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Titled

Study and protection the basic faults for medium voltage motors

Defended in front of the jury composed of:

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Dedication

With profound gratitude, I dedicate this work to my father and mother, whose boundless love and dedication have made everything possible.

*To **my wife** and my children **"Zakaria", "Djaida", "Meriem", "Yahya"** whose laughter and unwavering support have been my strength.*

*To All the members of HolcimLafarge HAMMAM DALLAA, moderatey mentioned: **Mr ZITOUNI, Mr BOUGUERRA, Mr BERROUDJI, Mr HAMADOU, Mr BOURASS** whose steadfast support and presence have been invaluable.*

To all help me to complete this memory

*To my dear supervisor **DJERIOU Salim**, I would like to express all my gratitude and respect. I present this work to you with great pride and gratitude for your enlightened guidance.*

Acknowledgments

First and foremost, we extend our deepest gratitude to Almighty God for bestowing upon us the strength, health, and perseverance to navigate through the challenges and triumphs of these long years.

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Additionally, we would like to extend our gratitude to all the members of the jury for their willingness to evaluate our work and provide their esteemed perspectives. Your time and insights are greatly appreciated.

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Thank you all for being a part of this significant milestone in our lives.

Abstract

Medium voltage (MV) motors play a critical role in industrial applications, where reliability and operational continuity are essential. These motors are subject to various electrical and mechanical faults that can lead to significant downtime, equipment damage, and safety hazards if not properly addressed.

This work aims to provide a comprehensive understanding of MV motors uses in LAFARGEHOLCIM company located on the Hammam Dallaa, Msila. In addition, an investigations of the fundamental and methods of protection fault focuses on the types of faults commonly encountered, such as line to line faults, ground faults, overcurrent, also thermal overloads. Furthermore, an analyzing protection strategies including the protective relays, circuit breakers, thermal sensors and differential protection schemes uses in industrial environments.

Key words:

Medium voltage, line-to-line faults, ground faults, overcurrent, undervoltage, thermal overloads, protective relays, circuit breakers, thermal sensors, differential protection schemes

ملخص

تلعب محركات الجهد المتوسط (MV) دورًا حاسمًا في التطبيقات الصناعية، حيث تُعد الموثوقية واستمرارية التشغيل أمرًا بالغ الأهمية. تتعرض هذه المحركات لأعطال كهربائية وميكانيكية متنوعة قد تؤدي إلى توقف كبير عن العمل، وتلف المعدات، ومخاطر تتعلق بالسلامة إذا لم تُعالج بشكل صحيح.

يهدف هذا العمل إلى توفير فهم شامل لاستخدامات محركات الجهد المتوسط في شركة LAFARGEHOLCIM الواقعة في حمام الضلعة، المسيلة. بالإضافة إلى ذلك، تركز التحقيقات في أساسيات وطرق الحماية من الأعطال على أنواع الأعطال الشائعة، مثل أعطال الخط إلى الخط، وأعطال التأريض، والتيار الزائد، بالإضافة إلى الأحمال الحرارية الزائدة. علاوة على ذلك، يتم تحليل استراتيجيات الحماية، بما في ذلك مرحلات الحماية، وقواطع الدائرة، وأجهزة الاستشعار الحرارية، وأنظمة الحماية التفاضلية المستخدمة في البيئات الصناعية.

الكلمات المفتاحية: الجهد المتوسط, أعطال الطور إلى الطور، أعطال التأريض، التيار الزائد، انخفاض الجهد، الحمل الزائد الحراري، قواطع الدائرة، المستشعرات الحرارية، أنظمة الحماية التفاضلية.

List of abbreviations

HV	High Voltage
MV	Medium Voltage
LV	Low Voltage
AC	Alternatif Current
DC	Direct Current
Hp	Horsepower
RTD	Resistance Temperature Detector
VSD	Variator Speed Driver
VFD	Variator Frequency Driver
IOC	Instantaneous Overcurrent
TOC	Time Overcurrent
DOL	Direct-On-Line
CT	Current Transformer
VT	Voltage Transformer
GIS	Gas Insulated Switchboards
AIS	Air Insulated Switchboard
HMI	Human Machine Interface
FUPLA	FUnction Programming Language
CB	Circuit Breaker
LED	Light Emitting Diode
LCD	Liquid Crystal Display
IEC	International Electrotechnical Commision
REF	Reference
AR	Auto Reclosure

Liste of Symbols

I_{1s}	the current on the primary side of the concerned current transformers
I_{2s}	the current on the secondary sides of the concerned current transformers
I_d	differential protection current

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GENERAL INTRODUCTION

General Introduction

Electric motors are part of our everyday environment and are fitted in our household appliances as well as the buildings in which we live. They are used for their motive power (driving force) in a wide variety of applications.

A distinction is made between several types of electric motor: asynchronous motors are regularly used in commercial and industrial applications. Single-phase asynchronous motors are more commonly used in domestic applications and building services, whereas other motors, such as synchronous motors and DC motors, are used in more specific applications.

Although most motors in our environment are single-phase, some applications call for the use of motors operating on all three phases, in order to boost the power. This is notably the case for applications in commercial environments (ventilation, air conditioning, etc), in industrial environments (pumps, compressed air, assembly lines) and for industries such as water (pumping), extracting materials (conveying, crushing) and even construction (lifting). Three-phase motors have very high power ratings (more than 400 kW) but the majority of them are low-power: more than 3/4 of three-phase asynchronous motors sold commercially have a power rating of less than 2.2 kW 400 V.

Motor protection is used to prevent damage to the electrical motor, such as internal faults in the motor. Also external conditions when connecting to the power grid or during use have to be detected and abnormal conditions must be prevented. Additionally, the protection relay prevents the disturbance to spread back into the grid.

Motor protection schemes have several protection functions to consider:

- Motor horsepower rating and type
- Supply characteristics such as voltage, phases, method of grounding, and available short-circuit current
- Vibration, torque, and other mechanical limits
- Nature of the process
- Environment of motor, associated switching device
- Hot and cold permissible locked-rotor time and permissible accelerating time
- Time versus current curve when starting the motor
- Frequency of starting

The protection relays provide main protection for synchronous and asynchronous motors. They can be used for circuit-breaker and contactor-controlled motors in a variety of drive applications, such as, motor drives for pumps, fans, compressors, mills and crushers.[6]

CHAPTER I

Medium voltage (MV) motors

I.1. Introduction

In this chapter, we begin by exploring the fundamental concepts of electric motors, then a motor is an electric machine that converts electrical energy to mechanical energy with typical 98% efficiency. Also it is powered from an external electric AC or DC power source.

The energy generated by the motor, also known as mechanical energy, can be used to drive several different types of equipment such as, pumps, compressors, fans, etc.

The power a motor generates determines how it is rated, and is measured in either kilowatts (kW) or horsepower (Hp). Horsepower and kilowatts the standard unit of measure for electric motors. One horsepower is equivalent to 746 watts.

Before we go any further, it would probably be wise to establish what is considered a medium voltage motor. the voltage motors are between 600 V and 11 kV, with the most common voltages being 2.3 kV, 4 kV, 4.16 kV, 6.6 kV, and 7.2 kV. These are usually form coil wound motors, and many times they are custom motors. There are still plenty of standard medium voltage motors.

I.2. Overview:

Medium voltage motors are widely applied to plant rotating machinery like compressors, pumps, fans, extruders, mills etc., ranging from a few horsepower to tens of thousands of horsepower. Safe, reliable and successful application of these motors require a system level approach. The focus of the tutorial will be application topics that can be used right away to specify, evaluate, procure and install a successful MV motor system. The dimensions of the course will be medium voltage (>2.3kv) and motor power ranging from 500HP thru 100,000HP.

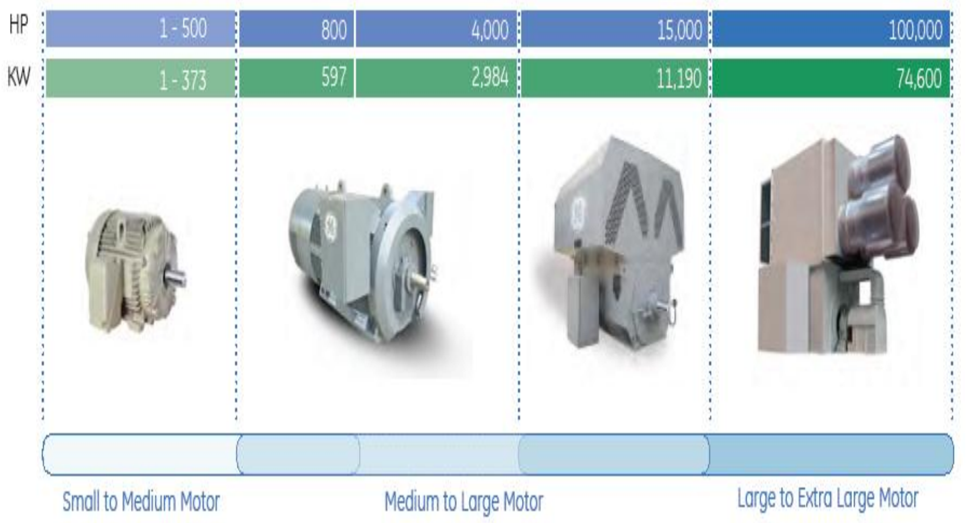


Figure 1.1 Motor power range

I.3. Motor Application Considerations

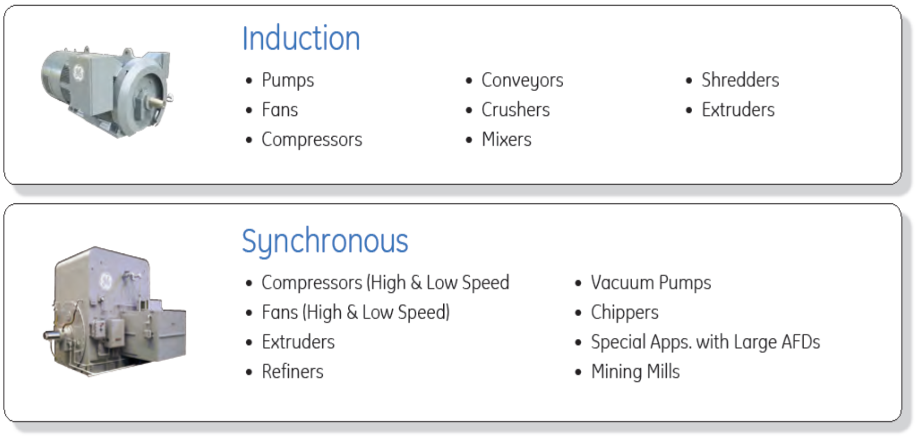


Figure 1.2 Typical applications for Induction and synchronous motors

I.3.1. Key Differences

Table 1.1 Key differences between inductions and synchronous motors

INDUCTION	SYNCHRONOUS
MV= High Efficiency	+~2% Higher Efficiency
Slip	No Slip
Good Starting torque	No Starting torque
Lagging Power Factor	Unity Power Factor
Soft Speed Control	Precision Speed Control
Lower CAPEX	Lower OPEX
Easy to start	VSD, Pony motor or Damper bars req.

I.3.2. Motor voltages

The difference between Low Voltage (LV) and Medium Voltage (MV) motors primarily lies in their operating voltage range, the figure -3- shows the difference between them in the voltage.

Figure 1.3 motor voltages

I.4. Definitions

Induction motors are the "standard" industrial motors with over +99% being Induction. It is an induction motor if it runs less than the "synchronous" speed. It is approx. 1785 not 1800 (% difference is "slip"). The reason is the power is "induced" on the rotor. Also called a squirrel cage motor.

I.5. Asynchronous or induction motor, characteristics and operation

An asynchronous motor is an electric motor powered by alternating current in which the speed of rotation of the rotor is different from that of the magnetic field of the stator. This type of motor is also known as an induction motor.

The induction motor is composed of a rotor and a stator, in which the inductor coils are located. The inductor coils are three-phase and are 120º out of phase with each other.

The asynchronous motor is based on the currents induced in the rotor from the stator's magnetic field; that's why it's called an induction machine.

In order to induce an electric current in the rotor, it is necessary for the rotor to be subjected to a variation in the magnetic flux generated by the stator at the supply frequency, or synchronism. Consequently, the rotor demagnetizes when it reaches synchronism since it does not see magnetic flux variation.

For this reason, the rotor rotates at a different speed than the stator field and therefore rotates asynchronously. In these motors, the rotating magnetic field has a synchronous speed according to the frequency of the feeder line.

An important characteristic of the asynchronous or induction motor is that the speed of the rotor, and therefore the power, cannot be varied gradually. The operating speed of induction motors depends on the supply frequency and the number of poles.

I.6. Asynchronous motors the most used in the industry

Induction motors are the most widely used motors in the industry due to their robustness and price, especially the three-phase asynchronous motor.

This success is mainly due to the following reasons:

- Compared with other electric motors of the same power, its cost is lower.
- These are engines of great simplicity with great ease of maintenance.
- The asynchronous motor has better performance compared to the single-phase motor. For this reason, the single-phase motor is relegated to small power appliances and household appliances.

Induction motors are also widely used in the construction of electric vehicles.

I.6.1. Induction motor work

The stator coil is powered by an alternating current. Thanks to the arrangement of the pole pairs, out of phase with each other, the current generates a general magnetic field that rotates in space with the same frequency as the supply current. This magnetic field is called the stator field or rotating field.

The rotor winding is immersed in this rotating magnetic field. Since the rotor rotates slower than the stator field, the magnetic flux subtended by the rotor winding varies; consequently, the rotating magnetic field induces currents in the rotor by magnetic induction (Faraday's law).

These induced currents, in turn, generate a rotor magnetic field, which opposes flux variations. The rotor's magnetic field interacts with the stator field, generating a torque in the rotor winding that causes the rotor to turn. The rotation of the rotor provides the mechanical energy that we can take advantage of.

In fact, according to Lenz's law, the induced magnetic field in the rotor always has the opposite direction with respect to the stator.

Induction in the rotor can only occur if the relative velocities of the stator and rotor fields are different. For this reason, the rotor always rotates at a speed lower than that of the rotating field.

I.7. Asynchronous motor types

The classification between different types of asynchronous motors depends on the voltage of the alternating current that is used:

- Three-phase asynchronous motor. This type of motor uses 400 volt or greater than that, three-phase current .
- Single-phase asynchronous motor. This type of motor uses 230 volt single current.

I.7.1. Three-phase motors

A three-phase motor is a robust type of motor that does not require a commutator. Most three-phase asynchronous motors have a balanced load. They are motors that consume the same in all three phases, whether they are connected in a star or in a triangle.

For a three-phase asynchronous motor, it can be started in different ways: star-delta, with a frequency inverter, by stator resistors or by rotor resistors.

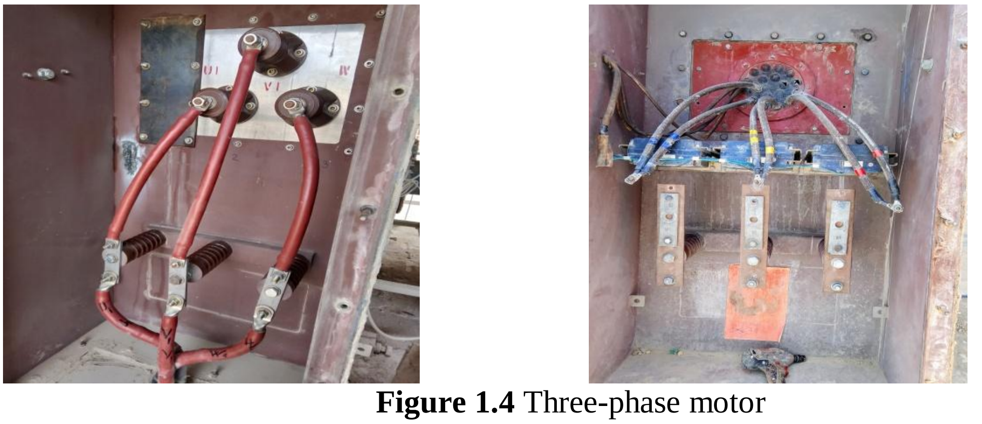


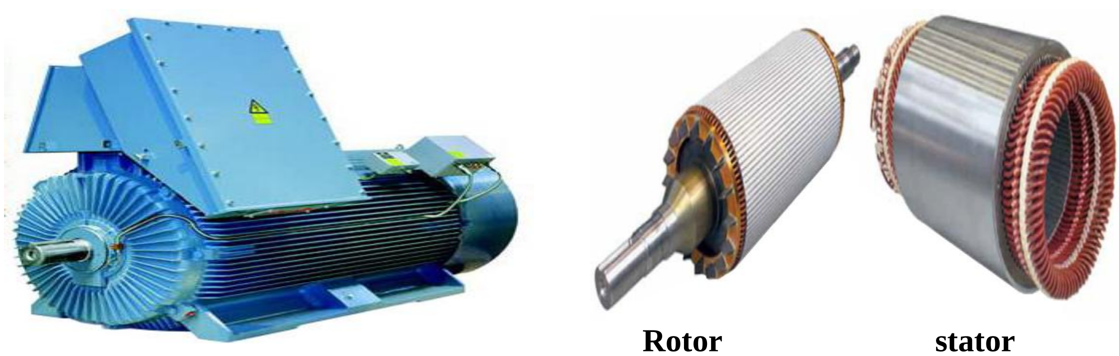
Figure 1.4 Three-phase motor

The voltages in each phase in this case are equal to the result of dividing the line voltage by the root of three. For example, if the line voltage is 400 volts, then the voltage of each phase is 230 volts.

I.7.1.1. Squirrel cage motor

The squirrel cage motor is a type of asynchronous motor that uses a rotor called a squirrel cage rotor. This type of rotor is made up of a series of bars arranged in the grooves of the rotor ring, joined at their ends to two rings. The starting torque is small and the current they absorb is high. Figure-5-

The vast majority of asynchronous motors are squirrel cage motors.

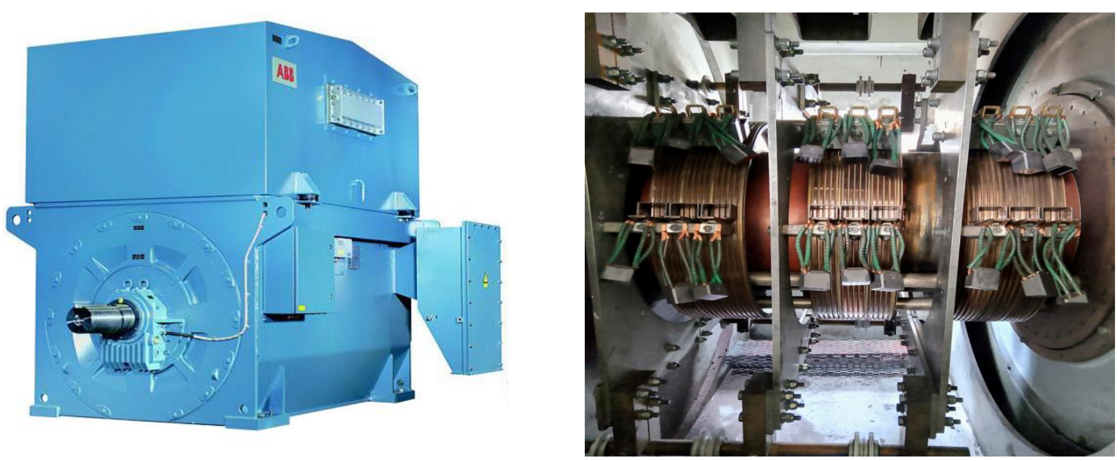


Rotor **stator**

Figure 1.5 The squirrel cage motor

I.7.1.2. Wound rotor motor

The wound rotor motor is a type of alternating current electric motor. In this type of motor the rotor ring grooves are inserted into the windings joined by a common point. This type of motor has copper rings, called slip rings, that rotate with the shaft making contact between it and some brushes that will allow the rotor windings to be connected to the outside. Figure 1.6



Fgure 1.6 wound rotor motor

The advantage of the wound rotor is that they allow progressive starting by means of rotor resistors. However, nowadays, with the use of electronic starters and variators they are not necessary and their manufacture is very limited.

I.8. Composition

An asynchronous motor is made up of several components such as the frame, rotor, stator, etc

There are two different categories of asynchronous motor depending on their rotor type:

• Asynchronous motors with short-circuited rotor, called **cage motors**. These motors are the most commonly used, due to their versatility, and their simple economical design[1].

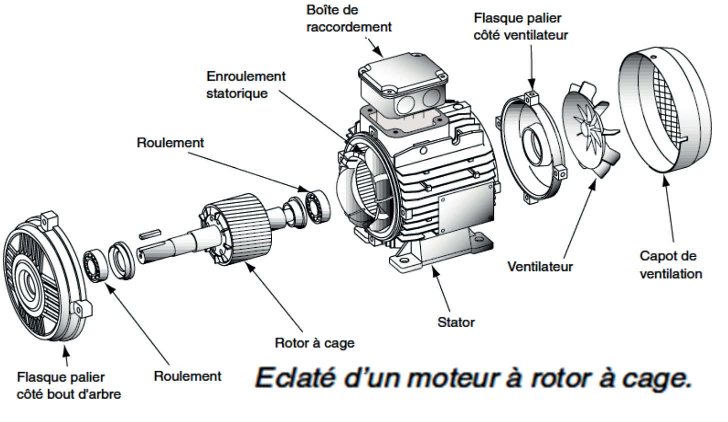


Figure 1.7 cage motor composition

• Asynchronous motors with wound rotor, called slip-ring motors, in which the rotor winding is extended by slip-rings to which stepped resistors are connected. They are connected to these slip-rings with brushes. They are less commonly used because they are more complicated to install and more expensive.

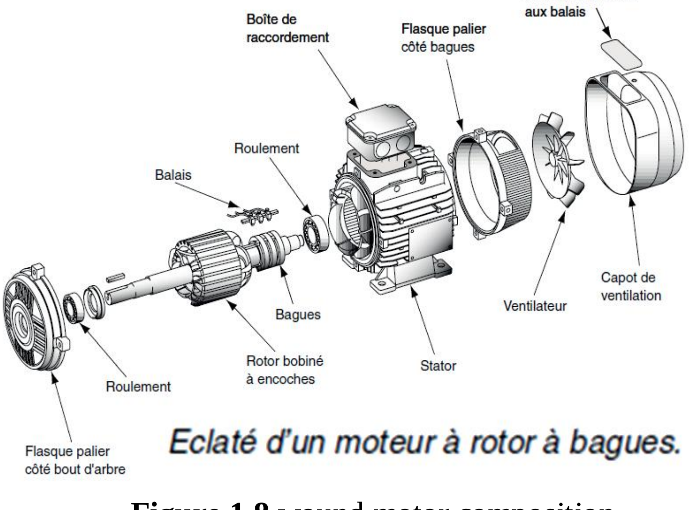


Figure 1.8 wound motor composition

I.9. OPERATING PRINCIPLE

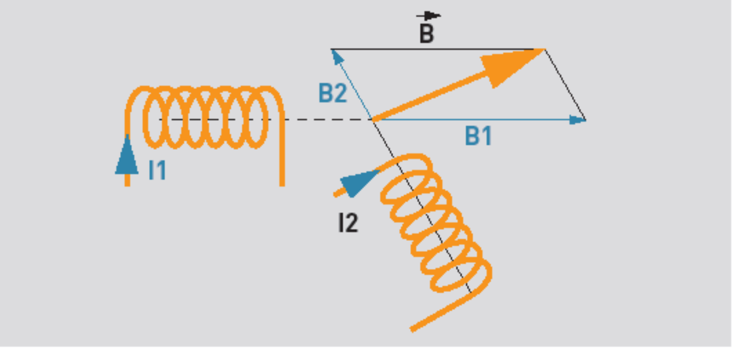
I.9.1. Stator

The stator is attached to the motor body and consists of a stack of very thin laminations and three windings. On a three-phase supply, each winding is wound around a stator core and forms an electromagnet (a pair of poles) when connected to a supply phase.

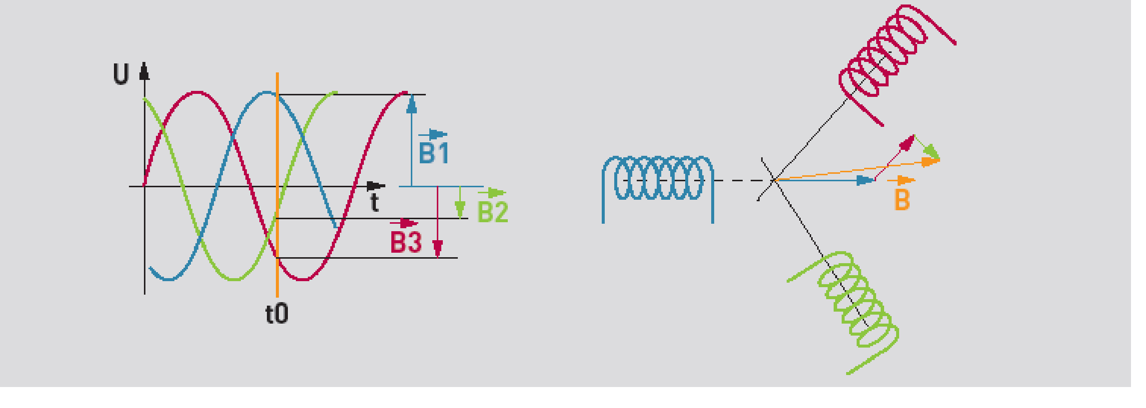
The AC three-phase asynchronous motor is the only one which works due to alternation of the phases of the electricity supply.

The physical explanation is as follows:

The flow of current in a coil creates a magnetic field H. This field is in line with the coil, its direction and its intensity are a function of the current I. If the current is AC, the magnetic field varies in direction at the same frequency as the current. If two coils are placed close to one another, the resulting magnetic field is the vectorial sum of the other two.



In the case of the three-phase motor, the three coils are positioned in the stator at 120° from one another, which creates three magnetic fields. Given the nature of the current on the three-phase supply, the three fields are phase-shifted.



When supplied in this way, the stator generates a magnetic field, called a stator field, rotating at a speed called synchronous (Ns).

The rotation frequency of this field is linked to the frequency of the mains supply and the number of pairs of poles in the winding.

Ns = 60xF/P (F frequency, P no. of poles), in number of revolutions per minute (RPM)[1].

I.10. OPERATING PRINCIPLE (CONTINUED)

I.10.1. Rotor

The second component is the rotor, which is a moving part. It consists of a stack of thin metal laminations which are isolated from one another (in order to prevent circulation of eddy currents), windings and short-circuited conductors. Its specific job is to react to the magnetic field generated by the stator (the stator field). According to Lenz's law, the current induced in the rotor opposes the effects of the induction field, because of its magnetic field. The variations in flow between the stator and rotor windings result in the appearance of a force: torque. The rotor thus starts rotating at a nominal speed (N) which is close to the synchronous speed

(Ns) which is the maximum speed of rotation linked to the frequency of the mains supply.

The difference in speed between Ns and N is called the slip speed, hence the name **"asynchronous motor"** which represents this difference in speed. Slip is expressed as a % of the synchronous speed and is calculated using the following equation: (Ns-N)/Ns.

When the motor is in the starting phase, the rotor speed is zero and the difference between the speed of rotation of the magnetic field and that of the rotor is at its maximum, which generates induction of strong rotor currents due to the absence of back electromotive force (which is the reason for the strong inrush current). When the rotor accelerates, there is less difference in speed and the rotor currents diminish. The rotor speed stabilizes at its speed N.

I.10.2. Air gap

The air gap is the gap between the rotor and stator. The smaller it is, the better the magnetic induction. The width of the air gap contributes directly to the motor efficiency.

I.11. Common Applications of Medium Voltage Motors

Medium voltage motors find extensive use across various industries due to their power and reliability. In the oil and gas sector, these motors are frequently employed to drive pumps, compressors, and other critical equipment in extraction and refining processes.

The mining industry relies heavily on medium voltage motors to power conveyor systems, crushers, and ventilation fans in underground operations.

In the water and wastewater treatment industry, these motors are essential for powering large pumps that move vast quantities of water through treatment facilities. The pulp and paper industry utilizes medium voltage motors in various stages of production, from wood processing to paper drying. Additionally, these motors play a vital role in power generation plants, driving boiler feed pumps and other auxiliary systems that support electricity production.

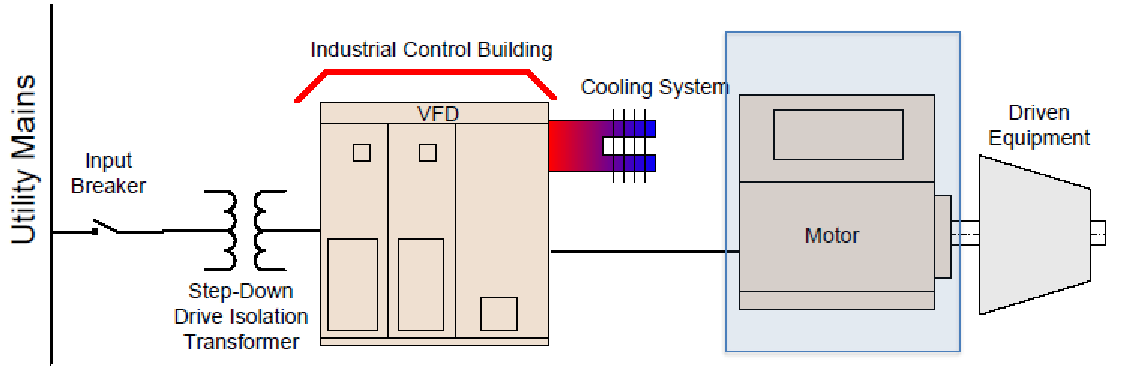


Figure 1.9 position of motor at network

I.12. Motors in a Typical Mining Application

Electric motors are the workhorse and backbone of industrial process applications. Motors ranging from medium voltage large motors to low voltage small motors can be found in applications such as oil & gas, water treatment, cement, and as shown below, the mining industry.

Medium voltage motors can be used in applications such as, crushers, grinding, and large pumps and fans where high horsepower ratings are required to process or move material.

Low voltage motors are typically used in secondary process

applications in the mid to final stages of the process of the material.

These motors are vital to ensure the process remains running in order to finalize the process of the material.

With motors found in many different processes in each application, it is vital to ensure each motor is adequately protected so that process uptime is not interrupted. Before motor protection can be implemented, vital information, known as motor performance data, is required to ensure correct configuration.

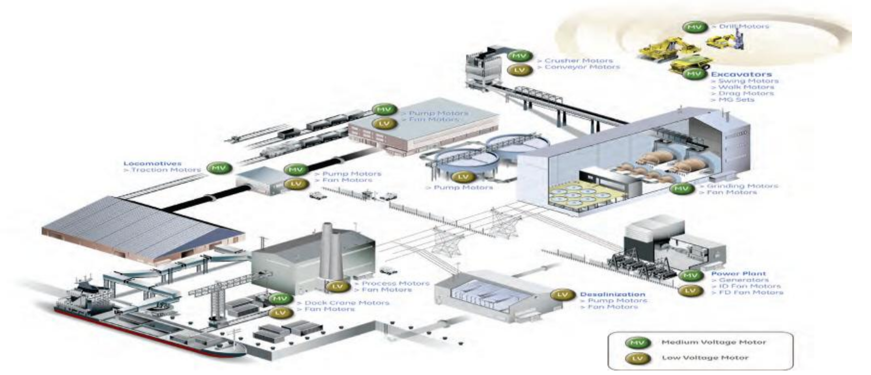


Figure 1.10 Motor applications in the mining process

I.13. Key advantages of AC medium voltage motors include

1.**Efficiency:** These motors are designed for optimal energy consumption, which helps reduce operational costs and improves energy efficiency.

2.**Power Density:** With a higher voltage, these motors can deliver greater power output without a corresponding increase in size or weight. This is especially important in industries where space is limited.

3.**Durability and Longevity:** Medium voltage motors are built to withstand harsh conditions and offer extended service life, making them a cost-effective long-term investment.

4.**Reliability:** They are generally more reliable in industrial settings, where continuous operation is crucial. Maintenance needs are relatively low, and modern motor technologies have made them more robust against failures.

5.**Versatility:** These motors can be used in a wide range of applications, from pumping stations to compressors, crushers, and conveyor systems, contributing to their broad industrial appeal.

However, there are also challenges to consider, such as:

- **Initial Cost and Installation:** The upfront cost of purchasing and installing medium voltage motors can be higher compared to low-voltage options, but the long-term savings in energy efficiency and durability often outweigh this investment.
- **Complexity of Maintenance:** While these motors are durable, the complexity of their maintenance and the need for specialized technicians can be a limitation for some users.
- **Size and Weight:** Though they provide more power in a compact form, medium voltage motors can still be quite large and heavy, which may pose challenges in certain installations[2].

I.14. Conclusion

In the first chapter, we understood that the AC medium voltage motors are essential components in industrial and commercial applications that require reliable, efficient, and high-power electrical motors for operations such as pumping, ventilation, and heavy machinery. These motors typically operate at voltages ranging from 1 kV to 35 kV and are designed to handle substantial loads in demanding environments.

In conclusion, AC medium voltage motors are a vital asset in industries requiring reliable, powerful, and efficient electrical machines. By balancing performance with energy efficiency, these motors ensure both operational excellence and long-term reliability in demanding industrial applications. Their continued development and adoption will likely support advancements in automation and industrial machinery.

CHAPTRE II

Protection of medium voltage motors

II.1. Introduction

There is a wide range of AC motors since they can be used in numerous applications. AC motors need to be protected but protection selection usually does not depend on the motor and load type. This selection is based on the fundamental AC motor operation processes. There are crucial differences between the protection of induction motors and synchronous motors. Motor operation characteristics have to be particularly considered when applying selected protection. This approach is more important for the motors than for any other power system element. For example, the starting and stalling currents/times have to be known and taken into account when using overload protection. Also the thermal withstand of the AC motor has to be precisely defined under balanced and unbalanced loading conditions[15].

II.2. MV Motor Fault protection

Model study

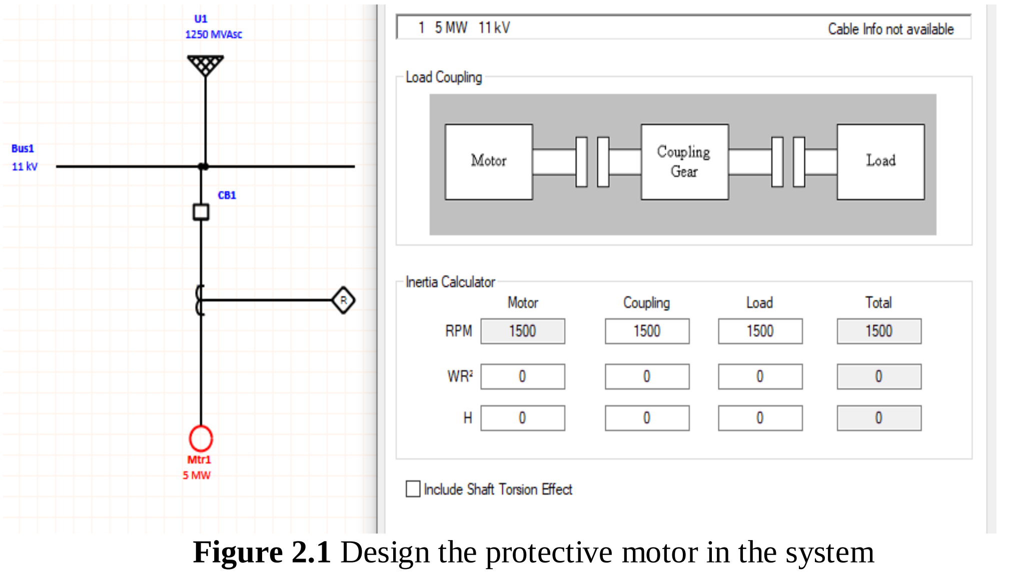


Figure 2.1 Design the protective motor in the system

There are two main risks for an overheated motor: Stator windings insulation degradation and rotor conductors deforming or melting.

Insulation lifetime decreases by half if the motor operating temperature exceeds its thermal limit by 10ºC. There are a number of conditions that can result in damage to three-phase motors.

These damages are a result of operating conditions or internal or external faults. External faults and operating conditions include: undervoltage, asymmetrical loading, phase and ground faults on the motor feeder and overloading during starting and running operation. Internal faults include: ground faults, faults between windings and inter-turn faults.

Table -2- Typical causes of motor faults[9]

Fault Type	**Protection Philosophy**
Internal Fault	
Stator ground Faults	Ground/Neutral IOC/TOC (50/51G/N), Neutral Directional TOC (67N)
Stator phase Faults	Phase differential protection (87), Phase IOC/TOC (50/51P), Phase short circuit (50 P)
External Fault	
Overheating	Overload - Thermal model with Programmable Curves and biased with RTD and/or Unbalance (49/51) Voltage Dependant Curve for Large Inertia Loads Overtemperature via thermistors and/or RTDs (38,49) Locked rotor / mechanical jam, Stall Protection (39, 51R) Jogging, Starts/hour, time between starts, restart time delay (66), Acceleration Time Logic Reduced voltage start (19) Incomplete sequence (48) Overload lock-out (86)
Phase Unbalance	Overload - Thermal model with Programmable K factor Setting
Phase reversal	Negative Sequence Overvoltage (47)
Abnormal Voltage	Overvoltage (57), Undervoltage (27)
Abnormal Frequency	Overfrequency (81O), Underfrequency (81U), Speed switch (14)
Loss of load	Undercurrent/minimum load (37), Underpower, Sensitive Directional Power (32)
Back-Spin	Back-Spin Detection
Breaker failure	Breaker failure (50BF)
Power factor	Power factor (55)
Feeder Ground Fault	Ground/Neutral IOC/TOC (50/51G/N) Neutral Directional TOC (67N)
Feeder Phase Fault	Phase differential protection (87), Phase IOC/TOC (50/51P), Phase short circuit (50 P)

II.3. Modern Relay Motor Protection Technology

Modern numerical motor relay protection technology must be sufficient to meet protection requirements of any one of the vast range of motor designs. Many motors designs do not tolerate overloads. A motor protection relay providing sufficient protection will have the following set of characteristics:

II.3.1. Induction And Synchronous Motors

- extended start relay protection
- loss-of-load relay protection
- number of starts limitation
- stalling relay protection
- short circuit relay protection
- thermal relay protection
- earth fault relay protection
- negative sequence current detection
- winding RTD measurement/trip
- under-voltage relay protection
- auxiliary supply supervision

Also, protection relays may provide options such as circuit breaker condition monitoring assessment that can be used for maintenance needs.

Manufacturers may also provide protection relays that use smaller number of functions in situations when less sophisticated relay protection is warranted (e.g. low rating asynchronous motors). The following paragraphs comment on possible motor fault types.

II.4. Thermal (Overload) Relay Protection

The majority of winding faults are either indirectly or directly triggered by overloading (prolonged or cyclic). Also winding faults can be caused by operation on unbalanced supply voltage, or single phasing. These effects cause excessive heating which deteriorates winding insulation and effectively creates electrical faults. Universally adopted rule is that insulation life is halved for each 10ºC rise in temperature above the rated value. This rule is affected by the length of time spent at the higher temperature. As electric motors have a great heat storage capacity, it means that occasional short duration overloads may not adversely impact the motor. Nevertheless, prolonged overloads of only several percent may end in premature ageing and insulation fault. Next, the motor thermal withstand capacity is impacted by winding heating prior to a fault. Hence, it is crucial that the protection relay features consider extremes of zero and full-load pre-fault. These are known as the 'Cold' and 'Hot' conditions, respectively. Different motor designs, various usages, variety of different abnormal working conditions and resulting fault modes result in a complex thermal formula. Therefore, it is not possible to create universal mathematical model[8].

II.5. Start/Stall Motor Protection

Once a motor starts, it takes a current greater than full load rating current. This lasts throughout the period that the motor needs to run-up to speed. Even though motor starting current decays as motor speeds up, in protection practice it is normal to assume that the motor current stays constant throughout the starting period. The starting current varies depending on the motor design and starting method. For direct-on-line (DOL) started motors, the nominal starting current can be 4-8 times of full-load current. Nevertheless, when a star-delta starter is used, the line current will be only $1/\sqrt{3}$ of the DOL starting current. In the case motor stalls whilst running, or fails to start, due to great load, the motor will take a current equal to its locked rotor current. Hence, it is not possible to recognize stall condition and a healthy start solely on the basis of the taken current. Discrimination between the two conditions has to be made based on the duration of the taken current. For motors where the starting time is lower than the motor safe stall time, relay protection can be easily made. Nevertheless, in situations, where motors are used to power high inertia loads, the stall withstand time can be lower than the starting time. In these situations, extra methods have to be given to allow discrimination between the two conditions[13].

II.5.1. Prolonged Start Time/Locked Rotor Protection

A motor may fail to speed up for a number of different reasons:

- loss of a supply phase
- excessive load torque
- insufficient supply voltage
- mechanical issues

A huge current will be taken from the supply, and create high temperatures within the motor. This situation gets even worse since the motor is not rotating, so it cannot be cooled down due to rotation. Winding faults can quickly happen– either to the stator or rotor windings. This depends on the motor thermal limitations (In this respect, motors are differentiated as stator or rotor limited). The protection method changes depending on whether the starting time is lower than or higher than the safe stall time. In both situations, starting may be detected by motor feeder switch closure (contactor or circuit breaker). Optionally it can be detected if current rises above a starting current threshold value – commonly 200% of motor nominal current. Sometimes, both conditions can be detected only if they happen within a narrow time aperture. Additional conditions may exist for certain motor types placed in hazardous areas. Relay protection has to take these into account. Occasionally, a permissive interlock for machine pressurization may be needed, and this can be conveniently accomplished by applying relay digital inputs and the built-in logic capabilities[13].

II.5.1.1. Case 1: Start Time Lower Than Safe Stall Time

Protection is accomplished by application of a definite time overcurrent option. Current setting is greater than full load current but is lower than the motor starting current. Relay time setting should be a slightly longer than the start time, but lower than the allowed motor safe starting time. Figure 2.2 shows successful start operation principle.

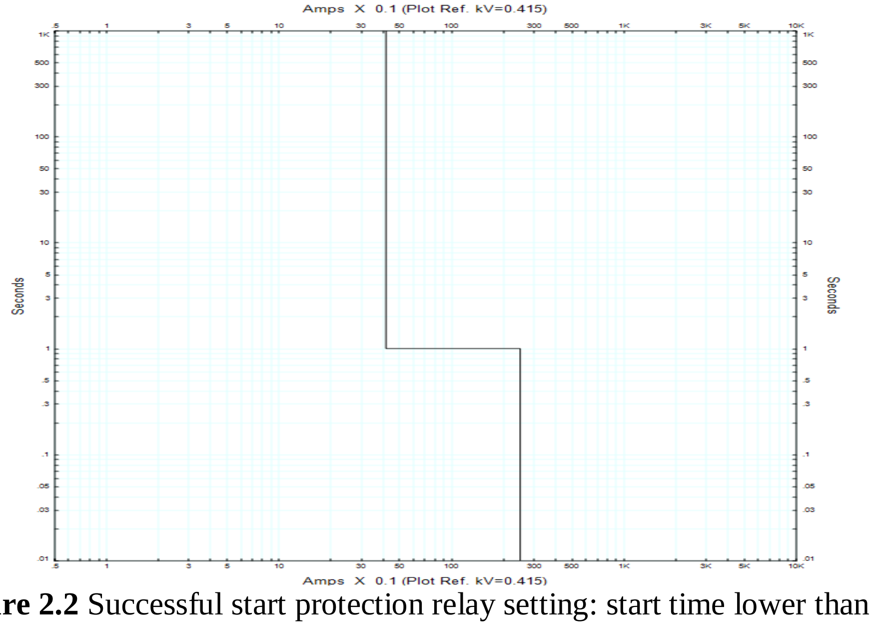


Figure 2.2 Successful start protection relay setting: start time lower than stall time

II.5.1.2. Case 2: Start Time Greater Or Equal To Safe Stall Time

In this situation, a definite time overcurrent option is not sufficient, since the needed delay time is greater than the motor maximum allowed starting time. Additional rotor movement detection, indicating a safe start, is needed. A speed-sensing switch typically gives this function. Successful start detection is used to choose the relay timer that is used for the safe run-up time of the motor. This time can be greater than the safe stall time due to decrease in current taken by the motor during the start. Also the rotor fans start to enhance machine cooling since motor accelerates. If a start is detected by the protection relay through monitoring current and/or start device closure, but the speed switch does not operate, the protection relay element uses the safe stall time setting to trip the motor before damage happens. Figure -13- shows operation principle for a successful and an unsuccessful start[3].

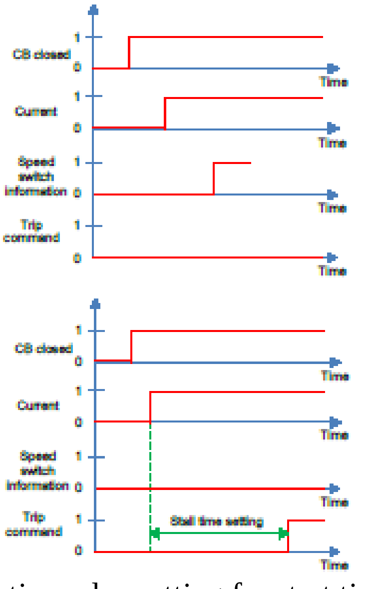


Figure 2.3 Protection relay setting for start time greater than stall time (a) Successful start (b) Unsuccessful start

II.6. Motor overcurrent differential relay (Device 87)

Motor overcurrent differential protection measures the current flow into a load and compares it to the current measured on the neutral side of the motor. A current difference is detected as a fault. These schemes can be technically applied to any motor load, but often are applied to large or critical motors only where damage could be costly or replacement difficult.

By detecting faults at a low level, damage may be confined to windings solely.

Three general recommendations for applying differential overcurrent protection are as follows:

1. With all motors 750 kW and above used on **ungrounded systems.**
2. With all motors 750 kW and above used on grounded systems where the ground-fault protection applied is not considered sufficient without differential protection to protect against phase-to-phase faults.

3. With smaller motors, especially at voltages above 2400 V, although justifying differential protection for large motors (i.e., 1900 kW and above) is easier[14].

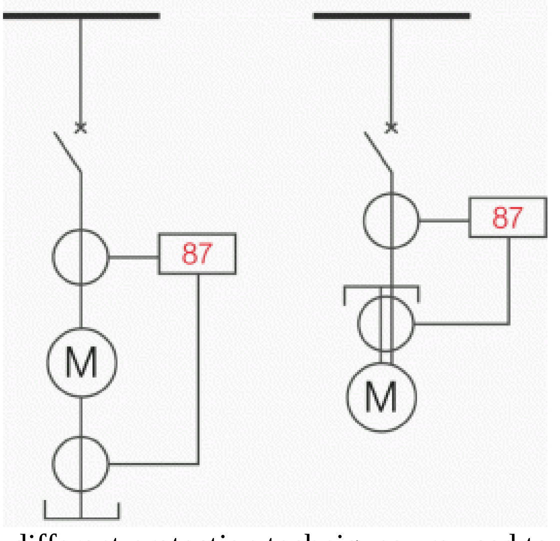


Figure 2.4 Two different protection techniques are used to carry out differential motor protection

II.6.1. Phase differential overcurrent relay

Phase differential overcurrent relay is used to sense low-level phase faults and to quickly remove the motor circuit before extensive damage develops.

This scheme uses **six** identical CTs (i.e., one pair for each phase) and three relays (i.e., one per phase). The CTs should be sized to carry full-load current continuously and to not saturate during an external or internal fault (see Figure 15). The currents from each pair of CTs circulate through the relay-restraining windings under normal (i.e., no-fault) conditions.

For a fault in the motor windings or in the cable, the CT secondary currents have different magnitudes and/or polarities, and the differential current from each CT adds to the other and operates the Device 87 to trip the motor circuit breaker.

While sometimes applied to delta-connected motors, this scheme is usually used with wye-connected motors. Note that wye-connected motors are much more common than delta-connected ones in the larger horsepower ratings.

With the wye-connected motor, three of the CTs are normally located at the starter (or motor switchgear) and the other three in the three phases at the motor winding neutral.

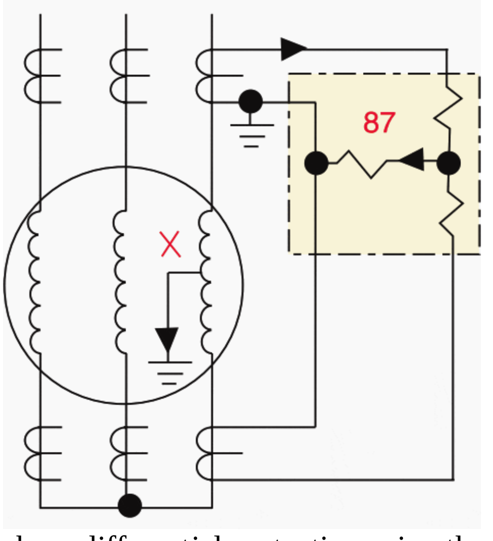


Figure 2.5 Conventional phase differential protection using three percentage differential relays (one shown)

II.6.2. Self-balancing differential using window CTs

Three window (or toroidal) CTs are normally installed at the motor. One CT per phase is used with the motor line, and neutral leads of one phase are passed through it so that the flux from the two currents normally cancels each other in the CT. A winding phase-to-phase or phase-to-ground fault results in an output from the CTs of the associated phases. That current operates the associated relays (see Figure 2.6).

The CTs and relays would normally be the same as the CTs and relays used for zero-sequence instantaneous ground overcurrent protection with the relay set between 0.25 A and 1.0 A pickup.

Therefore, this differential scheme usually has a lower primary pickup in amperes than the conventional differential scheme because the CT ratio is usually greater with the conventional scheme[14].

Therefore, this differential scheme usually has a lower primary pickup in amperes than the conventional differential scheme because the CT ratio is usually greater with the conventional scheme.

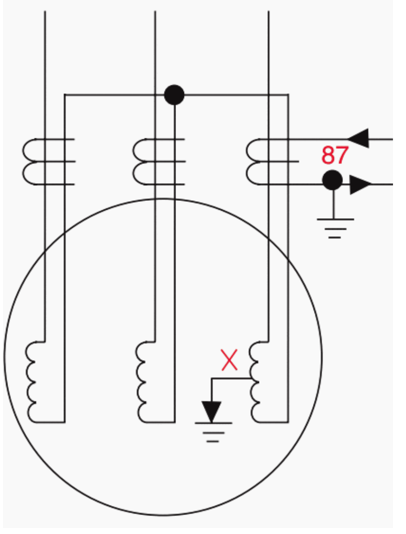


Figure 2.6 Self-balancing differential protection (one relay shown)

This differential scheme has a slight advantage over the scheme in Figure 2 in detecting ground faults. For motors installed on grounded systems this difference is significant because most faults begin as ground faults.

The usual objective of motor-fault protection is to remove the fault before the stator iron is significantly damaged.

Application problems have occurred with this scheme when the available fault current is very high and when high-speed balanced-core differential protection signals to trip the motor starter before the current-limiting fuses clear the fault and thus protect the starter. Because the starter has such a low fault rating, some engineers tend to slow down the operation of the relay, by delay or different relay type, in order to distinguish between a developing low-level fault and a direct short.

With the CTs located at the motor, this scheme does not detect a fault in the cables supplying power to the motor. A fault in these cables would normally be detected by the overcurrent protection.

For large motors, coordinating the supply phase-overcurrent protection with the motor overcurrent protection is often a problem. The presence of motor differential protection is sometimes considered to make this coordination less essential. In this regard, the conventional differential is better than the self-balancing differential because the motor cables are also included in the differential protection zone.

Hence coordination between the motor differential and supply phase-overcurrent relays is complete.

As with zero-sequence ground-fault overcurrent protection, testing the overall CT and relay combinations is important during commissioning. Current in a test conductor should be passed through the window of each CT. Because normally the relays do not carry current, an open circuit in a CT secondary or wiring to a relay can be discovered by this overall testing.

II.7. Split winding current unbalance (Device 87)

The purpose of the split winding current unbalance device is to quickly detect low-magnitude fault conditions. This protection also serves as backup to instantaneous phase-overcurrent and ground-fault overcurrent protection.

This protection is normally only applied to motors having two (or three) winding paths in parallel per phase (see Figure 2.7).

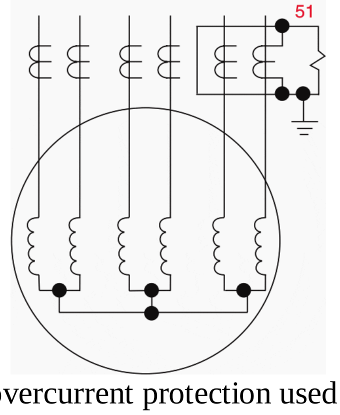


Figure 2.7 Split-phase motor overcurrent protection used with two paths per phase (one relay shown)

II.8. Ground-fault protection

Damage to a phase conductor's insulation and internal shorts due to moisture within the motor are common causes of ground faults.

A strategy that is typically used to limit the level of the ground fault current is to connect an impedance between the neutral point of the motor and ground. This impedance can be in the form of a resistor or grounding transformer sized to ensure that the maximum ground fault current is limited to a level that will reduce the chances of damage to the motor.There are several ways by which a ground fault can be detected.

The most desirable method is to use the zero sequence CT approach, which is considered the best method of ground fault detection methods due to its sensitivity and inherent noise immunity. All phase conductors are passed through the window of a single CT referred to as a zero sequence CT. Under normal circumstances, the three phase currents will sum to zero resulting in an output of zero from the zero sequence CT’s secondary. If one of the motor’s phases were shorted to ground, the sum of the phase currents would no longer equal zero causing a current to flow in the secondary of the zero sequence CT. This current would be detected by the motor relay as a ground fault.

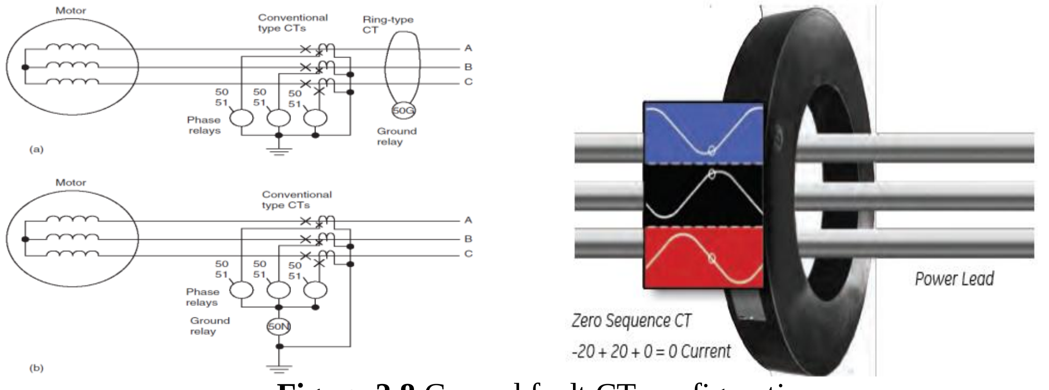


Figure 2.8 Ground fault CT configuration

II.8.1. Instantaneous ground-fault protection

Using a zero-sequence (or window) CT that has been designed for instantaneous ground-fault protection and tested with a specific ground-fault relay is recommended (see Figure 2.9).

For medium-voltage applications, the power system should be resistance-grounded, and the Device 50G should be set to operate for a primary ground-fault current in the range of 10 A to 30 A. A suitable time delay should be added when the installation has surge protection on the motors.

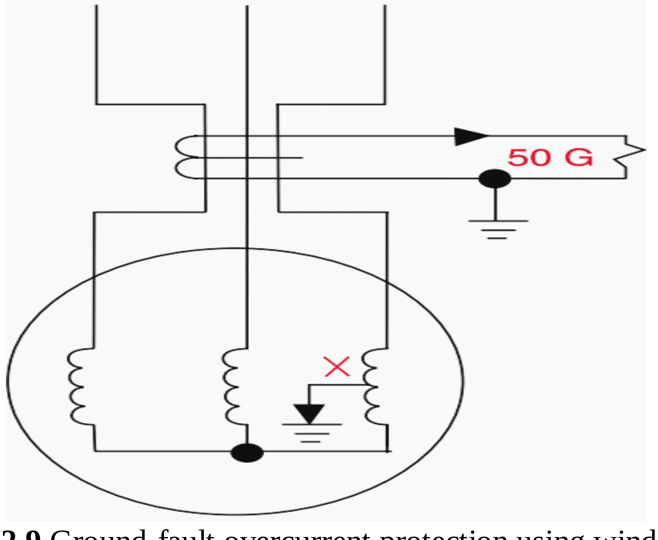


Figure 2.9 Ground-fault overcurrent protection using window CT

II.8.2. Time-overcurrent ground-fault protection

Many installations have surge protection at the motor terminals, and a surge discharge through an arrester could cause an instantaneous relay to have a false trip. To avoid this event, a Device 51G should be applied, in place of the Device 50G in Figure -19- above, and set to trip within a few seconds of the fault-sensing pickup.

II.8.3. Installation of cable for ground-fault protection

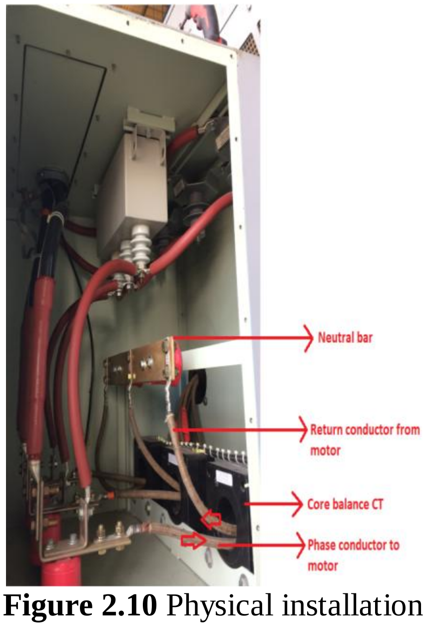
The following precautions should be observed in applying the relay and zero-sequence CT and in installing the cables through the CT:

Precaution #1 – If the cable passes through the CT window and terminates in a pothead on the source side of the CT, the pothead should be mounted on a bracket insulated from ground. Then the pothead should be grounded by passing a ground conductor through the CT window and connecting it to the pothead.

Precaution #2 – If metal-covered cable passes through the CT window, the metal covering should be kept on the source side of the CT, insulated from ground.

The terminator for the metal covering may be grounded by passing a ground conductor through the CT window and then connecting it to the terminator.

Precaution #3 – Cable shields should be grounded by passing a ground conductor through the CT window and then connecting it to the shields per Figure 2.10



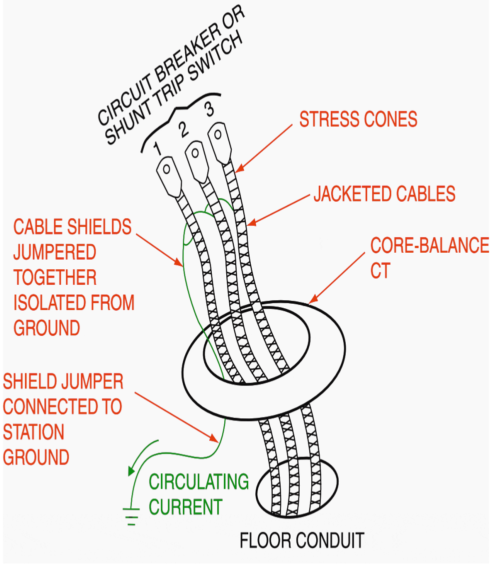


Figure 2.10 Physical installation of a core-balanced CT for shielded cable termination.

Precaution #4 – The overall CT and ground relay scheme should be tested by passing current in a test conductor through the CT window.

Because normally no current exists in the relay, an open circuit in the CT secondary or wiring to the relay can be discovered by this overall test.

II.8.4. Residually connected CTs and ground-fault relay

Applications have been made using the residual connection from three CTs (i.e., one per phase) to supply the relay. This arrangement is not ideal because high phase currents (e.g., due to motor starting inrush or phase faults) may cause unequal saturation of the CTs and produce a false residual current.

As a result, undesired tripping of the ground relay may occur, and the production or process may be jeopardized. For this reason, a Device 50N is not recommended in the residual connection.

A Device 51N installed in the residual connection would be more appropriate for these installations.

II.8.5. Selection of resistor for low-resistance system grounding

The purpose of resistance grounding is to provide current sufficient for protective relays to operate upon detection of a ground fault, but low enough to limit the magnitude and resulting damage to the motor.

For example, in mine distribution systems, the objective is to limit equipment-frame-to-earth voltages for safety reasons. However, the ground-fault current should not be so limited that the windings near the neutral end are unprotected.

Selection of the ground resistor should also consider the number of steps in ground-fault overcurrent protection coordination. On this basis, the ground resistor chosen for the system neutral grounding normally limits the ground-fault current within the range of 400 A to 2000 A.

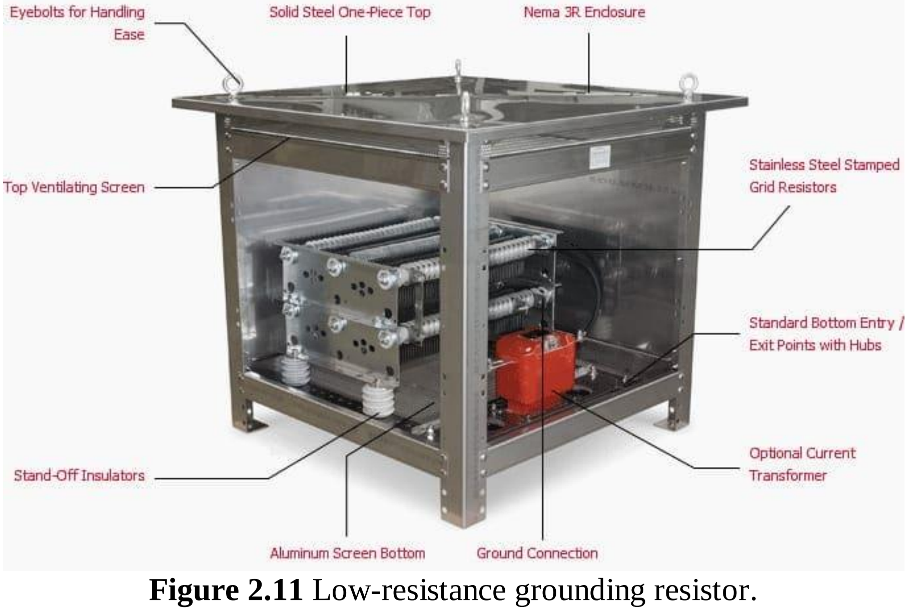


Figure 2.11 Low-resistance grounding resistor.

However, some companies prefer neutral ground-fault current limited to 200 A to 800. A This difference emphasizes the need to coordinate the protection of a system. A 10 s time rating is usually chosen for the resistor.

To avoid excessive transient overvoltages, the resistor should be chosen so that the following zero-sequence impedance ratio is achieved: R0 / X0 should be equal to or greater than 2.

Resistance Grounding Systems have many advantages over solidly grounded systems including arc-flash hazard reduction, limiting mechanical and thermal damage associated with faults, and controlling transient overvoltages. High resistance grounding systems may also be employed to maintain service continuity and assist with locating the source of a fault.

When designing a system with resistors, the design/consulting engineer must consider the specific requirements for conductor insulation ratings, surge arrestor ratings, breaker single-pole duty ratings, and method of serving phase-to-neutral loads.

II.9. Short Circuit

The short circuit element provides protection for excessively high overcurrent faults. When a motor starts, the starting current (which is typically 6 times the Full Load Current) has asymmetrical components. These asymmetrical currents may cause one phase to see as much as 1.7 times the RMS starting current. As a result the pickup of the short circuit element must be set higher than the maximum asymmetrical starting currents seen by the phase CTs to avoid nuisance tripping. The breaker or contactor that the relay is to control under such conditions must have an interrupting capacity equal to or greater then the maximum available fault current.

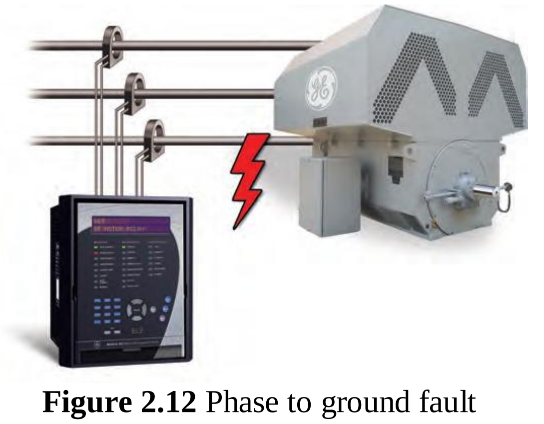


Figure 2.12 Phase to ground fault

II.10. Conclusion

In second chapter, we knew that the medium voltage (MV) motors are critical assets in industrial and utility systems, and their protection requires a comprehensive, multi-layered approach to guard against diverse electrical and mechanical faults. There are several types of protection mechanisms, each addressing specific failure modes to ensure reliability, safety, and extended equipment life.

Protecting medium voltage motors involves a diverse set of protective strategies, each targeting specific operational and fault conditions. Utilizing modern intelligent relays and condition monitoring systems allows for integrated, automated, and reliable protection**.** This not only minimizes equipment damage and downtime but also ensures safe and efficient operation across a wide range of applications. A well-designed protection scheme that combines electrical, thermal, and mechanical monitoring is essential for maximizing motor performance and lifecycle.

CHAPTER III

The medium voltage motor circuit breaker,

Multifunction Protection and Switch bay Control unit REF542plus

III.1. Introduction

This last party illustrate the basic operating principles of switching apparatus in relation to the different techniques used to date for monitoring and protecting medium voltage electrical installations. And study the Multifunction Protection and Switch bay Control unit REF542plus

III.1.1. General principles

First, the definitions provided by the Standards:

Circuit breaker (IEC 60050 441-14-20): “Mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified duration and breaking currents under specified abnormal circuit conditions, such as those of short-circuit.” (Mechanical) switch (IEC 60050 441-14-10): “Mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions which may include specified operating overload conditions and also carrying for a specified time currents under specified abnormal circuit conditions such as those of short-circuit.”

Thus the main functions of a circuit breaker in relation to the current to be interrupted are:
switching the load current (the same as its rated current or less), which the circuit breaker must be capable of carrying continuously making, carrying and breaking overload currents making, carrying and breaking short-circuit currents following a fault in the electrical installation.

The switch, on the other hand, is unable to break short-circuit currents. It is only capable of supporting them for a certain time and making them at most. If the switch is also a disconnector, it must provide, in the open position, the insulating requirements of a disconnector.

Contactor: (IEC 60050 441-14-33): "Mechanical switching device having only one position of rest, operated otherwise than by hand, capable of making, carrying and breaking currents under normal circuit conditions including operating overload conditions". Contacts are not capable of switching and withstanding short-circuit currents and must therefore be adequately protected.

Thus the circuit breaker is the only device designed to break short-circuit currents. A circuit breaker basically consists of two contacts (which are separated when the electrical circuit is open) and the relative actuating drive. The electric current is not interrupted immediately after the contacts have separated since an electric arc strikes between them and allows the current to keep flowing for a certain time.

In short, the operating principle of a circuit breaker is high-speed separation of the contacts so as to extinguish the electric arc and interrupt the current, at natural zero crossing of the alternating current. In addition, the voltage generated between the two contacts (Transient Recovery Voltage), imposed by the circuit in which breaking occurs, must be lower than that capable of restriking the arc (re-ignition voltage). This is why the arc quenching dielectric medium between the electrodes is so important and why it must possess high dielectric strength, considering the high temperature and ionizing state of the volume surrounding the arc.

Whichever the current that needs to be broken and the type of switching (opening or closing), the electric energy or mechanical impact that could occur or the effect on the insulation also depend on the type of breaking technology used.

III.2. Breaking techniques

To sum up the issues discussed in the previous chapter, one can say that to interrupt the currents circulating around an electrical installation in the best possible way, the dielectric medium in the arcing chamber of the circuit breaker must be an excellent open circuit insulation. But as soon as the arc develops it must initially become a good conductor, with good thermal conductivity, and then rapidly recover its dielectric characteristics so as to avoid successive restrikes.

III.2.1. SF6 interruption

Sulfur hexafluoride or SF6 is a synthetic gas with excellent insulating capabilities and optimum thermal and chemical stability. Thanks to these characteristics, it is widely used in HV and MV circuit breakers, where it improves their characteristics and general reliability.

Currently, 80% of the world production of SF6 is used in the electricity industry when smaller dimensions and low fire risk are required (compared to air insulation), as well as low maintenance.

SF6 was discovered by Henri Moissan in 1900 and since then, much research has been conducted for the purpose of characterizing the gas and identifying its properties. Measurement of its dielectric strength dates back to 1937 and since it was found to be much higher than that of air, SF6 soon began to be used by the electricity industry. SF6 gas became a commercial product in 1947 and since then, its field of application has broadened to include other sectors. SF6 gas possesses a high dielectric strength value, approx. 2-3 times more than that of air at the same pressure. Thanks to its optimum heat exchange aptitude and ability to capture electrons, it has been found to be especially suitable for interrupting arcs and able to restore its insulating properties very quickly. The high dielectric and interruption performance of SF6 stems from its strong electron affinity (electronegativity), since its molecule has a marked tendency to bind unbound electrons. The large collision diameter (~ 4.77 Å) allows accelerated electrons to be captured in an electric field well before they have sufficient energy to create further current carriers. This causes the discharge mechanism to either slow or cease. Use of SF6 optimizes the electrical performance and the overall dimensions of switchgear because in practice, the distances between contacts are halved while the mechanical stress to which the switchgear is subjected during the various operating sequences is reduced.

The first generation of circuit breakers used a double pressure system derived from the HV air circuit breakers. The second generation was designed to create a flow of gas, required to quench the arc, thanks to the thrusting action of a piston connected to the opening drive. However, the drive mechanism of this type of solution, called “puffer”, required a great deal of energy even at low current values and the risk was sharp interruption of the current before zero crossing (chopping current). A further development called “self-blast” used the actual arc energy to produce the flow of gas in the arcing chamber. This reduced the mechanical energy required by the drive to a considerable extent but with the risk of ineffective interruptions at low current values.

The latest generation proposed by ABB (figure-23-) is the so-called “auto-puffer” circuit breaker, which combines both solutions using the puffer technique for currents up to 30% of breaking capacity and the self-blast technique for higher voltage values. This mixed technique only requires a minimum amount of additional energy for the drive mechanism compared to the self-blast version, but achieves optimum arc interruption even at low fault current values. Even interruptions of small inductive currents are optimum and induce only small overvoltages in the installation (< 2.5 p.u.).

The ABB HD4 family of circuit breakers uses the auto-puffer technique described above. The operating principle of the pole is described further on (figure -23-):

Figure 3.1 The ABB HD4 Circuit Breaker

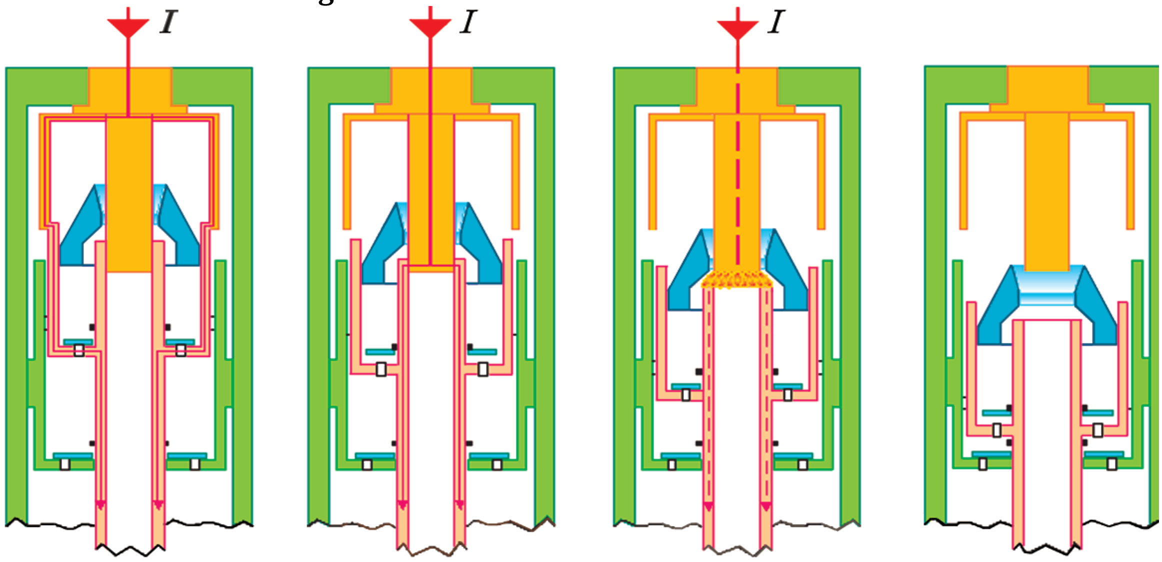


Figure 3.2 The HD4 circuit breaker positions

III.2.2. Multifunction apparatus

This apparatus conforms to the following Standards: IEC 62271-100 High-voltage switchgear and controlgear – Part 100: Alternating-current circuit breakers and to IEC 62271-102 High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches[10].

Integrated, very compact solutions have recently been developed combining the functions of three different devices in the same apparatus, i.e. the functions of circuit breaker, feeder disconnector and earthing switch. This integrated solution was designed for use in medium voltage switchgear for secondary distribution.

As can be seen in figure 3.3, the upper part includes the circuit breaker function and has a vacuum interrupter housed in its upper half-shell . The lower half-shell houses a feeder disconnector (so as to isolate the busbar cables) and an earthing switch (to earth the cables themselves).

Use of vacuum interrupters to break short-circuit currents isolates the arcing chamber of the circuit breaker from the remaining environment, filled with SF6, for disconnector isolating and operating purposes. Vacuum interruption also ensures high electrical performance.

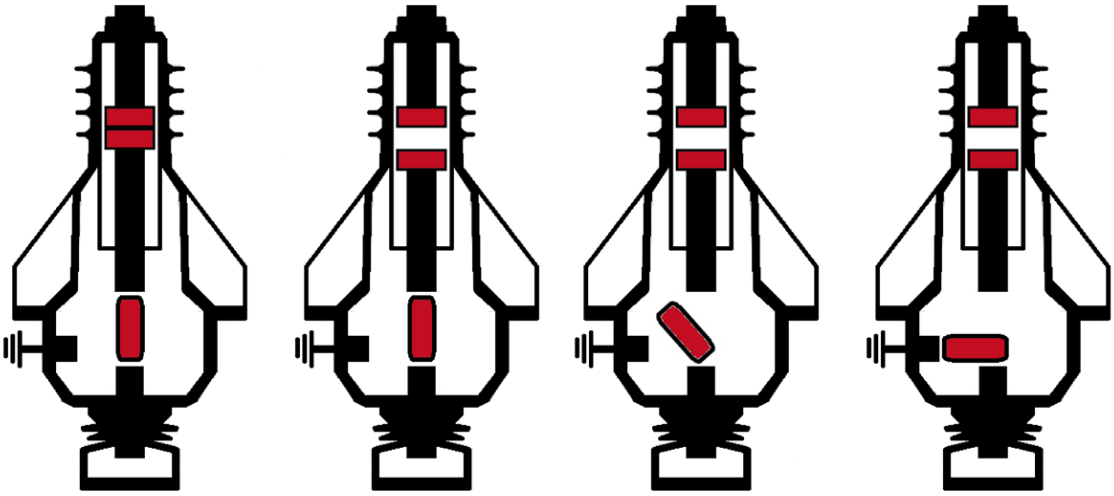


Figure 3.3 the upper part includes the circuit breaker

III.3. Multifunction Protection and Switchbay Control unit REF542plus

III-3-1- General

The REF542plus Multifunction Protection and Switchbay Control Unit is the further development of the former REF542 unit. Like its predecessor, it features the following functions: Protection, Measurement, Control and Monitoring

All functions mentioned above and power quality functions are integrated in a programmable environment. The exceptional flexibility and scalability of these new generation devices lead to a smart and clean solution where the traditional approach would be ineffective and expensive.

The following figures show examples of the REF542plus installation in several switchboards.

Figure 3.4 REF542plus installed in gas insulated switchboards (GIS)

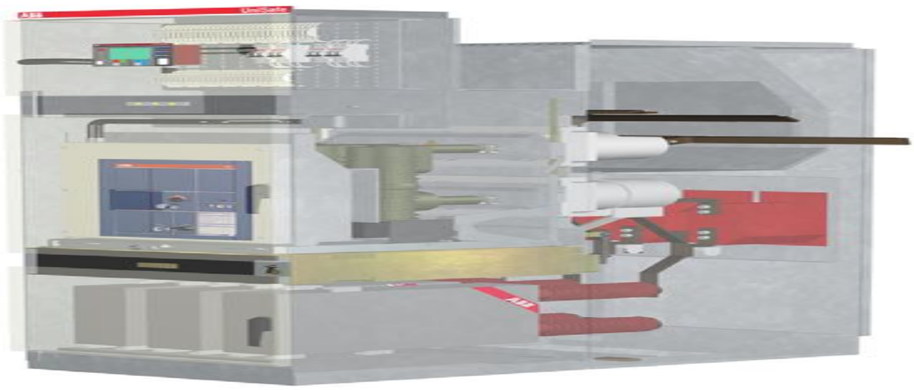


Figure 3.5 REF542plus installed in an air insulated switchboard (AIS)

The REF542plus is based on a real-time microprocessor system. The measurement and protection functions are executed by a **D**igital **S**ignal **P**rocessor (DSP), while a **M**icro **C**ontroller (MC) is executing the control functions. Due to this task separation there is no impact between the start and the trip behavior of the implemented protection scheme, should the control scheme be modified. The **C**ommunication **P**rocessor (CP) is needed for connection to a station automation system. A block diagram of the REF542plus is shown in figure 3.6

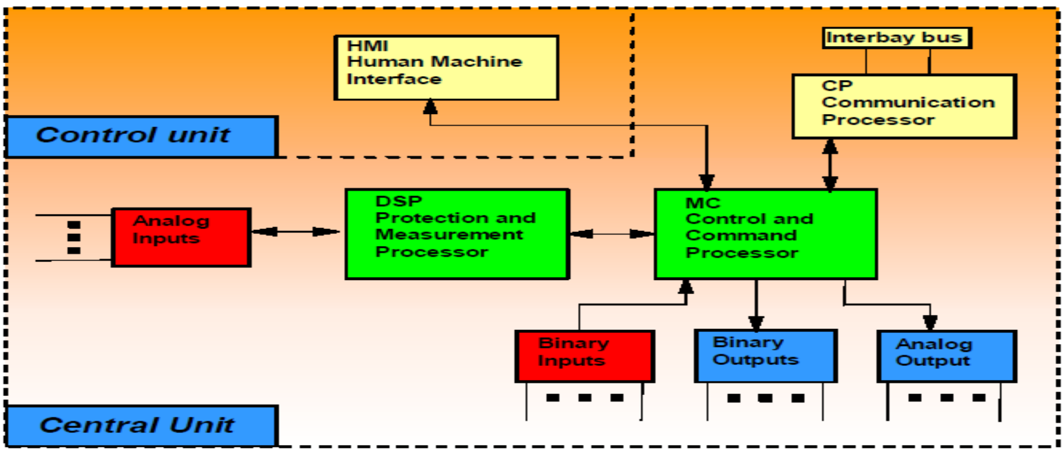


Figure 3.6 REF542plus Block diagram

REF542plus, as shown in figure 3.6, consists of two parts, a Central Unit and a separate **H**uman **M**achine **I**nterface (HMI). The Central Unit contains the power supply, processor and analog and binary **I**nput and **O**utput (I/O) modules, as well as optional modules for supplementary functions.

The HMI Control Unit is a stand-alone unit with its own power supply. It can be installed on the **L**ow **V**oltage (LV) compartment door or in a dedicated compartment close to the Central Unit. The HMI is normally used to set the protection parameters and to locally operate the switching devices in the switchbay. The HMI is connected to the Central Unit by a shielded, isolated twisted pair according to the RS485 interface. Figure 3.7 shows an installation of the Central Unit and the HMI Control Unit in the LV compartment of a switchboard for the switchbay.

Figure 3.7 Mounting of the Central Unit in the LV compartment and the HMI on the door

The HMI Control Unit, as shown in figure-30-, features a back-illuminated **L**iquid **C**rystal **D**isplay (LCD), eight push buttons, several LEDs and an electronic key interface. The language of the display can be selected via the related configuration software tool, which is also used to define the protection and the control scheme.

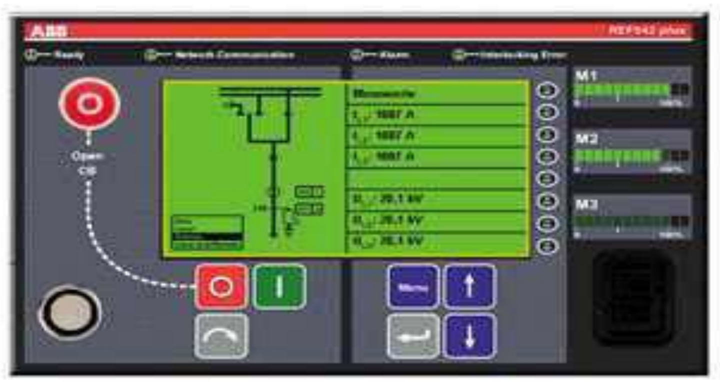


Figure 3.8 The HMI Control Unit

The left half of the LCD display is reserved for the Single Line diagram. The right half is used to display the appropriate menu or submenu as determined by the user. Two different electronic keys with different access rights are available. Each of the keys are programmed to permit either: protection functions parameterization of the mode selection of the control functions.

Three freely programmable LED bars have been provided on the front of the HMI Control Unit. Each LED bar consists of ten green and two red LEDs and is user configurable to display any required measurement value. The red LEDs are used to indicate values above the rated value.

The functions of the REF542plus can be tailored to the system requirements via a user-specific configuration. The user-specific configuration is loaded during commissioning. For that purpose the configuration computer, normally a personal computer (notebook) running Windows NT, is connected to the optical interface on the front side of the HMI Control Unit.

The interface of the multifunctional unit REF542plus to the **M**edium **V**oltage (MV) primary process is as follows:

- Analog inputs to measure current and voltage signals from instrument transformers or non conventional sensors
- Binary inputs with optical couplers for the galvanic separation of the external signals to be processed;
- Binary outputs with conventional mechanical relays or static outputs for the control of switching devices;
- Optional four channel analog outputs 0 to 20mA or 4 to 20 mA
- Optional connection to ABB or third party station automation system.

REF542plus is a certified product for compliance to the IndustrialIT architecture concept of ABB.

III.3.2. Functions

REF542plus Multifunction Protection and Switchbay Control Unit integrates all the secondary functions in a single unit. This multifunctional unit also features a self-monitoring function. All functions are designed as freely configurable software modules. Therefore, a wide range of operation requirements in MV stations can be met without any problems. The versatility of the software makes it possible to use the REF542plus on every switchboard independent on the specific application required.

III.3.3. Configuration

Each application for protection and control can easily be configured by software function modules, which make arbitrary definition of the following features as part of the secondary system possible:

- LED's (meaning and colors) for local indication
- Single Line diagram to show the status of switching devices
- Protection schemes
- Control schemes
- Interlocking schemes
- Automation sequences

All functions in the switchbay can be specified in collaboration with ABB. The result of the configuration is saved and delivered together with the switchboard to the users. By using the "**FU**nctional block" **P**rogramming **LA**nguage (FUPLA) the REF542plus Multifunction Protection and Switchbay Control Unit offers engineers, especially those who are not software experts, the opportunity of easily updating the operation and handling of the switchbay.

With REF542plus the user has the benefit of a secondary system that is fully integrated in a true programmable controller. This flexibility is very advantageous for defining control functions for automation sequences, which can, for example, include the interlocking of the switching devices, blocking the release of specific protection functions, as well as starting switching sequences.

REF542plus multifunctional unit provides a wide range of logical functions so that each required control schemes can be configured. The range of logical functions includes: AND logic gate, NAND logic gate, OR logic gate, NOR logic gate, XOR logic gate, Bistable and monostable flip flop, Counters, Timers, Pulse generators and Memories.

Similar to the free definition of the control scheme, each required protection scheme can be configured by the combination of the available protection function modules. For example, the following protection functions areavailable:

- Definite time overcurrent protection
- Inverse time overcurrent protection
- Directional overcurrent protection
- Under- or overvoltage protection
- Distance protection
- Differential protection for transformer and motor
- Thermal protection for cable, transformer and motor
- Reverse power protection
- Synchronism chec

The protection scheme parameters can be changed via the HMI Control Unit without using a personal computer. Additional functions can be excuted with a personal computer running the configuration software and connected to the optical interface on the front of the HMI unit.

- These additional functions are:
- Parameterization of the protection scheme,
- Read-out of the current measurement values,
- Read-out of the status of the binary inputs and outputs,
- Read-out of the fault recorder and
- Viewing of the FUPLA logic I/O states

III.3.4. Operation

A wide range of functions can be controlled and operated using the simple, user-friendly interface on the HMI Control Unit. This user-friendly interface is shown in the figure 3.9

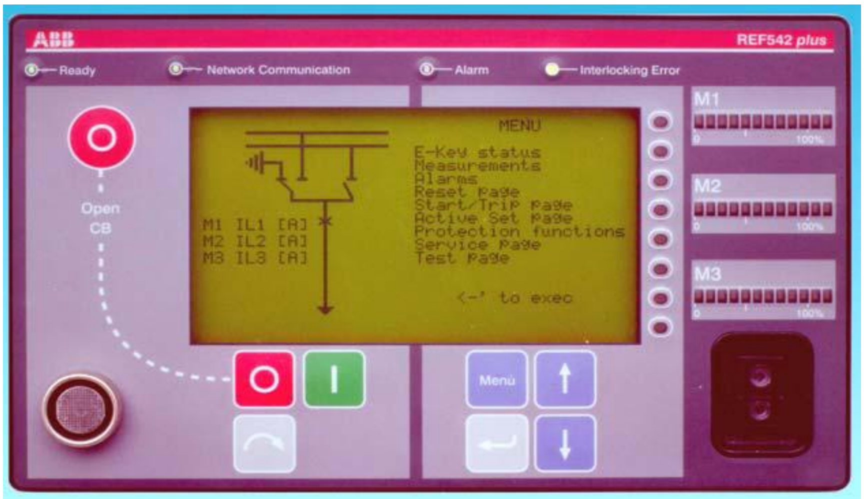


Figure 3.9 HMI as Control Unit

III.3.4.1. LCD display

The back-illuminated LCD display of the HMI provides a graphical display of the switching devices in the switchbay controlled by the REF542plus. The intensity and the duration of the illumination can be set as required. The Single Line diagram shows the current status of all the switching devices. The right half of the LCD display is for plain text, such as measurement values, main menu and submenus descriptions, protection signals and event recording.

On the LCD display, the following can be shown:

- Up to eight switching device icons (when the binary I/O boards with mechanical relays are used, a maximum of seven switching devices can be controlled)
- Various icons for motors, transformers, sensors, transducers
- A maximum of 40 individual lines.

III.3.5. Status Indication

Four system LEDs, describe in the following chapters, indicate the status of the REF542plus.

III.3.5.1. Operational status

On the HMI front panel, the operational status is called 'Ready' and is displayed by a green LED. The unit is not operational when this LED is off, and this occurs for example during the downloading of the configuration for the operation of the switchbay or if a fault condition is detected in the Central Unit.

III.3.5.2. Communication status

On the HMI front panel, this communication status is called 'Network Communication'. If the REF542plus is to be connected to a station automation system, the appropriate communications board is required. In this case a green LED is used to indicate the correct operational status of this optional board. The LED color changes to red if a communication failure has occurred.

III-3-5-3- Alarm indication

Several arbitrary alarm conditions can be defined and configured by the user. If one of these conditions is fulfilled, the red LED will be on.

III.3.5.4. Interlocking status

The LED is green if no interlocking conditions have been violated. In case of a switching action, which violates the interlock conditions such as switching a disconnector in the closed condition of the **C**ircuit **B**reaker (CB), the color will change temporarily to red.

III.3.6. LED Indication

Eight freely programmable, three color LED's are provided for local indication. The number of LED display options can be quadrupled through the menu structure. As a result, a total of 32 indication options are available for status indication regarding protection, control, monitoring and supervision functions.

III.3.7. Bar displays

Three freely programmable LED bars are provided for showing the measurement values. The LED bars are used to display arbitrary measurement values as required. Each bar consists of ten green and two red LEDs. The nominal values of each LED bar, which corresponds to the ten green LEDs are defined by the configuration software. If the measurement values are higher than the rated values, the red LEDs will gets illuminated indicating an overload situation.

III.3.8. Control push buttons

The control push buttons are used for operation of the switching devices during local control. A total of eight push buttons are available, four for commanding the primary equipment and four for browsing the display. The emergency push button can be configured in the FUPLA to open the circuit breaker when pressed simultaneously with the normal open push button.

III.3.9. Electronic key

Two different electronic keys are provided. One key can only be used for the protection scheme parametrization. The other one is for control modes selection: local, remote or local/remote. By using these two keys a certain separation between protection and control operation can be achieved. If required a general key that permits access to both modes is provided. The sensor for recognizing which electronic key has been used is located on the front panel of the HMI Control Unit.

III.3.10. Measurement

REF542plus can have a maximum of 8 analogue input channels for measuring current and voltage signals. These channels are organized into three groups.

Group 1 and group 2 have to be homogeneous, that means they can measure 3 currents or 3 voltages. For example, measurement of 1 current and 2 voltages is not allowed. Group 3 can get any type of signals: 2 currents, 2 voltages, 1 current and 1 voltage, etc. Channel 8 in the current REF542plus release can be used for measurement purposes only (no protection). REF542plus analogue inputs are very flexible, as this flexibility is needed to support all the protection functions of the unit itself.

Group1 and group 2 can be used for homogeneous current or voltage measurements both from instrument transformers and non conventional sensors. Group 3 can be used in a heterogeneous way, as well with instrument transformers as also with sensors. Channel 7 in group3 can be used for earth fault current with current transformer type input; or for the synchronism check function with voltage transformer type input.

The most common configuration uses three current and three voltage inputs and one earth fault current input. All values are shown on the display as primary values. The values registered over an extended time period, for example energy, number of CB operations, maximum and measurement values are permanently saved. Even after power interruptions this data is still available. Using this common configuration, the following measured values are displayed:

III.3.10.1. Values measured directly

- Line currents, three phases
- Phase voltages, three phases
- Earth current or residual voltage
- Frequency
- From the above measured quantities the following values can be calculated:

III.3.10.2. Calculated values

- Line voltages, three phases
- Earth current or residual voltage
- Average value/maximum value current, three-phase (determined over several minutes)
- Apparent, active and reactive power
- Power factor
- Active and reactive energy
- Moreover, the following quantities for monitoring purposes can be provided:

III.3.10.3. Other values

- Operating hours
- Switching cycles
- Total switched currents
- Metering pulses from an external metering device (up to 10)

III.3.11. Protection

The REF542plus offers a wide range of functions for protection. As mentioned before, a wide range of protection schemes for the protection of several system components can be configured. The available protection functions can be combined together to form the required protection scheme. Figure 3.10 shows an example of a configured protection scheme.

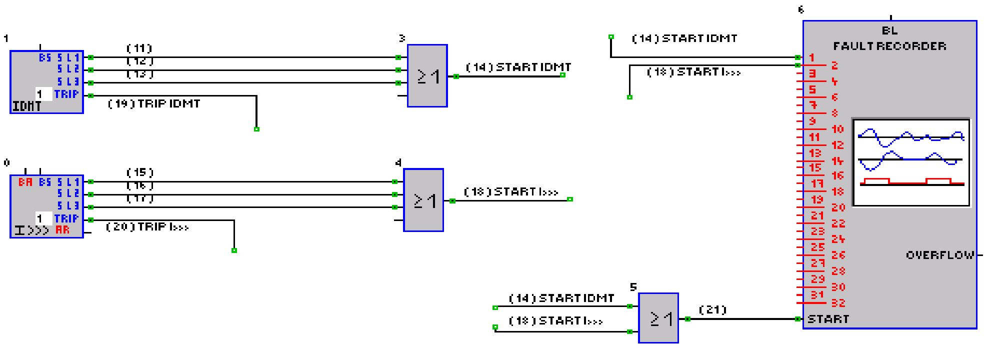


Figure 3.10 : FUPLA protection scheme

III.3.12. Control

The REF542plus permits convenient local operation with full interlocking against switching errors. The switch position of the various switching devices in the switchbay can be shown on the LCD display of the HMI Control Unit. If local control mode is selected, switching actions can be input locally using the control push buttons on the HMI Control Unit. Switching to another control mode can only be achieved by using the correct electronic key.

In remote control mode, only switching actions from a remote control unit like a station automation system are feasible. A special control mode, Local and Remote, is provided for users who want to perform simultaneous Local and Remote switching.

Interlocking between the switchbays connected to the same bus bar system can also be taken into account. This requires the availability of status information of the switching devices to and from other switchbays. The status information must be provided either by a conventional, hard wired ring bus system or by the more sophisticated ABB station automation system. Figure 8 shows an example of a configured control scheme of the CB.

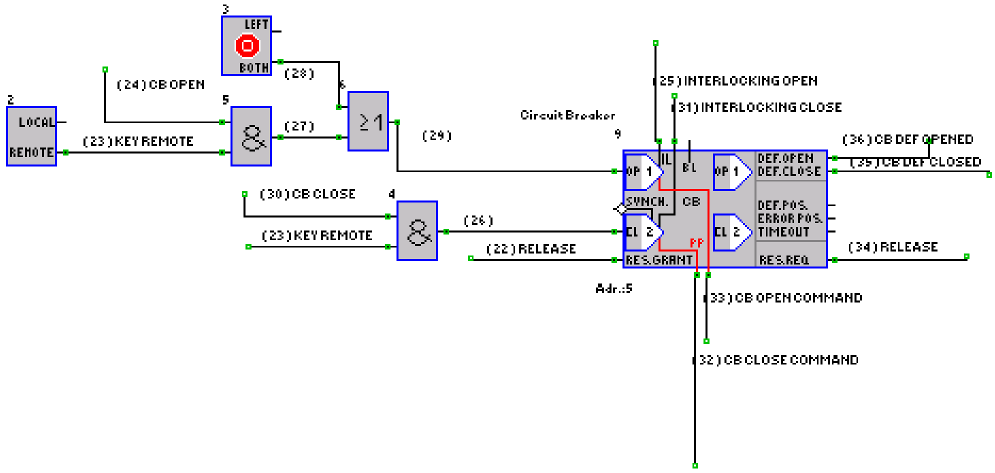


Figure 3.11 : FUPLA control scheme

III.4. Differential Protection with REF 542plus

The three-phase differential protection incorporated in REF542plus is primarily designed for the protection of two-winding power transformers and high-voltage motors. The operation of the protection is based on the biased differential current principle, which is shown in Figure 3.12

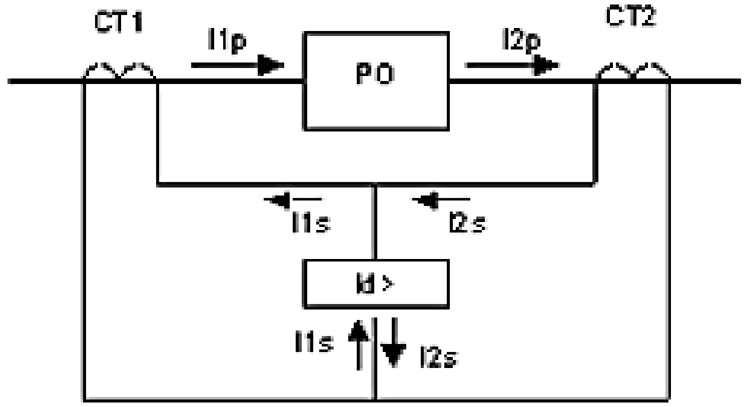


Figure 3.12 Operation principle of the bias differential protection

PO is the protected object, CT1 and CT2 the current transformers in the boundary zones I1p and I2p the current on the primary side of the concerned current transformers, and I1s and I2s the current on the secondary sides of the concerned current transformers. The secondary currents of the current transformers are routed through the differential protection Id>, as shown in Fig. 2.-1. Assuming that the current transformers have no error, it can be seen, that during normal load conditions or during through-fault conditions no current is flowing through the differential protection Id>. However, should an internal fault arise between the two current transformers a trip might be initiated, because then the differential current Id is no longer zero.

$$I_d = I_{1s} - I_{2s} \quad \text{(III.1)}$$

In principle, this basic approach of a differential protection scheme is implemented using an overcurrent relay placed in the differential current path formed by the two current transformer secondary circuits.

Because current transformers always have a certain inherent error, the differential current is never zero, once load current is flowing. Especially under through-fault conditions with a high short- circuit current magnitude, the differential current may be very high too due to the current transformer errors. Furthermore, the on-load tap-changer of the power transformer causes an additional error due to the change of the transforming ratio of the winging. Depending on the sensitivity of the setting of the basic differential protection solution, i.e. the overcurrent protection relay, unwanted tripping may occur.

Therefore, it is necessary to stabilize the differential current protection by means of a so called bias current. For the biased differential protection the following measurement quantities are used:

-operating quantity: $\underline{I}d = |\underline{I}1s \,.\, \underline{I}2s|$

-biasing quantity: $\underline{I}b = (|\underline{I}1s + \underline{I}2s|)/ 2.$

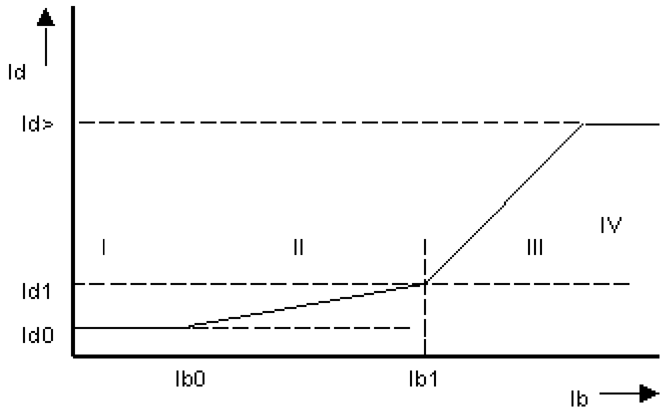


Figure 3.13 Tripping characteristic of a biased differential protection

The above equation shows that the biased current is almost the same as the load current under normal load conditions or under through-fault conditions. By using the biasing quantity it is possible to define the dependency between the tripping of the differential protection and the through-fault current. The higher the load current or the through fault current, the higher the level of the differential current required for tripping.

The tripping characteristic consists of four different areas. The first area is dedicated to low load conditions, the second one to normal and heavy load conditions, the third one to through-fault conditions and, finally, the fourth one by Id> to tripping due to a through fault current condition.

III.4.1.Technical implementation

III.4.1.1. Connection diagram

Due to its flexibility, the REF542*plus* offers a lot of options for connecting the device to the current transformers. **Figure-36-** below shows one of these CT connection options.

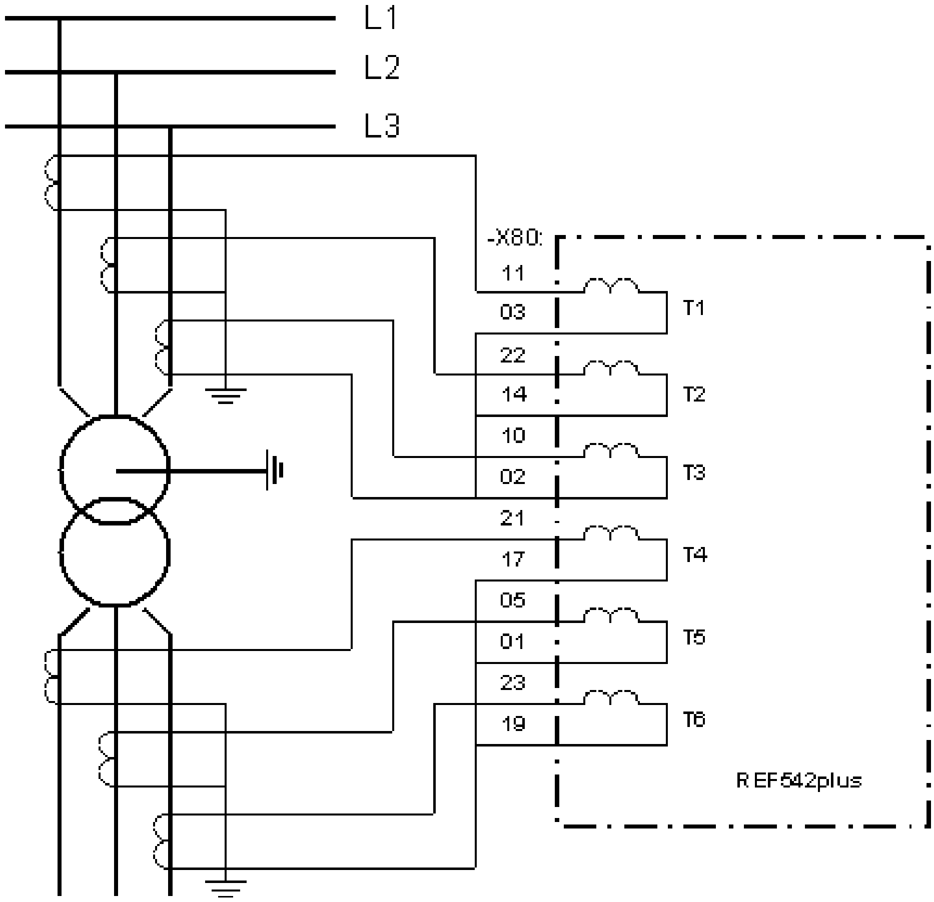


Figure 3.14 Connection diagram for REF542plus using 6 input CTs

In differential protection applications, REF542*plus* is to have at least six CT inputs. The first group including T_1,T_2 and T_3 is connected to the three phase current transformers on the high-voltage side and the second group including T_4, T_5 and T_6 is connected to the corresponding current transformers on the low-voltage side of the power transformer.

III.5. Example of motor protection setting

An example for setting the REF542*plus* for motor protection will be described in the following section. The motor is assumed to have the following technical data:

rated voltage	**3.3 kV**
rated frequency	**50 Hz**
rated power	**2500 kW**
rated current	**492 A**
locked rotor current	**4.8 p.u**

The current transformers are located in either end of the stator windings. All CTs have the same rated current 600 A/1 A.

III.5.1. Configuration of analog inputs

The configuration of the analog inputs is shown in Figure 3.15

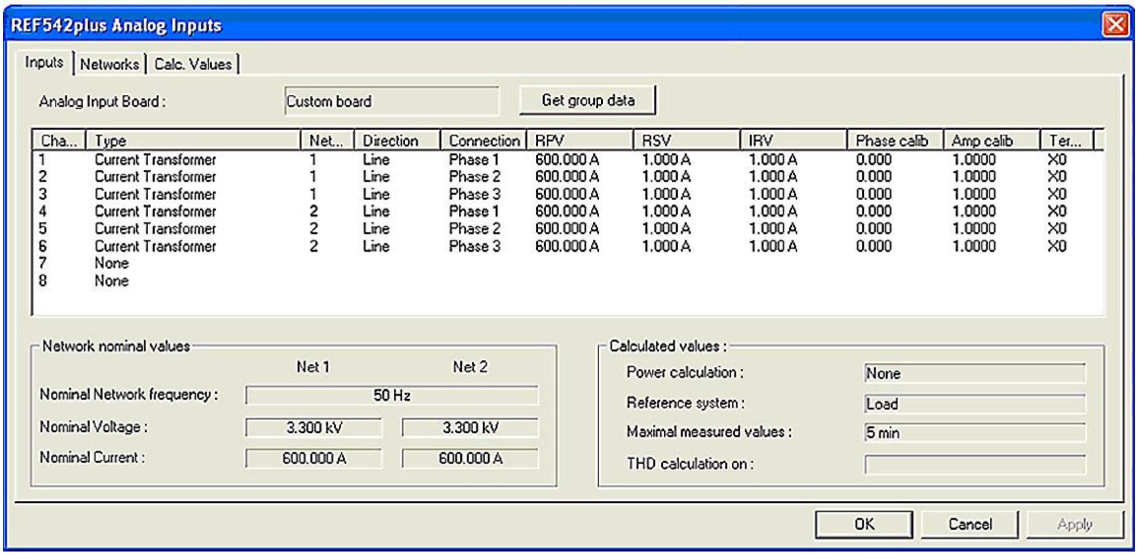


Figure 3.15 Setting of the analog inputs for motor protection

The CTs at one stator end are to be connected to AI 01, AI 02 and AI 03, which is defined as NET 1, while each CT at the other stator end is connected accordingly to AI 04, AI05 and AI06. For all CTs the direction line is selected.

The Figure 3.16 shows the adaptation of the connection for the selected example.

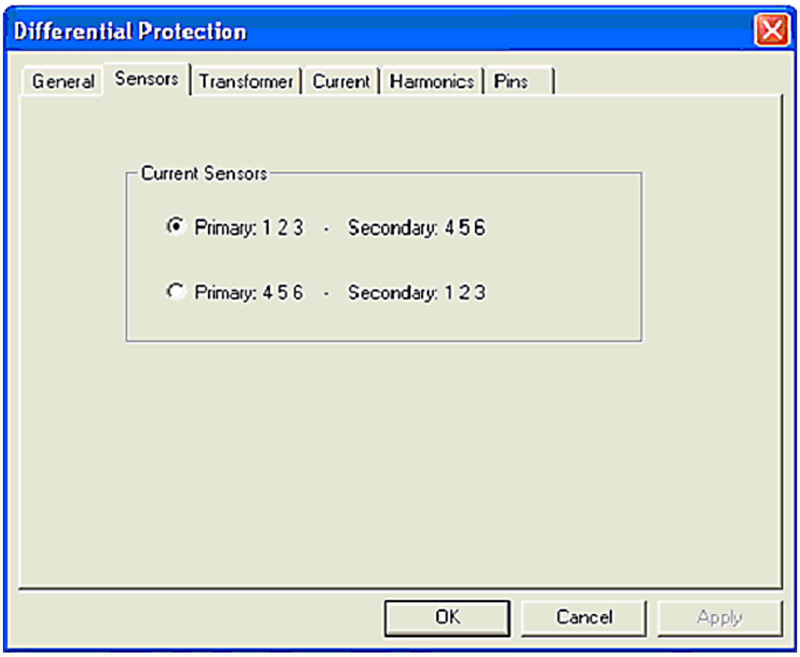


Figure 3.16 Adaptation of the analog inputs

The Figure 3.17 shows the vector group setting. Because the currents to be compared in the motor are not shifted from each other, vector group 0 shall be selected.

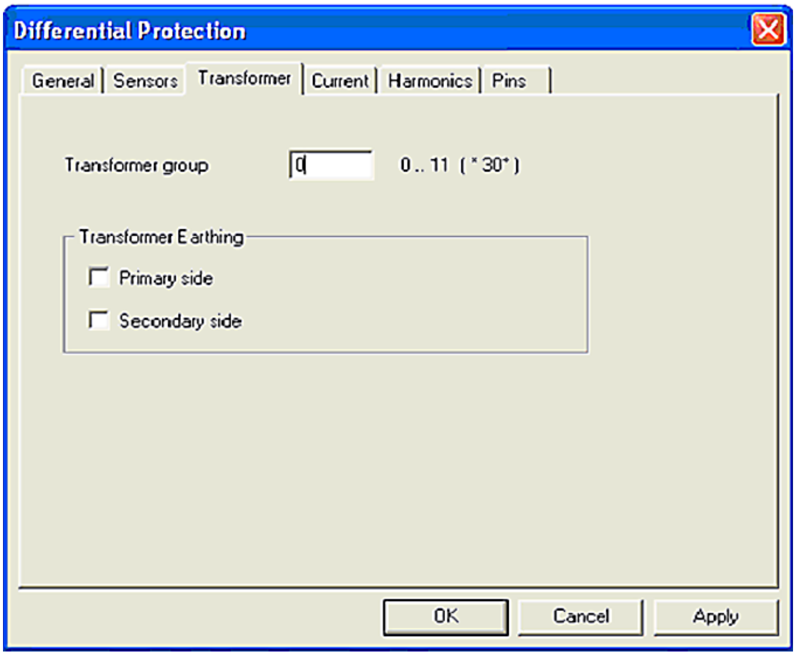


Figure 3.17 Configuration of the vector group and the earthing of the power transformer

III.5.2. Setting the tripping characteristic

In case of a locked rotor the current will be 4.8 x Ir. A locked rotor is identical to the condition of a three-phase short circuit at the end of the stator winding of the motor. To be able to detect this fault situation the maximum possible differential current Id> is set as follows:

Trip by Id> = 0.8 x 4.8 x In = 3.8 x Ir.

The tripping characteristic, as shown in Fig. 2.-2, will now be defined accordingly. During the low load condition in the range up to 0.5 x Ir the differential protection shall be given a very sensitive setting. The differential current of the motor protection arrangement depends only on the accuracy of the CT. So the lowest threshold value can be used:

-threshold current Id0 = 0.10 x Ir

-unbiased region limit Ib0 = 0.5 x Ir

The maximum load current for normal load condition shall be from 1.2 to 1.5 x Ir. Assuming that the CT up to this load current range has a maximum error of ±1%, the total error of the differential current in a worst case situation can be assumed to be approximately 2%. So, the total error is:

-Total error = 2%.

From 0.5 x Ir to 1.5 x Ir, the tripping characteristic shall have a slightly biasing slope. The safety margin of 120% shall also be considered. The threshold value Id1 can be calculated as follows:

Slightly biased region threshold Id1 = (1.5 x Ir . 0.5 x Ir) x 0.02 x 1.2 + 0.10 x Ir

= 0.125 x Ir.

The lowest possible setting is 0.2 x Ir.

Slightly biased region limit Ib1 = 1.5 x Ir.

The heavily biased slope can also be defined by the lowest value 0.4.

The Figure 3.18 shows the setting for the tripping characteristic for the above given example.

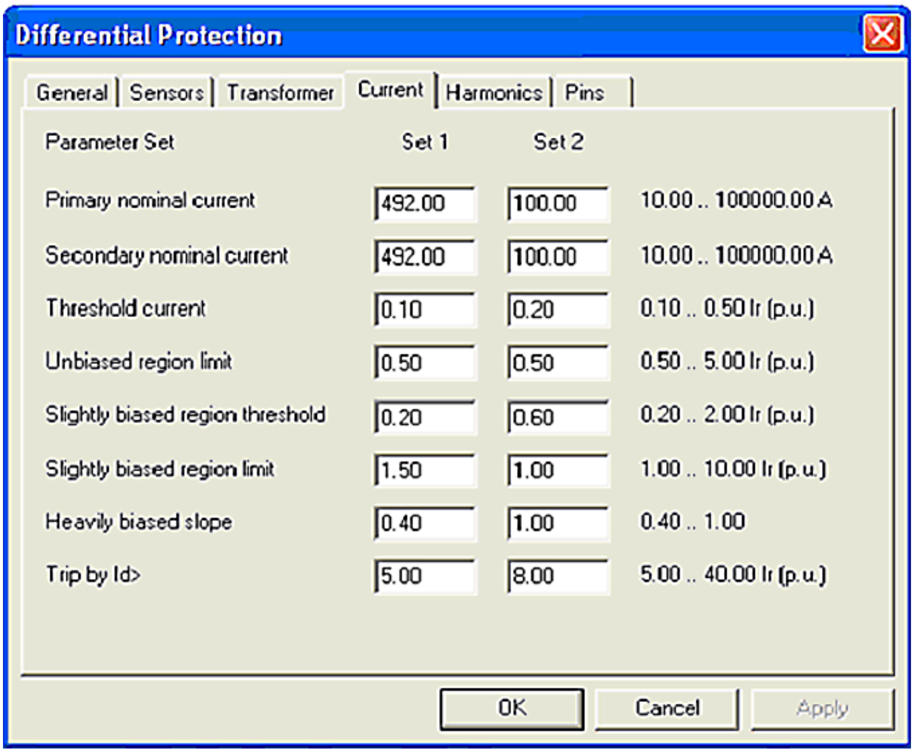


Figure 3.18 Setting of the tripping characteristic

III.5.3. Stabilization against inrush current

For motor protection, stabilization against inrush current is not necessary, because during normal operation the currents through the two CTs always are equal. Therefore it is not necessary to enable the harmonics blocking function.

III.5.4. CT requirement

For motor protection there is only one requirement to be fulfilled and that is that the CTs must be able to carry the locked rotor current without saturating. Thereby the time constant of the DC component shall be taken into account. It is recommended, that the CT group, placed at either end of the motor winding, have the same characteristic, so that in the case of a through fault no differential current appears.

III.6. Summary

The application of the three-phase differential protection being part of the REF542*plus* terminal for transformer and motor protection is described in this Application Note. The settings of the protection are demonstrated by means of appropriate calculation and setting examples.

III.7. Conclusion

Finally in this last chapter, we took a kind of protection and control that REF542plus is doing as part of study and analysis, which is differential protection. The medium voltage (MV) motor circuit breaker and the REF542plus multifunction protection and switchbay control unit together form a comprehensive solution for protection, control, and monitoring in medium voltage switchgear applications.

The combination of a medium voltage motor circuit breaker and the REF542plus unit represents a modern, intelligent approach to medium voltage power system management. It enhances system protection, streamlines control operations, and supports future-ready automation needs, making it a valuable asset in power distribution infrastructure.

GENERAL CONCLUSION

General conclusion

The protection of medium voltage motors is crucial for ensuring the reliability, efficiency, and safety of industrial electrical systems. These motors are commonly used in heavy-duty applications, and their protection is vital to prevent damage, minimize downtime, and extend their lifespan.

The protection of medium voltage motors involves a combination of monitoring, detection, and corrective actions to ensure that these motors perform efficiently and safely throughout their operational life. By employing appropriate protection strategies. such as overload, short-circuit, and ground fault protection. alongside regular maintenance, industries can minimize motor failures, reduce downtime, and improve overall system reliability.

A general problem that has existed over the years with regard to motor protection is the lack of availability of complete data on the system driven by a motor to the protection engineer. Electrical engineers responsible for specifying and setting motor protection frequently do not communicate with the mechanical engineers who are familiar with the nature of the loads that are driven. As a result, motor protection is often applied on the basis of best estimates, standards, and on motor name-plate data. If the motor trips during starting conditions, the setting is increased in small steps until nuisance trips subside. This practice may be satisfactory for small, general-purpose applications in which investment is small and the process is not critical. However, for larger or more critical applications, the protection engineer should make every effort to understand the details of the loading conditions that are connected to the motor as well as the operating characteristics of the motor, so that the related protection can be properly specified and set to minimize the potential for damage to the motor or shutdown of the process that it serves. Oscillography capability provided by many modern microprocessor relays provides an effective tool for obtaining pertinent data during the process of placing a facility in service and while functioning during normal in-service conditions.

References

1. www.GEMultilin.com
2. AC Motor Protection, Continuing Education and Development, Inc. 22 Stonewall Court Woodcliff Lake, NJ 07677, Course No: E03-034, Credit: 3 PDH
3. IEEE Recommented Practice for Industrial and Commercial Power Systeme analysis, IEEE Standard 399-1997, Sept 1997.
4. NEMA Motors and Generators, NEMA MGI- 2009.
5. LEGRAND, Head office and International Department 87045 Limoges Cedex – France, EXB19046 - October 2022
6. ABB Oy Distribution Automation P.O. Box 699 FI-65101 Vaasa FINLAND, 1MRS 756281 EN 01.2007
7. REF 542 plus Technical Catalog, 1VTA100001en-5, Updated and valid from version V4C01, PTMV, 10.02.2002.
8. Prenc, R., et al., *On the development of overcurrent relay optimization problem for active distribution networks.* Energies, 2022. **15**(18): p. 6528.
9. Obuliraj, D. and P. Loganathan, *Enhanced Back Controlled Phase Fault and Earth Fault Busbar Protection Scheme using Overcurrent and Earth Fault Relays.* Journal of The Institution of Engineers (India): Series B, 2021: p. 1-8.
10. ANSI=IEEE Standard C37.96, Guide for AC Motor Protection, IEEE Service Center. Brighton, R.J. Jr. and Ranade, P.N., Why overload relays do not always protect motors,
    IEEE Trans. Ind. Appl., IA 18, November–December 1982, pp. 691–697.
11. Dunki-Jacobs, J.R. and Ker, R.H., A quantitative analysis of grouped single-phased induction motors, IEEE Trans. Ind. Appl., IA 17, March–April 1981, pp. 125–132.
12. Gill, J.D., Transfer of motor loads between out-of-phase sources, IEEE Trans. Ind. Appl., IA 15, July–August 1979, pp. 376–381; discussion in IA 16, January– February 1980, pp. 161–162.
13. Lazar, I., Protective relaying for motors, Power Eng., 82, No. 9, 1978, pp. 66–69.
14. Linders, J.R., Effects of power supply variations on AC motor characteristics, IEEE Trans. Ind. Appl., IA 8, July–August 1972, pp. 383–400.
15. *Dr. Md Sajid Assistant Professor, EED, MJCET, Hyderabad*, International Journal of Research , ISSN NO:2236-6124, https://www.researchgate.net/publication/349643214