relay trip

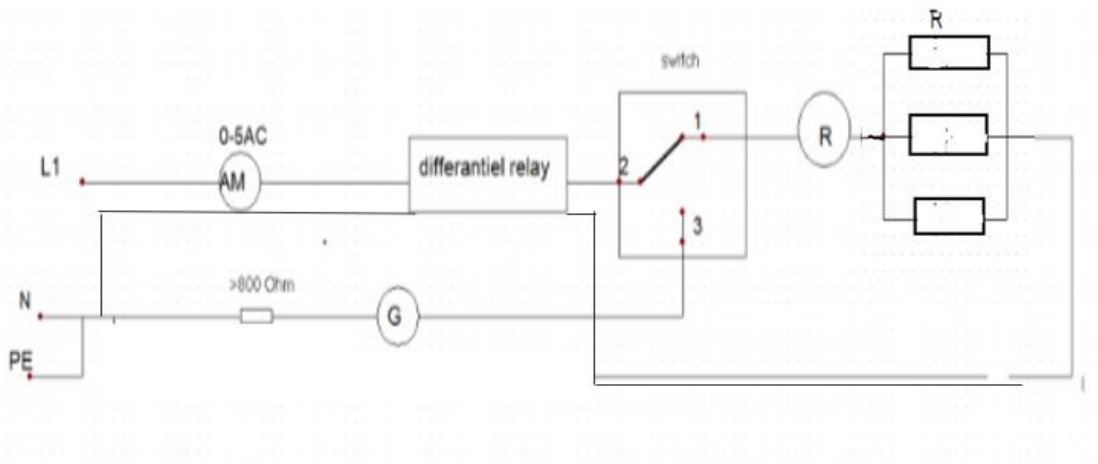


Figure 4.9: TN earthing system protection circuit diagram using differential relay.

Result:

In this experiment the relay reacts as it did in the previous experiment.

Conclusion:

The differential relay detected discrepancies and tripped instantaneously, ensuring rapid isolation of faults.
The relay effectively detected earth faults by identifying the difference between incoming and outgoing current.
The differential relay could be reset immediately after fault clearance, allowing for prompt resumption of normal operations

4.3.3PART 3: USING BOTH ‘’THERMAL AND DIFFERENTIAL RELAYS’’

Objectives

1. To design and test a protection circuit for a TNCS earthing system using both a differential relay and a thermal relay in series.
2. to detect and respond to various fault conditions, including overcurrent and ground faults.

Discussion

In the realm of electrical engineering, the assurance of safety and reliability in electrical systems is paramount. The TNCS (Terra Neutral Combined Separate) earthing system stands as a stalwart solution, widely embraced for its efficiency and cost-effectiveness. By amalgamating the neutral and protective earth (PE) conductors into a single entity within the distribution network, the TNCS configuration simplifies the intricacies of earthing arrangements and mitigates the complexities of wiring.

However, despite the inherent advantages of TNCS systems, they are not impervious to faults that can potentially jeopardize the safety of both individuals and equipment. Among these potential pitfalls, overcurrent and ground faults stand out as formidable adversaries, capable of causing significant damage if not promptly detected and rectified.

To counteract these looming threats, the integration of protective devices becomes imperative. Among the arsenal of protective apparatuses, thermal relays and differential relays emerge as stalwart guardians, each equipped with unique capabilities designed to address specific types of faults. While thermal relays specialize in the detection of overcurrent conditions, differential relays are adept at discerning ground faults or leakage currents.

The fusion of these protective entities in series heralds a holistic approach to fortifying TNCS earthing systems against multifarious fault scenarios. By orchestrating a symphony of detection and response mechanisms, this amalgamation promises to fortify the robustness of electrical installations and imbue them with an aura of invincibility against potential threats.

In this experiment, we embark on a journey to explore the intricate dance between differential and thermal relays within the confines of a TNCS earthing system. Through meticulous design and rigorous testing, we endeavor to unravel the mysteries of their symbiotic relationship and uncover the secrets to their unparalleled efficacy.

By simulating fault conditions such as overcurrent and ground faults, we aim to scrutinize the responsiveness and effectiveness of the differential and thermal relays. Through a tapestry of empirical observations and analytical insights, we aspire to unravel the intricacies of their interplay and glean invaluable lessons on the art of safeguarding TNCS earthing systems.

Through the crucible of experimentation, we seek not only to validate theoretical conjectures but also to pave the way for transformative innovations in the realm of electrical safety. As we embark on this voyage of discovery, let us chart a course towards a future where TNCS earthing systems stand as bastions of safety and reliability, fortified by the unwavering vigilance of differential and thermal relays working in perfect harmony.

Instruments and components

Pilot Lamp, Red

Pilot Lamp, Green

Differential relay

Thermal relay

AC Metering Module (5A)

Power Supply Module

(0-220V 3ϕ, 380V 3ϕ)

Resistive load module

Resistance(<800)

Switch module

Procedure

1.a) Connect PE to the earth and N to the load and other components.

b) Install the differential relay around the line and neutral conductors. The differential relay should be set to monitor the difference in current between these conductors.

c) Insert the thermal relay in series with the load. This relay will monitor the current flowing through the circuit.

d) Perform the circuit showing bellow.

2.a) Set the switch at the first position.

b) Make sure that the resistive load at maximum value.

Note: the differential relay pickup current is: 300 mA and the ground resistance greater than 800 Ohms.

c) Turn on the power supply.

d) Repeat the steps of PART 1.

3.a) Set the switch at the second position.

b) Repeat the steps of PART 2.

4. What can you conclude from this experiment?

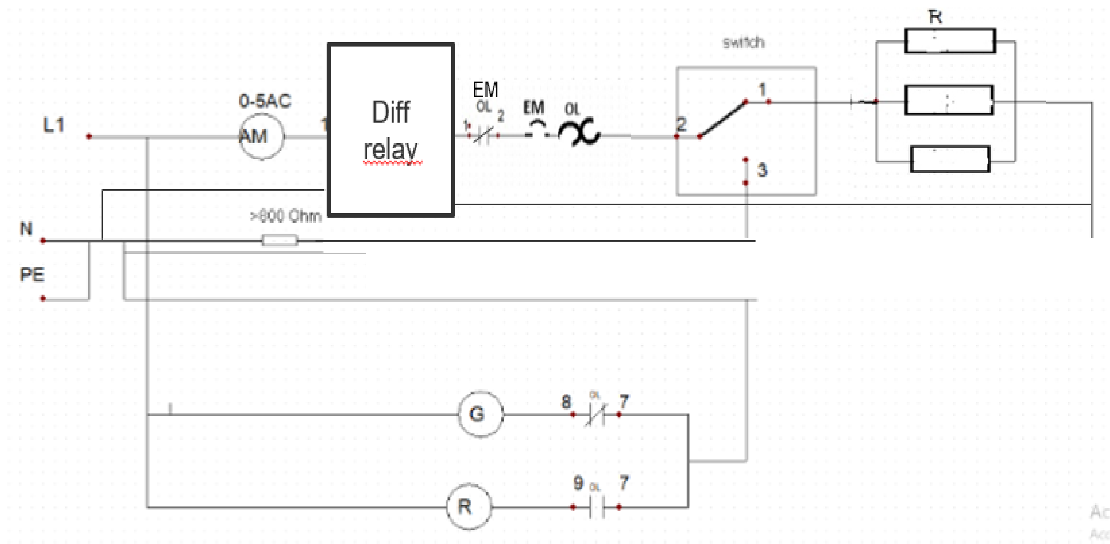


Figure 4.10: TN-C earthing system protection circuit diagram using both thermal relay and differential relay.

Results :

Also in this experiment the relays react as they did in EXPEREMNT 2 PART 3.

Conclusion:

The combined use of thermal and differential relays in a TN-C earthing system provides a robust protection mechanism. The thermal relay offers delayed response to overcurrent conditions, while the differential relay ensures immediate detection and isolation of both overcurrent and earth faults.

The combination of thermal and differential relays ensures thorough detection and response to both overcurrent and earth faults.

The thermal relay provides a delayed trip to manage sustained overcurrent conditions, while the differential relay ensures immediate response to current discrepancies.

The differential relay's instant response to earth faults enhances safety, while the thermal relay adds an extra layer of protection against prolonged overcurrent.

The differential relay's immediate response ensures rapid fault isolation, reducing the risk of damage and enhancing safety.

The thermal relay's automatic reset after cooling and the differential relay's immediate reset capability ensure quick recovery and minimal operational downtime.

The thermal relay's delayed response prevents unnecessary trips due to transient overcurrent conditions, ensuring smooth operation.

The combined protection ensures thorough management of different fault scenarios, enhancing the overall protection and reliability of the electrical system.

4.4 Experiment 4: NUMERICAL RELAY CONFIGURATIONS

Objectives

This experiment aims to provide a holistic approach to understanding and setting up numerical relays, ensuring you are equipped with the necessary skills and knowledge for effective power system protection.

Discussion

Numerical relays are advanced protection devices used in modern power systems to enhance the reliability and safety of electrical networks. Unlike traditional electromechanical relays, numerical relays utilize microprocessors to perform complex protection algorithms, providing superior accuracy, flexibility, and functionality. These relays are essential in protecting electrical equipment from faults and abnormal conditions, ensuring the continuous and safe operation of power systems.

Setting up a numerical relay involves configuring various parameters to match the specific requirements of the electrical system it protects. This process includes understanding the system's earthing type, configuring current and voltage transformer ratios, setting protection parameters, and verifying the relay's performance through comprehensive testing. The ability to program custom logic schemes and perform detailed diagnostics makes numerical relays a critical component in modern power engineering.

In this guide, we will explore the detailed steps involved in setting up a numerical relay, drawing on practical experience and best practices in the field. This will provide a thorough understanding of how to configure and test numerical relays to ensure optimal protection and performance in electrical systems

Procedure

1. Connect numerical relay to the computer; we get many choices. we have to choose « new » to get which « relay » we are dealing with. Since in IGEE;there is only 451 relay.

So we have to select it. After that; we find a lot of kind of protection in it (over current; ground fault;…. Ect). But we have to select just the one we needed.

2. Follow the following steps to input system parameters:

a) Set the system frequency (e.g., 50 Hz or 60 Hz).

b) Input the correct current transformer (CT) and voltage transformer (VT) ratios.

c) Enter the nominal voltage, current, and other relevant parameters.

3.then configurate protection settings:

a) Set the pickup current, time delays, and curves.

b) Configure sensitivity settings and time delays.

c) Set thresholds for undervoltage and overvoltage protection.

d)Configure settings for over-frequency and underfrequency protection.

e)Depending on the relay, set parameters for differential protection, distance protection, and other specific protections.

4.a) Once the configuration is complete, save the project.

b) Export the settings file if needed for use in an actual relay.

The following cuptions guides you to configurate our relay :

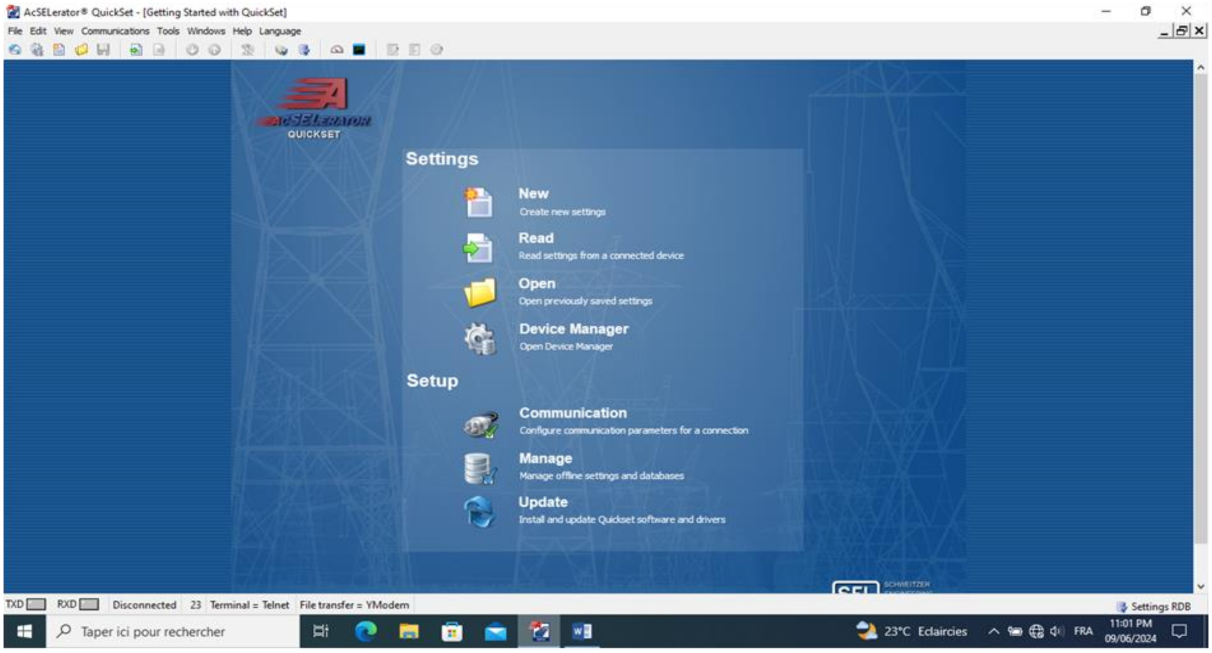


Figure 4.11: how to choose the relay type.

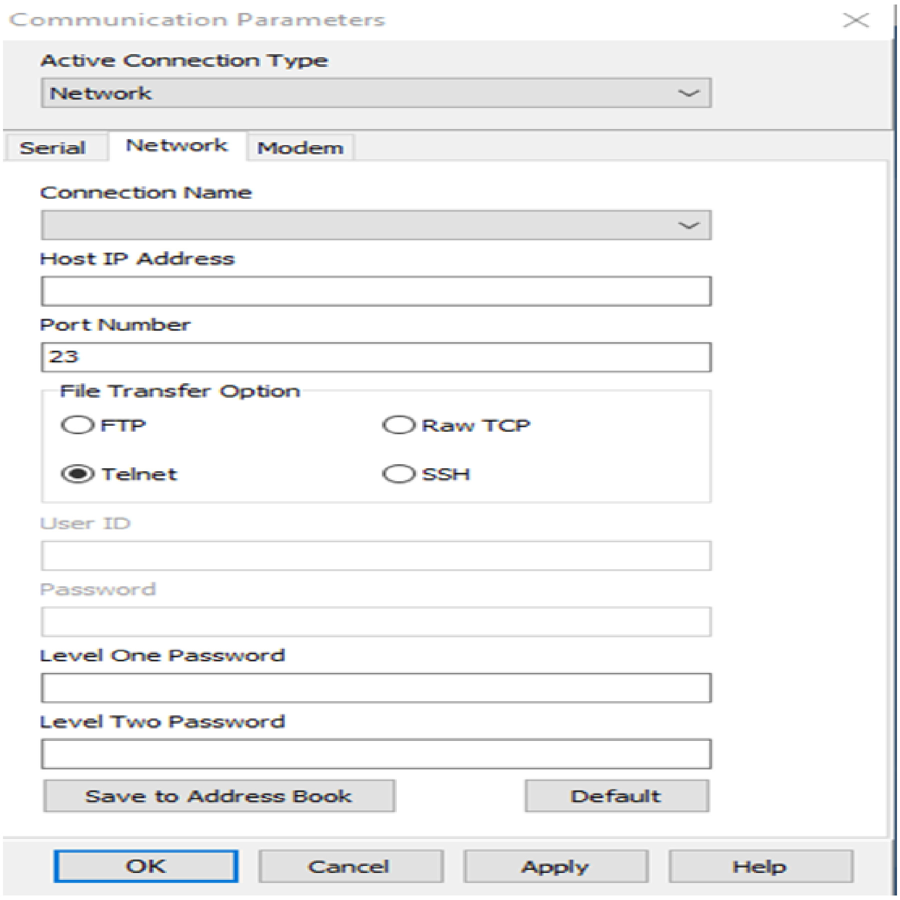


Figure 4.12: choose the parameters of the relay.

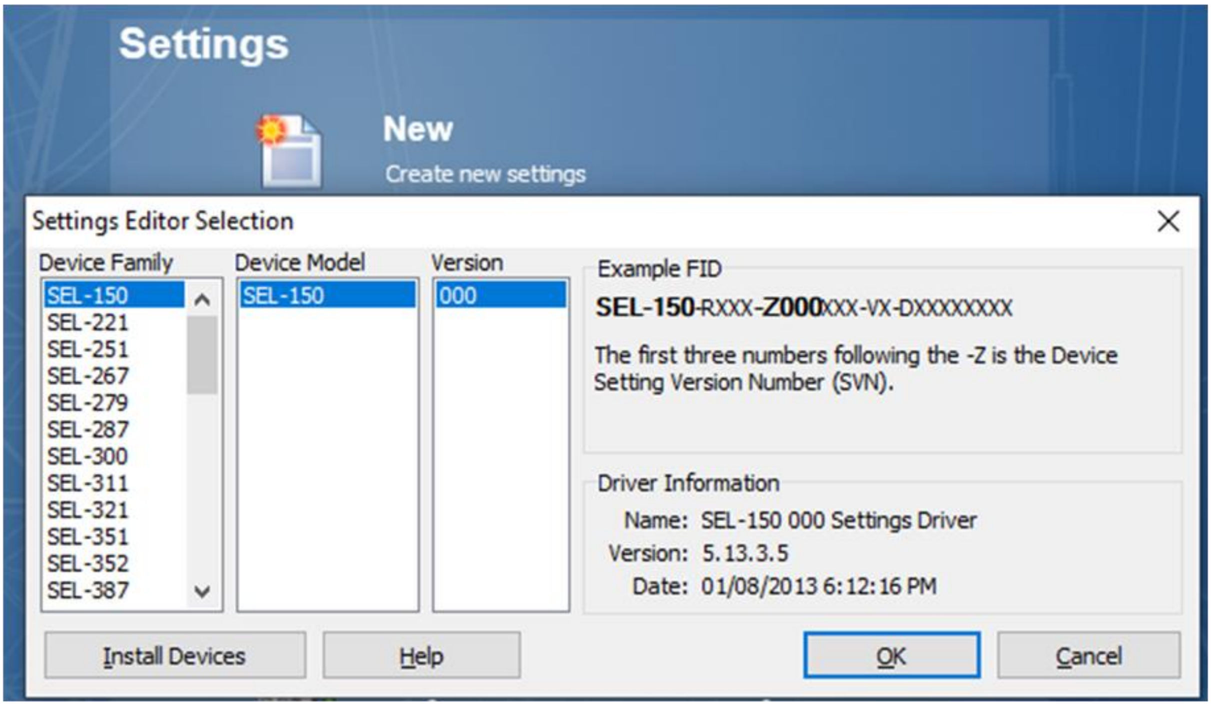
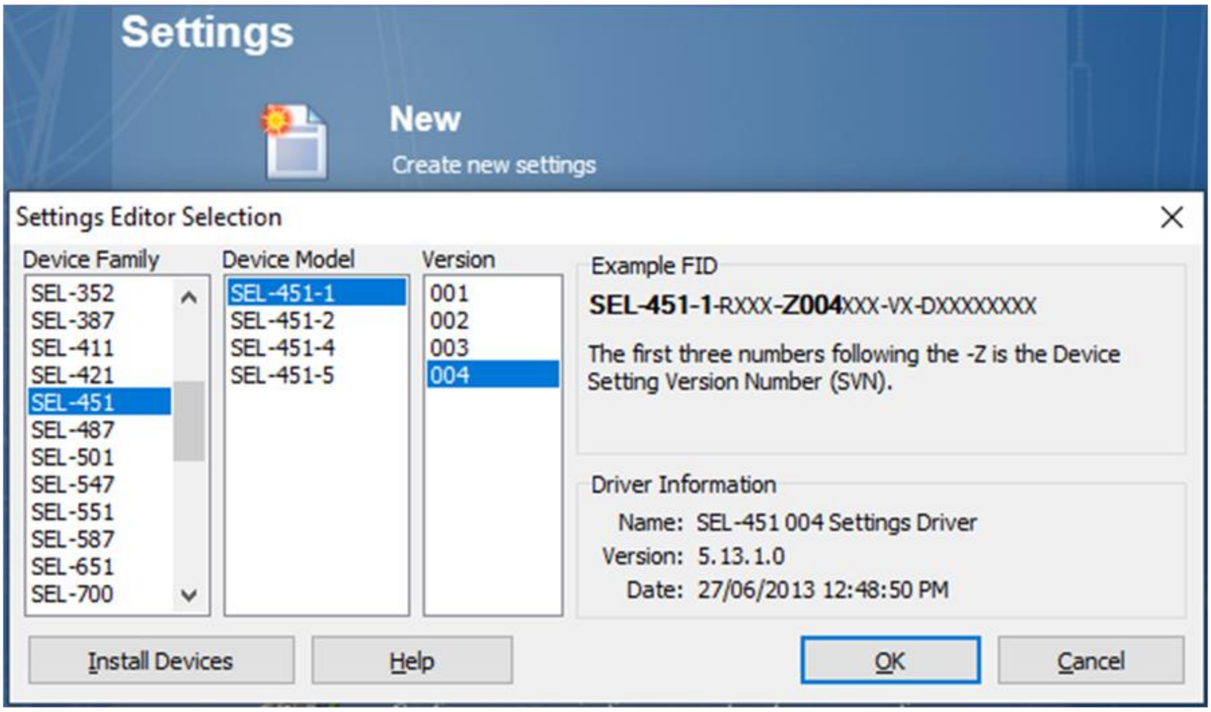
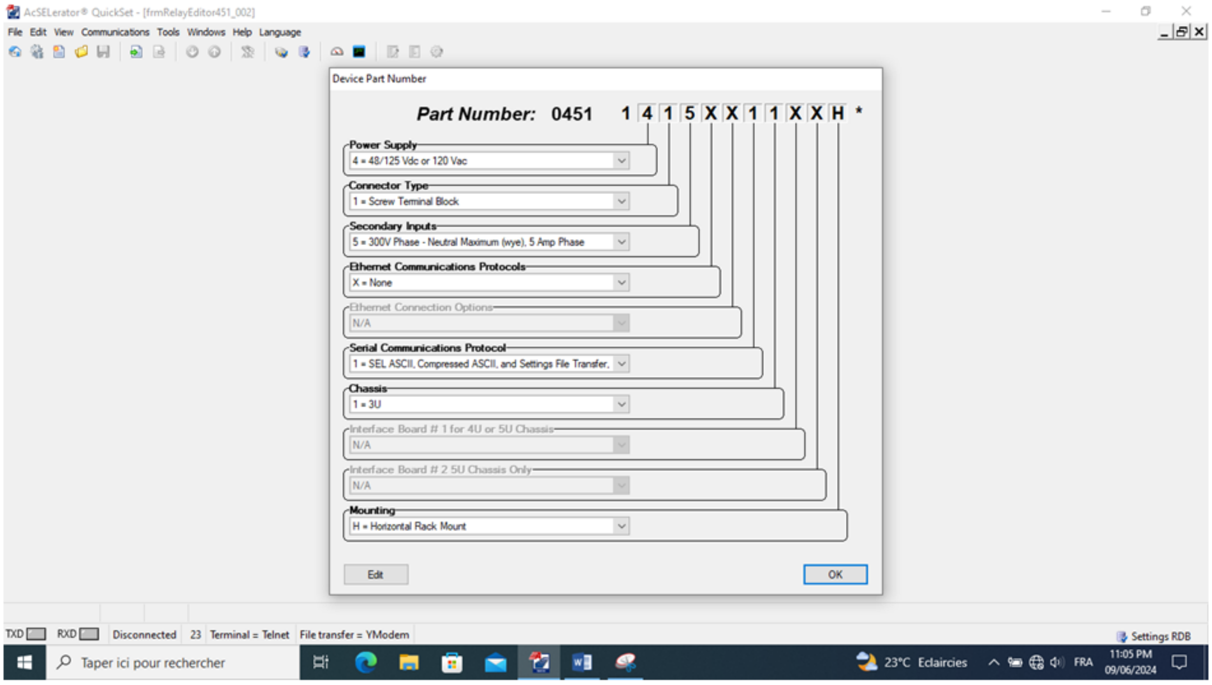
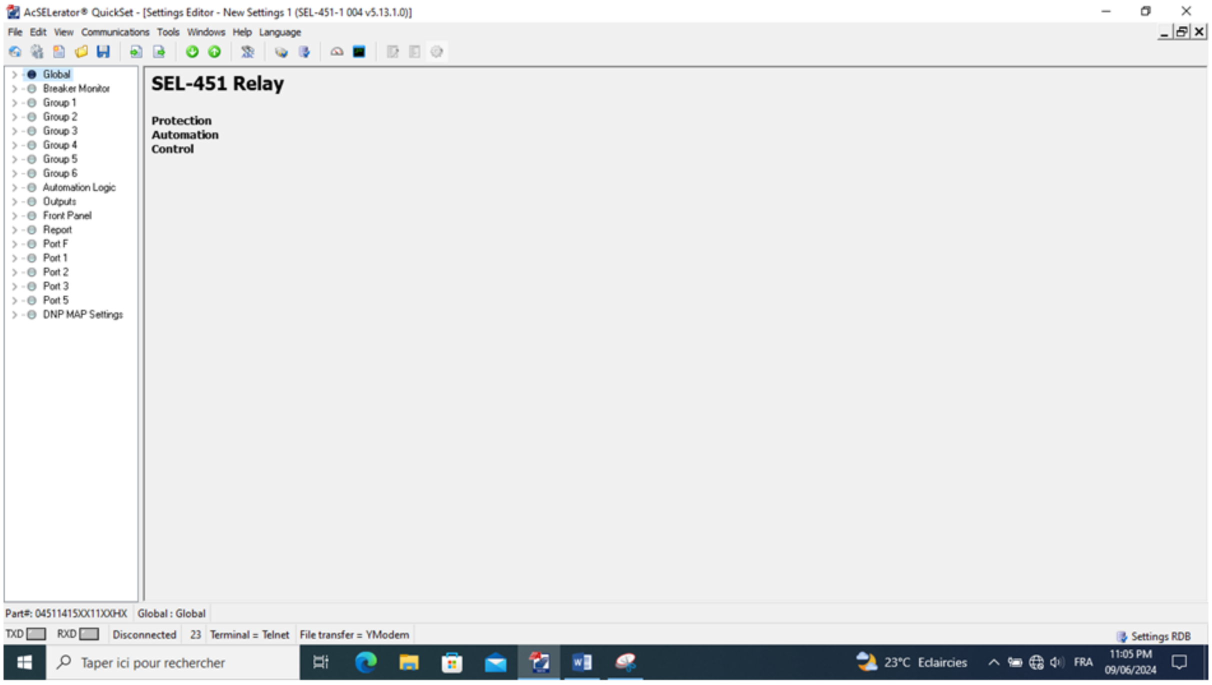


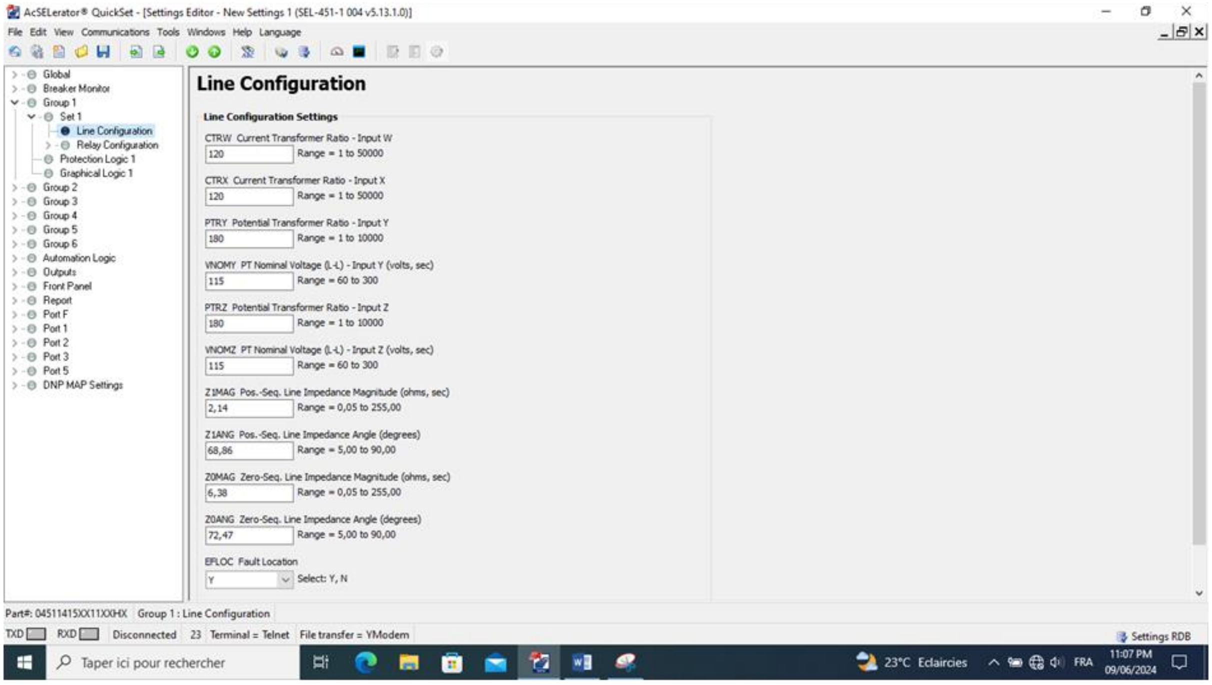
Figure 4.13: the relay type.

Following figures shows how we can configurate our relay.




AcSELerator® QuickSet - [frmRelayEditor451_002]
Device Part Number
Part Number: 0451 1 4 1 5 X X 1 1 X X H *
Power Supply
4 = 48/125 Vdc or 120 Vac
Connector Type
1 = Screw Terminal Block
Secondary Inputs
5 = 300V Phase - Neutral Maximum (wye), 5 Amp Phase
Ethernet Communications Protocols
X = None
Ethernet Connection Options
N/A
Serial Communications Protocol
1 = SEL ASCII, Compressed ASCII, and Settings File Transfer,
Chassis
1 = 3U
Interface Board # 1 for 4U or 5U Chassis
N/A
Interface Board # 2 5U Chassis Only
N/A
Mounting
H = Horizontal Rack Mount
Edit
OK


AcSELerator® QuickSet - [Settings Editor - New Settings 1 (SEL-451-1 004 v5.13.1.0)]
Global
Breaker Monitor
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Automation Logic
Outputs
Front Panel
Report
Port F
Port 1
Port 2
Port 3
Port 5
DNP MAP Settings
SEL-451 Relay
Protection
Automation
Control
Part#: 04511415XX11XXHX Global : Global


AcSELerator® QuickSet - [Settings Editor - New Settings 1 (SEL-451-1 004 v5.13.1.0)]
File Edit View Communications Tools Windows Help Language
Global
Breaker Monitor
Group 1
Set 1
Line Configuration
Relay Configuration
Protection Logic 1
Graphical Logic 1
Group 2
Group 3
Group 4
Group 5
Group 6
Automation Logic
Outputs
Front Panel
Report
Port F
Port 1
Port 2
Port 3
Port 5
DNP MAP Settings
Line Configuration
Line Configuration Settings
CTRW Current Transformer Ratio - Input W
120
Range = 1 to 50000
CTRX Current Transformer Ratio - Input X
120
Range = 1 to 50000
PTRY Potential Transformer Ratio - Input Y
180
Range = 1 to 10000
VNOMY PT Nominal Voltage (L-L) - Input Y (volts, sec)
115
Range = 60 to 300
PTRZ Potential Transformer Ratio - Input Z
180
Range = 1 to 10000
VNOMZ PT Nominal Voltage (L-L) - Input Z (volts, sec)
115
Range = 60 to 300
Z1MAG Pos.-Seq. Line Impedance Magnitude (ohms, sec)
2,14
Range = 0,05 to 255,00
Z1ANG Pos.-Seq. Line Impedance Angle (degrees)
68,86
Range = 5,00 to 90,00
Z0MAG Zero-Seq. Line Impedance Magnitude (ohms, sec)
6,38
Range = 0,05 to 255,00
Z0ANG Zero-Seq. Line Impedance Angle (degrees)
72,47
Range = 5,00 to 90,00
EFLOC Fault Location
Y
Select: Y, N
Part#: 04511415XX11XXHX Group 1 : Line Configuration
TXD RXD Disconnected 23 Terminal = Telnet File transfer = YModem
Settings RDB
Taper ici pour rechercher
23°C Eclaircies
FRA
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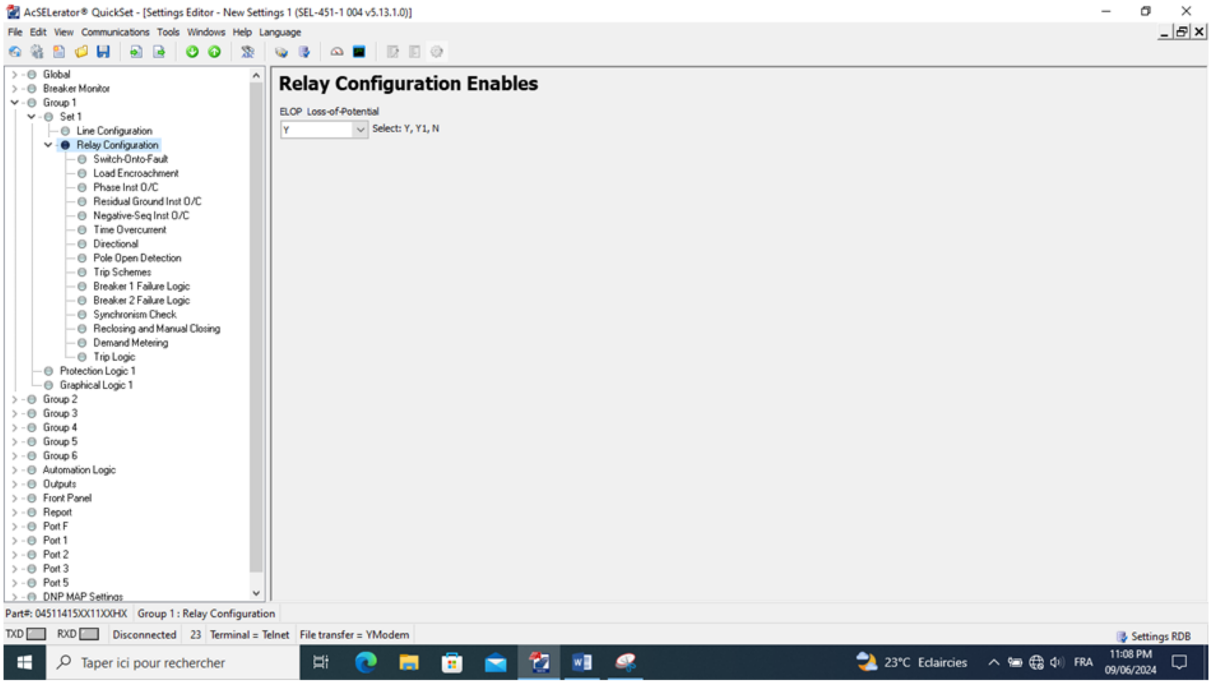
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Switch-Onto-Fault
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Phase Inst O/C
Residual Ground Inst O/C
Negative-Seq Inst O/C
Time Overcurrent
Directional
Pole Open Detection
Trip Schemes
Breaker 1 Failure Logic
Breaker 2 Failure Logic
Synchronism Check
Reclosing and Manual Closing
Demand Metering
Trip Logic
Protection Logic 1
Graphical Logic 1
Group 2
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Group 4
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DNP MAP Settings
Relay Configuration Enables
ELOP Loss-of-Potential
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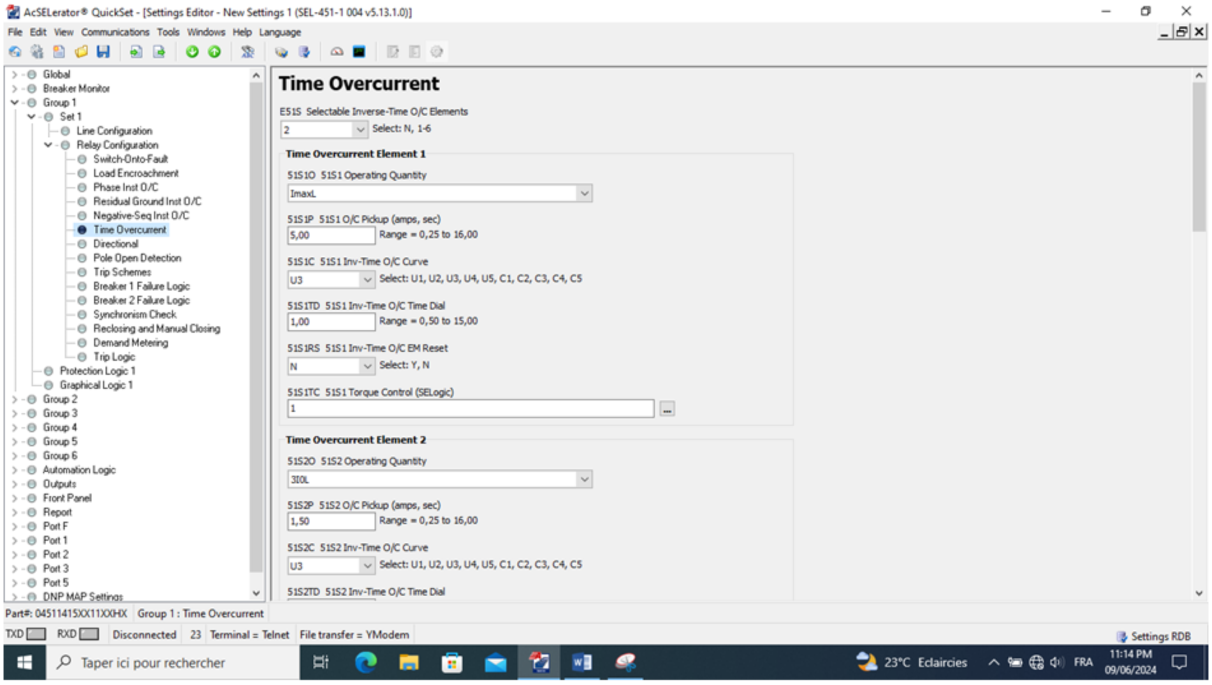

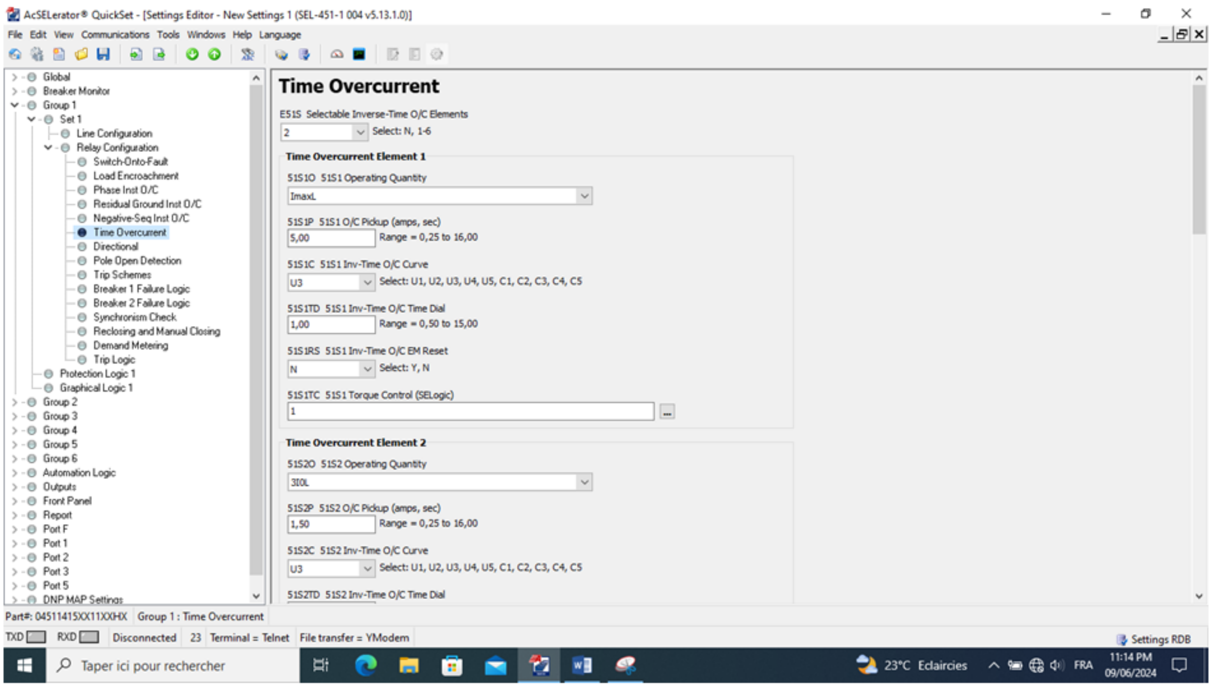

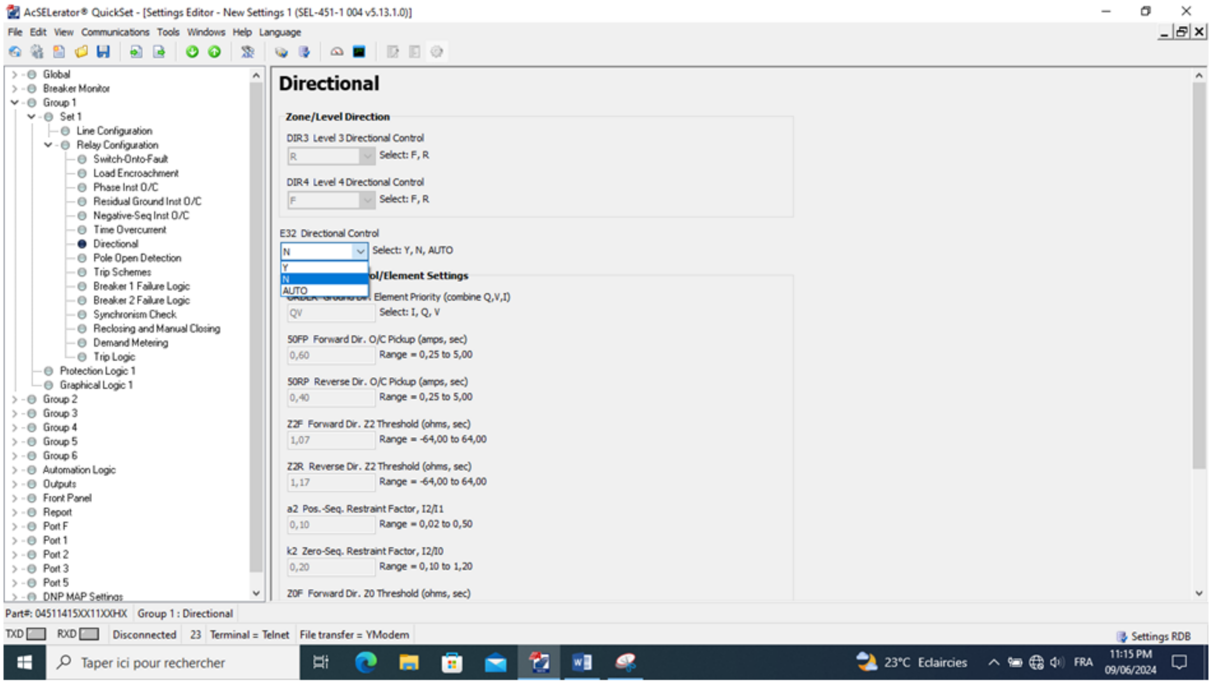

Conclusion

Configuring a numerical relay using simulation software is a critical task that significantly enhances the protection, reliability, and efficiency of electrical systems. This process involves several detailed steps that ensure the relay is correctly set up to respond appropriately to various fault conditions.

By starting with the installation and setup of the relay configuration software, users can create a new project tailored to their specific needs. Selecting the appropriate relay model and inputting accurate system parameters such as system frequency, CT and VT ratios, and nominal values is crucial. These initial steps lay the groundwork for precise and effective relay operation.

Configuring the protection settings is a core part of the setup process. Users must carefully set parameters for overcurrent protection, earth fault protection, voltage protection, and frequency protection, among other specific protections. Each setting needs to be calibrated to match the characteristics and requirements of the electrical system being protected.

Communication settings are another important aspect, particularly for systems that require remote monitoring and control. Properly configuring IP addresses, baud rates, and other communication parameters ensures seamless integration and functionality within the broader system.

One of the most valuable features of using simulation software is the ability to simulate fault conditions. This allows users to create various fault scenarios and observe how the relay responds. By testing and adjusting settings based on these simulations, users can fine-tune the relay's performance to ensure it acts correctly and promptly during real-world fault conditions.

Saving and exporting the configuration settings, generating detailed reports, and documenting the entire configuration process are essential final steps. These practices not only provide a record of the settings but also facilitate easier troubleshooting and future adjustments if needed.

Overall, the use of simulation software for configuring numerical relays offers a safe, efficient, and highly accurate method for preparing relays for operation. This approach minimizes risks, enhances the reliability of protection systems, and ensures that the relays are ready to safeguard the electrical system effectively.

Conclusion

The completion of the project "Design and Implementation of Laboratory Papers on Protective Relays for Master Students" represents a significant advancement in the methodologies of graduate-level electrical engineering education. This project has effectively bridged the gap between theoretical knowledge and practical application, focusing on the critical role of protective relays in power system engineering. It has provided a robust framework for practical learning, equipping students with essential skills and enhancing the overall quality of the academic program.

The project begins with the foundational principles outlined in the first chapter, delving into the intricacies of electrical system protection. This chapter provides an in-depth analysis of the necessity for protective systems to maintain the reliability and stability of power networks. Various types of faults, including short circuits, overloads, ground faults, and earthing faults, are explored in detail. Earthing faults, in particular, are highlighted due to their significance in grounding systems and their role in enhancing safety and preventing equipment damage. Understanding these principles is crucial for appreciating the subsequent discussions on protective relays. The detailed exploration of earthing faults provides students with a clear understanding of the impact of these faults on power systems, setting the stage for the practical experiments conducted later in the project.

The second chapter focuses on the specifics of protective relays, detailing their evolution and technological advancements. The transition from electromechanical relays, which rely on physical movement to operate, to static relays that use electronic components, and finally to digital and numerical relays, which employ microprocessors and sophisticated algorithms for enhanced accuracy and functionality, is examined comprehensively. The chapter provides an overview of relay operation principles, including concepts such as pickup, drop-off, time delay, and selectivity. By understanding these principles, students can better appreciate the critical functions these devices perform in ensuring the safety and efficiency of electrical systems. The detailed discussions on each type of relay, their operational mechanisms, advantages, and typical applications, provide students with a solid theoretical foundation.

The third chapter provides a detailed examination of the specific relays utilized in our experiments: thermal relays, differential relays, and numerical relays. Each relay type is discussed comprehensively, including their operational mechanisms, advantages, and typical applications.

Thermal relays operate based on the principle of thermal expansion. They are primarily used for overload protection in motors and other electrical equipment. When the current exceeds a certain threshold, the heat generated causes a bimetallic strip to bend, triggering the relay and disconnecting the circuit. The advantages of thermal relays include their simplicity, reliability, and ability to provide continuous protection without requiring complex settings. They are particularly effective in protecting against prolonged overloads, which can cause overheating and damage to equipment. The discussion on thermal relays highlights their importance in providing basic yet essential protection in various electrical systems.

Differential relays are used for protecting equipment such as transformers, generators, and busbars. They operate by comparing the current entering and leaving the protected zone. Under normal conditions, the currents are equal, and the relay remains inactive. However, if a fault occurs within the protected zone, the currents become unbalanced, triggering the relay. Differential relays are highly sensitive and provide fast and accurate fault detection. They are essential for detecting internal faults that might not be evident through other protection methods, ensuring the integrity of critical power system components. The detailed exploration of differential relays underscores their role in providing precise and reliable protection for critical electrical infrastructure.

Numerical relays represent the latest advancement in relay technology, utilizing microprocessors to perform complex protection functions. These relays offer significant advantages in terms of accuracy, versatility, and communication capabilities. Numerical relays can perform multiple protection functions within a single device, reducing the need for multiple discrete relays. They also support advanced features such as self-diagnostics, remote monitoring, and integration with substation automation systems. Numerical relays are highly adaptable, allowing for easy reconfiguration and updating of protection schemes to accommodate changes in the power system. The comprehensive discussion on numerical relays highlights their versatility and advanced features, emphasizing their importance in modern power systems.

The final chapter presents a series of practical experiments designed to apply the theoretical knowledge gained. These experiments include designing and implementing an electrical protection circuit using a thermal relay, protecting a TT earthing system using thermal and differential relays both individually and in combination, protecting a TNC earthing system using thermal and differential relays both individually and in combination, and exploring the settings of numerical relays.

The first experiment involves designing and implementing an electrical protection circuit using a thermal relay. Students design and implement an electrical protection circuit using a thermal relay, evaluating the relay's response to various overload conditions. This experiment emphasizes the importance of proper calibration to ensure effective protection without unnecessary interruptions. The hands-on experience gained from this experiment allows students to understand the practical applications of thermal relays in real-world scenarios.

The second experiment focuses on the TT earthing system protection, conducted in three parts. In the first part, students analyze the protection of a TT earthing system using a thermal relay, observing its response to fault conditions. In the second part, the experiment continues with the protection of the TT earthing system using a differential relay, highlighting its accuracy and speed in fault detection. In the final part, students combine both thermal and differential relays to study the complementary protection provided by these devices, enhancing the overall reliability and effectiveness of the protection scheme. This multi-faceted approach provides students with a comprehensive understanding of how different types of relays can be used together to improve system protection.

The third experiment mirrors the second but focuses on the TNC earthing system protection, also conducted in three parts. In the first part, students assess the TNC earthing system protection using a thermal relay. The next part involves using a differential relay to protect the TNC earthing system, emphasizing its capability in identifying internal faults. Finally, students combine the use of both relays, examining the enhanced protection provided by integrating these technologies. This experiment reinforces the concepts learned in the second experiment, while also highlighting the differences between TT and TNC earthing systems.

The fourth experiment is centered on numerical relay settings. In this experiment, students focus on the general settings and configuration of numerical relays. They explore the relay's advanced features, such as programmable logic, communication capabilities, and integration with automation systems. This activity provides a comprehensive understanding of the versatility and functionality of numerical relays. By interacting with advanced relay settings and configurations, students gain valuable insights into the practical applications of numerical relays in modern power systems.

These practical exercises allow students to interact directly with the relays, simulating real-world scenarios and gaining hands-on experience. The key outcomes of this project include an enhanced learning experience, valuable skill development, curriculum improvement, increased student engagement and motivation, opportunities for research and innovation, and professional preparedness.

The practical approach of the laboratory papers provides a deeper understanding of protective relays, effectively linking theoretical concepts with real-world applications. Students gain firsthand experience in testing and configuring relays, which reinforces their theoretical knowledge and improves their problem-solving skills. This hands-on experience is crucial for preparing students for their future careers in the power engineering industry.

Students acquire valuable skills in using modern relay testing equipment and simulation software. These skills are essential for their future careers, preparing them to handle the challenges of designing, implementing, and maintaining reliable power systems. The hands-on experience also fosters a greater appreciation for the complexities and nuances of protective relay technology.

The integration of these laboratory papers into the existing curriculum significantly enriches the educational experience. The structured, practical assignments complement the theoretical lessons, ensuring a well-rounded understanding of protective relays. This alignment with current industry standards and technological advancements enhances the overall quality of the academic program.

Feedback from students indicates a high level of engagement and satisfaction with the laboratory exercises. The interactive and relevant nature of the experiments fosters greater student interest and enthusiasm. By directly involving students in practical tasks, the project helps to sustain their motivation and commitment to learning.

The project also opens opportunities for further research and innovation in protective relay technology. By working on advanced concepts and technologies, students are encouraged to explore new ideas and contribute to the ongoing development of the field. The hands-on experience provides a solid foundation for future research projects and professional endeavors.

Ultimately, the laboratory papers help prepare students for their professional careers in the power engineering industry. By simulating real-world engineering challenges, the laboratory exercises develop students' problem-solving skills, critical thinking, and technical expertise. These competencies are essential for success in designing, implementing, and maintaining reliable and efficient power systems.

The success of this project suggests several future directions, including the integration of emerging technologies, enhanced simulation capabilities, collaboration with industry partners, and expanded research opportunities. Future iterations of the laboratory papers could incorporate emerging technologies such as renewable energy integration, smart grid applications, and advanced communication protocols. This would ensure that the curriculum remains relevant and up-to-date with industry trends.

Improving the simulation capabilities of the laboratory exercises could provide students with even more realistic and comprehensive training experiences. Advanced simulation tools could model complex power system scenarios, allowing students to test and analyze protection schemes under a variety of conditions.

Collaborating with industry partners could enhance the practical relevance of the laboratory papers. Industry partners could provide access to state-of-the-art equipment, share insights on current challenges and innovations in the field, and offer internship opportunities for students.

The laboratory papers could serve as a foundation for expanded research opportunities. Students could undertake independent research projects based on the laboratory exercises, exploring new protection methods, relay technologies, and applications in greater depth.

In conclusion, the "Design and Implementation of Laboratory Papers on Protective Relays for Master Students" project has made a substantial contribution to electrical engineering education. It has provided a robust framework for practical learning, equipped students with essential skills, and enhanced the overall quality of the academic program. This project serves as a model for future educational initiatives aimed at integrating practical experience with theoretical learning, ensuring that graduates are well-prepared to meet the demands of the modern engineering landscape. The integration of theoretical knowledge with hands-on experiments has not only enriched the learning experience but has also prepared students to tackle real-world challenges in their future careers.

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