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Protection relays in power plants

A project thesis submitted in partial fulfilments of the requirements for the degree of Bachelor of Science in Energy Engineering

By Group

1. **Mohammed Sabih Sami**
2. **Jalal Qasim Hamid**
3. **Esraa Hameed Aliwi**

Supervised By

Dr. Mohammed Ali

بسم الله الرحمن الرحيم

((إِنَّ هَٰذَا كَانَ لَكُمْ جَزَاءً وَكَانَ سَعْيُكُم مَّشْكُورًا))

صدق الله العلي العظيم

[الأنسان: 22]

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CONTENTS

Abstract

This project investigates protection relays and their applications in power stations. Considering the multitude of protection devices available, the overcurrent relay was selected as an example to illustrate the significance of protection devices in addressing issues encountered in power system.

In chapter one, The different generations of protection devices were reviewed with their advantages and how they differ from each other.

In chapter two, the overcurrent protection relay has been considered. Where, different topics related to this protection device were studied briefly.

Finally, chapter three has discussed the phenomenon of inrush current, which refers to the temporary surge in electrical current when an electrical device is switched on.

CHAPTER ONE

CHAPTER ONE

1 INTRODUCTION

A *protection relay* is a smart device that receives inputs, compares them to set points, and provides outputs. Inputs can be current, voltage, resistance, or temperature. Outputs can include visual feedback in the form of indicator lights and/or an alphanumeric display, communications, control warnings, alarms, and turning power off and on. A diagram answering the question what is a protection relay is shown below.

Figure 1.1 differential protection relay

1.1 Historical background

The methods of manufacturing protection devices passed through several generations, starting with Electromagnetic Relays devices, passing through Static Relays protection devices, and ending with Digital Relays protection devices. In the next part, we briefly review the multiple generations that passed through the methods of manufacturing protective devices, and we will take the Overcurrent Relay device as an example when explaining:

1.1.1 First generation Electromagnetic/Electromechanical Relays

In the first generation of manufacturing methods, and as is clear from the name, the idea of the device working was dependent on exploiting the property that the electric current that passes through a coil always creates a magnetic field accompanying it, and is also accompanied by a magnetic force that can attract an iron arm and move it, as in the case of Hinged Armature Relay shown in the figure 1.2

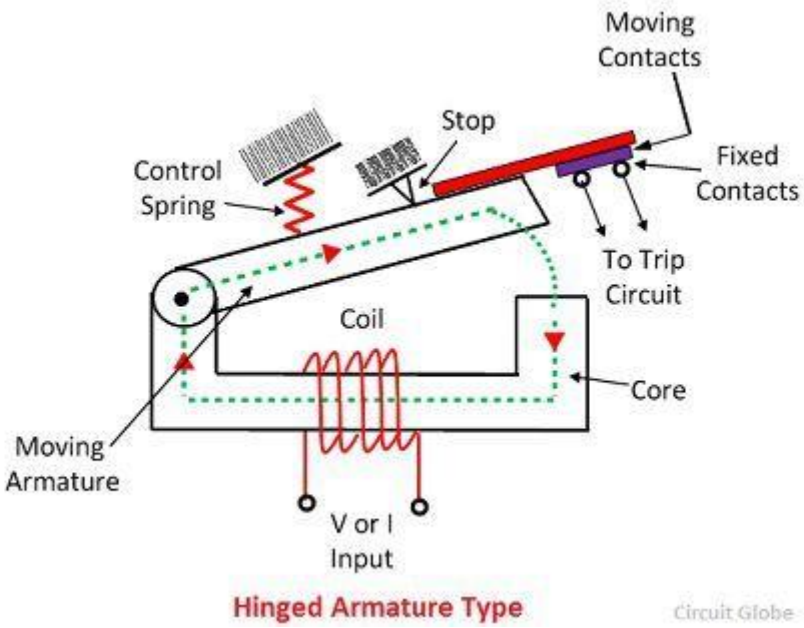

Figure 1.2 Hinged Armature Relay

Sometimes this magnetic force is exploited to influence a rotatable iron disk, making it rotate at a speed commensurate with the intensity of the current. This idea was used, as in the case of Induction Disc Relays, which appears in Figure 1.3

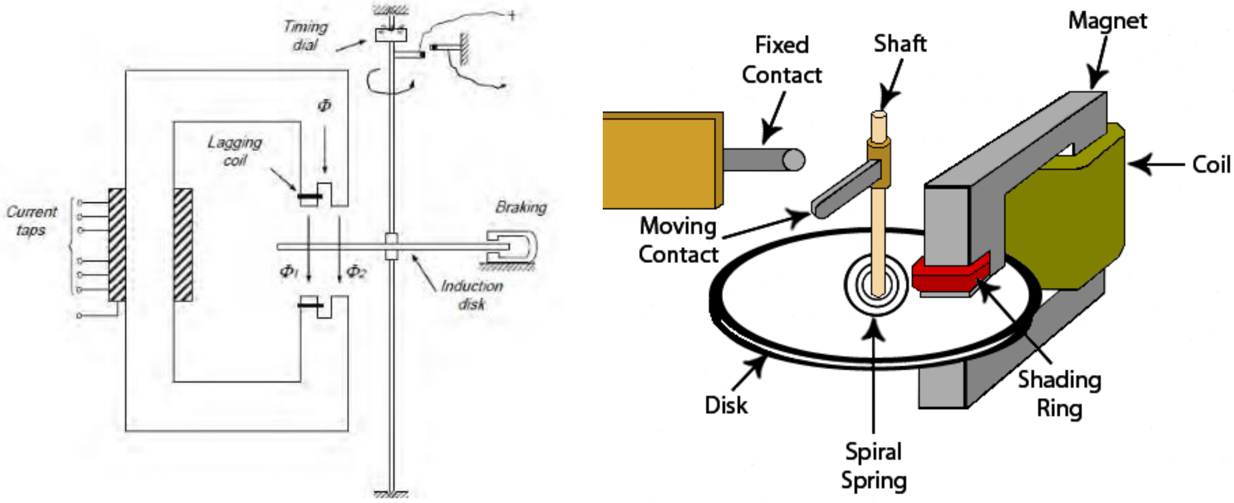

Figure 1.3 Induction Disc Relays

These types are also called Electromechanical Relays, and the reason for the name is clear. In Figure 1.4 there are examples of one of the previous types

Figure 1.4 Electromechanical Relays

Movement in both types is used to close another electrical circuit, which is the operating circuit of the cutter. Since the force that will move the arm, or turn the disc, is directly proportional to the intensity of the current passing through the coil, and therefore in natural conditions, where the current is a small value, this force will not be sufficient. To move the arm or turn the disc to close the circuit, while in the event of faults, where the value of the current rises greatly, this force will be sufficient to make the required movement, and close the CB operation circuit.

This type of device is always stable, and is not affected by tremors that may occur in the network, and engineers have gained extensive experience in dealing with these devices over many years, and this explains the reason why they remain in service despite the emergence of many new generations after them. However, it is flawed by the relatively slow response because the moving parts have inertia, so it needs time to start moving, and one of its disadvantages is also that it needs regular maintenance of the moving parts, and it needs calibration from time to time to ensure the accuracy of the measurement.

1.1.2 Second generation: Static relays

The second generation of methods for manufacturing protective devices appeared in the early sixties, and it is known as the generation of Static Relays, and the most important thing that distinguished it was that it dispensed with the moving parts used in the previous generation, which were a source of errors in the operation of the devices, as this generation relied on what is known as Operational Amplifier, which used to compare the value of the current passing through the circuit with certain tuning limits. If the current passing through the circuit exceeded the tuning values used, the Op Amp sends a signal to the CB to separate it. An example of this generation is shown in Figure 1.5

Figure 1.5 One form of protection devices from the generation of static

One of the most important defects of this generation is that the Op Amp devices were affected by temperature change, and therefore they are unstable, and therefore this quality did not last long, as the third generation of protection devices appeared in the late sixties and early seventies, which is known as digital relays.

1.1.3 Third generation Digital Relays

This generation, which is also called the Digital Protection Generation, Numerical Relays, or Digital Protection Devices, was able to overcome all the problems that previous generations faced, and therefore this type is now prevalent in the market for protective devices. The basic idea of this new technology is to convert voltage and current signals into digital numbers that are stored in the computer's memory and are continuously updated during very small time periods of 1 millisecond or less. Figure 1.6 block diagram represents the most important components of a digital protection device.

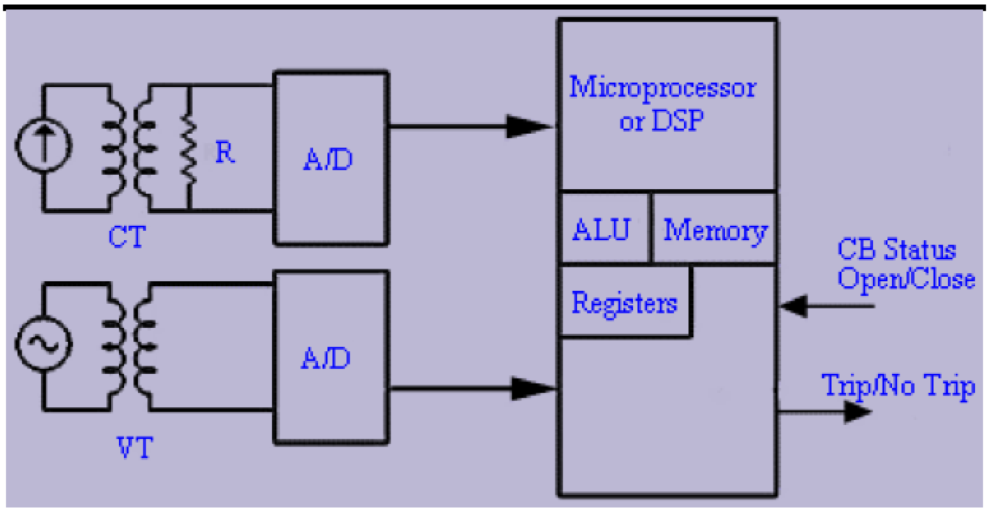

Figure 1.6 block diagram represents the most important components of a digital protection device.

Where the voltage and current signals of the 3-phases coming from the 3CTs, and from the 3VTs pass through the Anti-alias low-pass filter, it passes the frequencies up to a certain cut-off frequency, in order to ensure that the sampling rate that will be used later in the A/D is always more than twice as high. Frequency is in reference, according to the Nyquist Theorem.

After that, the stage of converting the Analog Signal to Digital Numbers begins, starting with cutting the signal into Samples using Sample and Hold as in Figure 1.7 , and then passing it to Analog to Digital Converters.

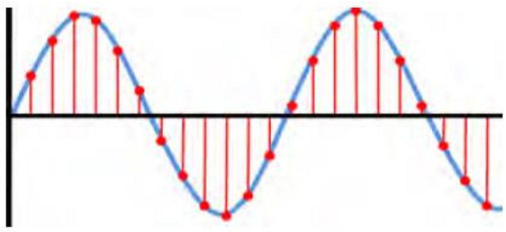

Figure 1.7 Sample and Hold Wave

An Analog Multiplexer may be used between or before the Sample and Hold S/H, so the six voltage and current signals enter it and exit successively from one output, and therefore we can use one A/D instead of six as in Figure 1.8

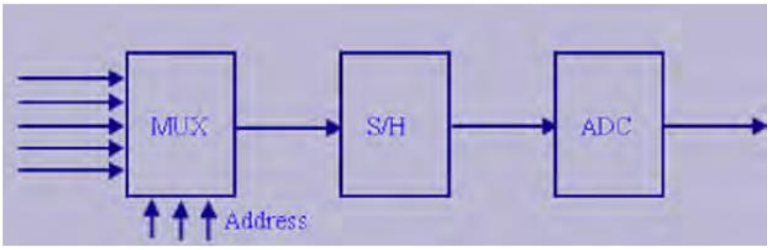

Figure 1.8 Analog Multiplexer

And since it is impossible to store all the values that are read, only a cycle or two of voltage and current are stored in the memory of the device, RAM, and whenever a new value comes, it deletes the oldest stored value, and so on. Then, by means of the Algorithm prevention program stored in the device, the change in the values of these signals is tracked directly through equations, and based on the size of the change that appears from the numerical values entered into the device, it is possible to determine whether there is a malfunction or not, and it is possible to develop new capabilities for the protection device that could not be implemented By using old technology, Static or Electromechanical, it was possible, for example, to change the setting values automatically for the device, then the biggest development of these devices occurred after the development of digital communication systems, so that the exchange of information between digital protection devices became an easy thing, which revolutionized the capabilities of this type of devices and their ability to detect Faults are classified with great accuracy. An example is shown in Figure 1.9

Figure 1.9 Digital protection relay

1.1.4 Fourth generation Adaptive Digital Relays

In the late eighties, thinking began to tend to increase the benefit first from the experiences gained by workers in the field of digital protection during the past years, and secondly to benefit more from the capabilities of the microprocessor technology used in these devices, as until this period digital protection devices were still imitating their old counterparts with Some improvements.

One of the most important developments introduced in this generation was the introduction of the possibility of adjusting the setting values automatically, especially since the relay has all the information about the network. The device must not be deceived by any increase. There are many researches in this field.

1.1.5 Fifth generation Multifunction Digital Relays

In the 1990s, a new development appeared on digital protection devices, as the producing companies began to merge many protective devices into one device. The philosophy of this was that the hardware for all digital protection devices is almost the same, and the difference between them is only in the software stored inside it, and with the development in storage techniques it became possible to store many programs representing different devices within one relay, and therefore it was called Multifunction Relay meaning a multi-functional protection device. Of course, it will come to mind that the problems of this technology are many, the most important of which is that stopping this multi-functional device causes a disaster due to the absence of the entire prevention system, while in the past, the stopping of a device was compensated by the rest of the devices that are still working. Of course, this observation was not lost on the minds of the manufacturers, so they made it a backup protection - often from another company - as some others took advantage of the presence of the old protection devices in the station, making it a backup protection for this new device, and thus he wins twice: once when he benefited from the new technology, which has many Features, again while keeping the old hardware that still performs well.

1.2 The most important features of digital protection

Here are the most important features of digital security devices:

- Additional monitoring functions.
- Functional flexibility.
- They can implement more complex and accurate function.
- Self-checking and self-adaptability.
- Able to communicate with other digital equipment (peer to peer).
- Less sensitive to temperature ،aging.
- More Accurate.
- Signal storage is possible.
- Low CT /PT burden.
- Metering.
- Fault report.
- Fault location.
- Event logging.
- Oscillography record/fault data information.
- Standard hardware.
- Flexibility in operation.
- Multifunction.
- Communication.
- Adaptive relaying.

CHAPTER TWO
Over Current Protection

CHAPTER TWO

2 Over Current Relays

Overcurrent Relays have been taken as an example in order to study the protection relays. The prevention device is the oldest, most famous and widest device, because most of the faults it results in an increase in the current, hence the thinking has always been, and from the beginning, tends to study and follow up the change In the value of the current passing through any element of the power system, and the current is separated from it directly if its value exceeds a limit Specific to this element. In this chapter, we study the principles and basics of Overcurrent Relays in detail.

2.1 Factors affecting the value of fault current

It is known that the value of the fault current is often very high compared to the normal values of the current in the circuit, and in this part of the chapter we will review the most important factors that affect the values of the fault current, which are:

2.1.1 The place of the malfunction

It is known that the farther the fault is from the location of the Relay, the greater the resistance it sees for the Relay, and therefore The fault current value decreases. This explains why it is difficult to detect faults far from the source, where it is The rise in the value of the fault current is slight.

2.1.2 RF fault resistance value

When an overhead TL falls, for example, to the ground and a short circuit occurs, the fault current It passes the distance from the location of the protective device R to the fault position through the line resistance (LFZ), and then passes in another resistance The fault resistance is called F, RF fault Resistance, as in Figure 2.1. And this resistance FR is affected by the quality of the soil (rocky-muddy, etc.), and is also affected by whether or not there is a spark in the fault issue. And various other factors, and therefore the fault current if we take into account the value of the fault resistance becomes according to Eq. 2.1

$$f_x = \frac{V_s}{Z_{lf}+R_f} \text{.................................} \quad Eq\ 2.1$$

This equation explains the reason for the difficulty in detecting high impedance faults. Because the rise in the value of the fault current is slight. There are special digital protection methods used with devices modern technology to discover this type of fault, which is characterized by a slight increase in the value of the fault current The book is a list of some of the author's published researches in the field of overcoming this problem.

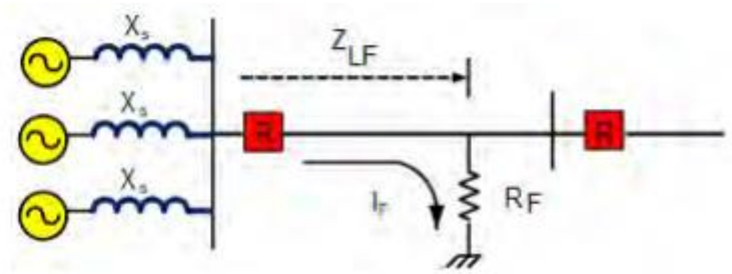

Figure 2.1 Malfunction on line through impedance

It should be noted here that the fault resistance FR is due to the sparks resulting from the fault in addition to the tower grounding resistance in a wide range between a value of less than one ohm and values exceeding hundreds of ohms. As for the spark resistance, it is calculated by one of the following approximate equations in Eq. 2.2

$$R_{arc} = \frac{8750}{I^{1.4}}$$

$$R_{arc} = \frac{350}{I} \qquad \text{..............................} \quad \text{Eq2.2}$$

$$R_{arc} = \frac{3000}{I^{1.3}}$$

All previous equations give the value of spark resistance in units of ohms. For each linear foot of the spark length, noting that the higher the fault current, the greater the effect of spark resistance limited as it is clear from all the previous equations

2.1.3 Power of feeding source

Also among the fundamental factors on the value of the fault current is the power of the effective feeding source, and it is expressed in the decrease in impedance Source(Low Source Impedance) If we imagine a feeding station with three generators, and that all generators In service, connected in parallel as in Figure 2-1, their equivalent source impedance value will be $(\frac{X_S}{3})$ so the total impedance from the source to the fault location will be small, hence the current The fault is large. In this case, the source is Strong Source. If we assume that only one generator is in service, then the source resistance will be X_S and not $(\frac{X_S}{3})$ As in the previous case, therefore, the total impedance from the source to the fault location is large, and there is a current A. The fault is small and the source is considered a Weak Source at the time

2.2 Different types of overcurrent relays

There are multiple types of Overcurrent Relays devices, and their design takes into consideration the variance A In the value of the fault current that was previously discussed in the previous section, and to take into account the period of time also after which it is required to disconnect the faulty circuit, and is it a fixed or variable period, and is it short or long...etc. All these considerations eventually resulted in several types of Overcurrent Relays devices, for example:

2.2.1 Definite Time/ Definite Current devices

which are types, including:

1- For the first type, devices are disconnected momentarily if the current exceeds a specified value, the Definite Current Relay, and it is known as Also OC Instantaneous, and it appears in Figure 2.2 (upper). This type is suitable for disconnecting malfunctions. The high current that does not bear any waiting, because even if the malfunction does not last for only a short period, it must be disconnected due to its seriousness

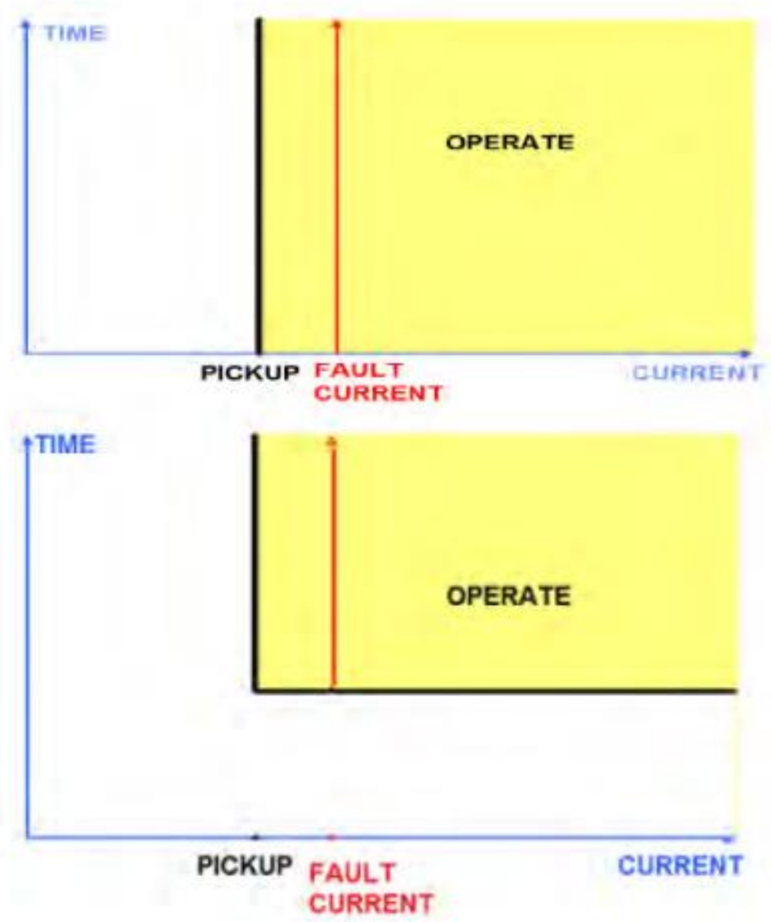

Figure 2.2 the Definite Current Relay, and it is known as Also OC Instantaneous

The main disadvantage of this type is that it often happens, especially when there are two short lines in it length and consecutive, in this case it is difficult to coordinate between the protection devices of this type because the difference between the fault current on both lines is not large. For example, in the case of the fault at point F1 in Figure 2.3, it will be difficult to coordinate Relay A with Relay B if they are Definite current

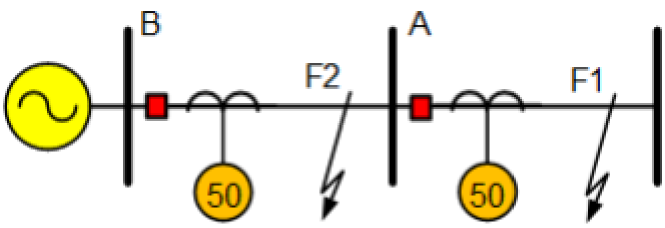

Figure 2.3 Shows the failure condition between point F1 and point F2

2- The second type is devices that are disconnected if the downtime exceeds a specific value, the Definite Time Relay, as shown in the figure 2.2 (lower), of course, after the current also exceeds the specified value.

This second type (Definite time) is suitable for less dangerous breakdowns, as it is separated if the value exceeds The current is a specific setting value, in addition to the passage of a period of time, it also maintains a malfunction, and therefore has the ability to avoid disconnecting the circuit due to a transient fault, because the device will wait for a specified period Before giving the signal for the chapter, if the chapter was transient, it will disappear before the expiration of the period specified for the chapter. The circuit will not disconnect, while if the fault is of the permanent type, it will be disconnected as soon as it ends The specified period for which the device is set

This type is used (Source Z is greater than Line Z) (when the difference between Line Z and Short Circuit a) at the beginning and end of the line is small, this means that it has overcome the problem of the first type. Very large near the source as in the figure 2.4

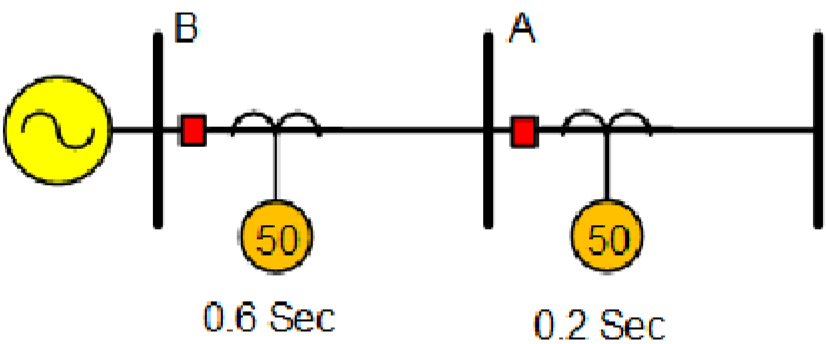

figure 2.4 It appears that the separation time is large near the source because of the coordination

2.2.2 Inverse OC devices

They are also of several types, including a type known as Normal Inverse, NI, which combines the features of the two previous types, and is separated according to an inverse relationship between the fault current and the fault time, and is characterized by not being affected by transient faults. At the same time, it disconnects quickly in the event of high current faults. This type of device is usually provided With curves of multiple inclinations to suit all uses, and to give various speeds for the same value of current as in figure 2.5

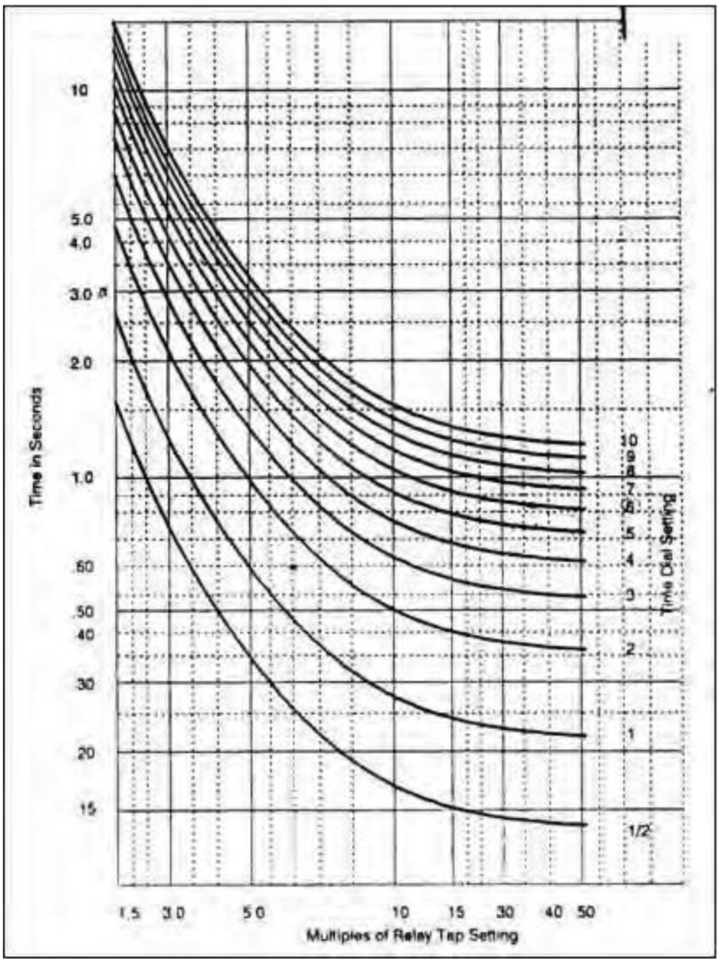

Figure 2.5 curves the normal invers

However, these devices are not suitable for use in systems with variable generating capacity. This type is often used when In other words, Z_{source} is less than Z_{line} When the difference between the short circuit level at the beginning and end of the line is large. In most cases, the Overcurrent Relay device is composed of two units: the first is of the Inverse OC type, so that it turns off after a certain delay time according to the operating curve used, and the second unit is of the Instantaneous type, that is, it turns off instantly as soon as the value of the current exceeds Setting, as in Figure 2.6 , which The curve is for the Inverse OC with a variable value Instantaneous OC .

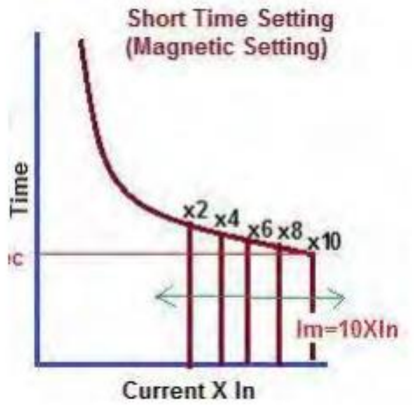

Figure 2.6 short time setting

This was done in the old devices using two separate units, as in the case of electromechanical devices. In the case of modern digital devices, it has become within one device, and in a much easier way, in terms of control In the *behavior* of the device is to change the equation used inside the device.

Inverse Relay devices are accompanied by two other types of the same category, namely:

2.2.2.1 Separators have a curve with very inverse characteristic, which is It is used in cases where the lines are fed from different directions, and one of the advantages of these devices is that the time Its work doubles when there is a shortage of current from seven to four times the setting on which the device is set. This leads to the possibility of using several relays in succession with the same value of the Time multiplier Which we will get to know shortly

2.2.2.2 Curve separators with Extremely inverse characteristic, It is used in cases where it is required to coordinate disconnect times with fuse. These devices are designed to be used Primarily for feeders in distribution networks that are characterized by relatively constant loads. These devices are They are preferred for protecting equipment from overheating and are typically used with transformers capacity and cables. Figure 2.7 shows the two types compared to Normal

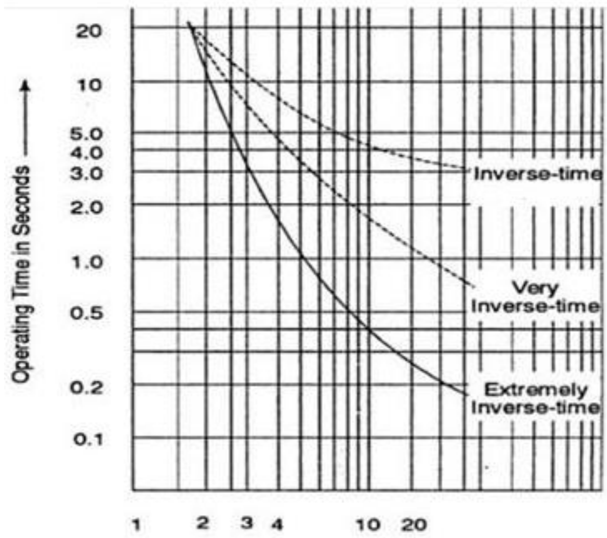

Figure 2.7 shows the two types compared to Normal

2.2.3 Digital protective relays

The digital protective relay is a protective relay that uses a microprocessor to analyses power system voltages, currents or other process quantities for the purpose of detection of faults in an electric power system or industrial process system. A digital protective relay may also be called a "numeric protective relay". It is also called numerical relay.

2.2.3.1 Input Processing

Low voltage and low current signals (i.e., at the secondary of a voltage transformers and current transformers) are brought into a low pass filter that removes frequency content above about 1/3 of the sampling frequency (a relay A/D converter needs to sample faster than twice per cycle of the highest frequency that it is to monitor). The AC signal is then sampled by the relay's analog-to-digital converter from 4 to 64 (varies by relay) samples per power system cycle. As a minimum, magnitude of the incoming quantity, commonly using Fourier transform concepts (RMS and some form of averaging) would be used in a simple relay function. More advanced analysis can be used to determine phase angles, power, reactive power, impedance, waveform distortion, and other complex quantities.

Only the fundamental component is needed for most protection algorithms, unless a high speed algorithm is used that uses sub cycle data to monitor for fast changing issues. The sampled data is then passed through a low pass filter that numerically removes the frequency content that is above the fundamental frequency of interest (i.e., nominal system frequency), and uses Fourier transform algorithms to extract the fundamental frequency magnitude and angle.

2.2.3.2 Logic Processing

The relay analyse the resultant A/D converter outputs to determine if action is required under its protection algorithm(s). Protection algorithms are a set of logic equations in part designed by the protection engineer, and in part designed by the relay manufacturer. The relay is capable of applying advanced logic. It is capable of analysing whether the relay should trip or restrain from tripping based on parameters set by the user, compared against many functions of its analogue inputs, relay contact inputs, timing and order of event sequences.

If a fault condition is detected, output contacts operate to trip the associated circuit breaker(s).

2.2.3.3 Parameter Setting

The logic is user-configurable and can vary from simply changing front panel switches or moving of circuit board jumpers to accessing the relay's internal parameter setting webpage via communications link on another computer hundreds of kilometres away.

The relay may have an extensive collection of settings, beyond what can be entered via front panel knobs and dials, and these settings are transferred to the relay via an interface with a PC (personal computer), and this same PC interface may be used to collect event reports from the relay.

2.2.3.4 Event Recording

In some relays, a short history of the entire sampled data is kept for oscillographic records. The event recording would include some means for the user to see the timing of key logic decisions, relay I/O (input/output) changes, and see, in an oscillographic fashion, at least the fundamental component of the incoming analogue parameters.

2.2.3.5 Data Display

Digital/numerical relays provide a front panel display, or display on a terminal through a communication interface. This is used to display relay settings and real-time current/voltage values, etc.

More complex digital relays will have metering and communication protocol ports, allowing the relay to become an element in a SCADA system. Communication ports may include RS232/RS485 or Ethernet (copper or fibre-optic). Communication languages may include Modbus, DNP3 or IEC61850 protocols.

2.3 Ground Fault Protection

One of the main uses of Overcurrent Relays is for ground fault protection Earth Faults, EF. It is named so because the Earth is part of a closed circuit In which the fault current passes. As for the faults in which the earth is not part of its circuit, they are called Phase Faults.

Although the Earth Fault Relay is originally nothing but an Overcurrent Relay, it takes a different number .The Inverse overcurrent device is known as 51 or 50, which appears in panels (Instantaneous OC), while the Earth Fault Relay will appear in the panels with the number 64 because its connection method FP circuit is different (if EF is placed in a Neutral circuit, it is called 51N, and otherwise it is called 64). In this part, we review The different types of Earth Fault Relays, and the basic idea behind each device.

2.3.1 Residual connected earth fault relay method

It is known that in normal operating conditions, the currents in the three phases are equal $I_A = I_B = I_C$, and the sum of the directions of the three currents is equal to zero. In the case of faults, this sum is equal to a value greater than zero. This is the idea on which this method was built, as the EF device (64) connects The sum of the three currents passes through it, as shown in Figure 2.8 . The device sends a disconnect signal in the event of an increase in the current For a value greater than zero (set to 20% of the normal current in Phases. In the case of ground faults, the current component known as Zero Sequence Current or vehicle appears zero, and it does not appear unless the fault is connected to the ground, and it is known from the rules of justice Symmetrical components that the sum of the three currents IC + IB + IA = I = zero in normal conditions, 3Io is equal to three times the Zero sequence component in the case of ground faults, and therefore this type of device is sometimes called Zero Sequence Relay

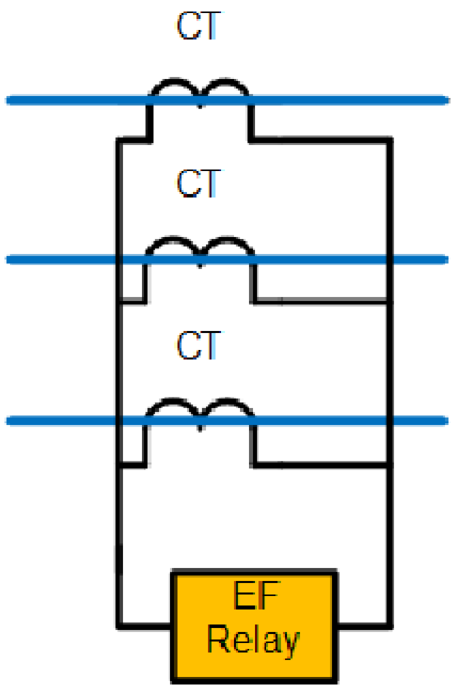

Figure 2.8 Residual connected earth fault relay

2.3.2 For the second method, EF In Neutral Connection

As it is known, most of the generators are grounded at the tie point by means of a grounding link, and this link may It may be connected to the earth directly or Solid or it may be connected through a resistance as in Figure 2.9. It is also known that the current passing through the earthing Connection is zero in the current situation Even in the presence of currents leaking along the line through Stray Capacitances, The sum of these currents equals - in the worst case - a very small value compared to the natural values of the current. Now, if we suppose that a ground fault occurred on one of the three lines, the fault current must find a way For him through the earth Al-Jilani(2019) to return to the generator, uh, otherwise there will be no closed circuit and there will be no fault current at all. And this The road is nothing but the mass of the earth itself (affected by the moisture of the groundwater and the waters of its soil) inevitably ends up Earthing connection to return to the generator and complete the closed circuit

Hence, the current through the Neutral grounding link during normal operation is zero or close to Zero, while this link carries a high current during the holiday period, and this is the basic idea on which it was built

This connection, which appears in Figure 2.9 , is where the EF Relay device is placed in the grounding connection through CT on this link, and it is set so that it disconnects the circuit if a current higher than the normal current is ordered for this The link, which is equivalent, as we mentioned, in the worst case, to 20% of the value of the natural current passing through the desired element protect it

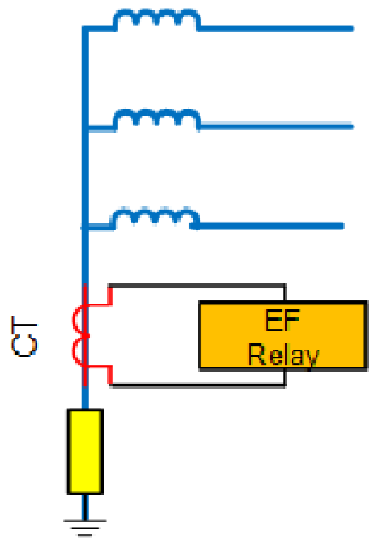

Figure 2.9 The position of the EF Relay device in the ground connection is indicated by the CT on this connection

2.3.3 The third method is Core Balance EF Protection

This method is valid if it is not possible to reach the grounding link in the second method, or if a current transformer cannot be placed In each face separately, as in the first method (as in the case of cables, for example). This method appears in Figure 2.10. In it, a single current transformer is used, mounted on a core in the form of a ring, in which the carrier wires are inserted. for the three currents, while the EF Relay is installed on the secondary terminals of the transformer. During normal operating conditions The total flux inside the loop is zero, while it has a large value It is higher than zero in case of failure only

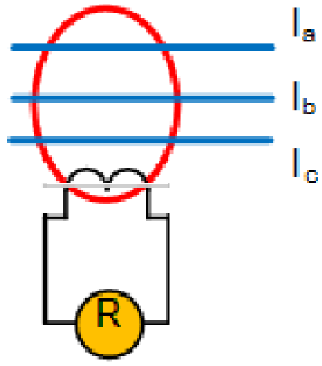

Figure 2.10 A single current transformer mounted on a core is shown as its ring

Note that in the event of a cable failure, the Earth Connection may be incorrectly connected It causes the relay not to work, as in the second part of Figure 2.11 , where the current inside the core remains zero. Even in case of holidays. But if there is a Sheath inside the Core, you must enter the Earth Connection to the Core and then exit from the Core as in the last part of the figure until its effect is canceled out

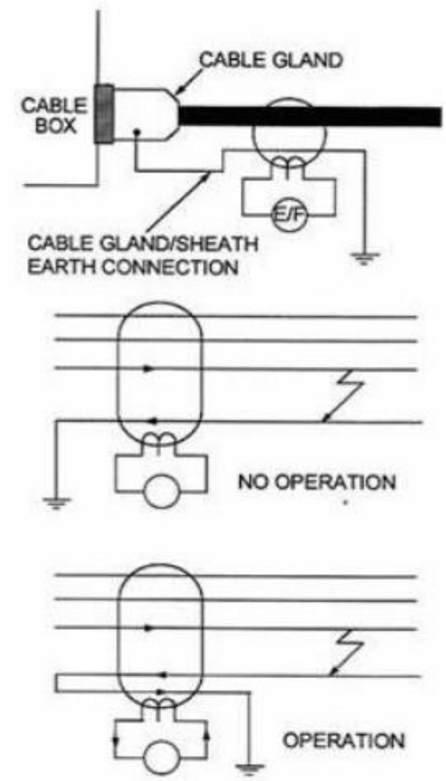

Figure 2.11 show the current inside the core remains zero. Even in case of faults

2.3.4 The forth Method Frame Leakage

There is another way to detect ground faults, by connecting the protective device in a connection between the body (The metal) of the transformer, for example, and the ground, as in Figure 2.12 . Note that when contact occurs between the coils, for example and the external body will pass a high current through this link and thus will be detected quickly

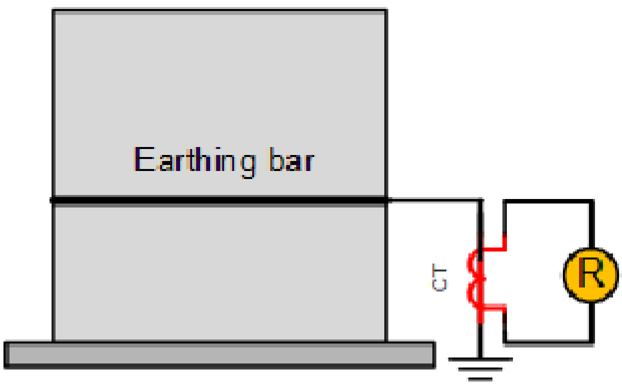

Figure 2.12 Frame Leakage

2.3.5 The fifth method

Unlike the previous methods, we can combine the use of EF Protection with Phase Protection As in Figure 2.13 . It is certainly an economical method, but it is more reliable.

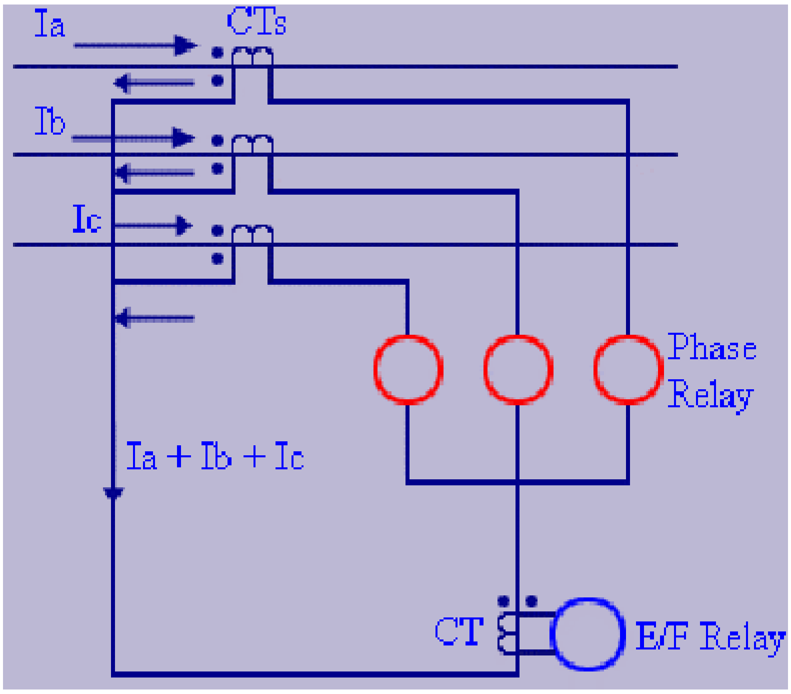

Figure 2.13 the fifth method Combined EF and Phase Fault Protection

2.3.6 The Sixth Method Residual Voltage Relay

One of the well-known ways to discover ground faults is to collect the voltages of the three faces instead of collecting the currents And the sum of VC + VB + VA is called Residential Volt, and it is equal to zero. o3v In the case of ground faults

2.3.7 Advantage EF Protection

from a review The previous methods show that the main advantage of using EF relays for ground fault prevention is, Which is superior to Phase OC Relays used in the prevention of Phase Faults is the high accuracy, Since the EF Relay does not have a current at all in normal conditions (or in the worst case a small current passes through it very compared to the natural current) Then, in the event of a malfunction, a very high current passes through it, hence the discrepancy and discrimination is clear Very between the current holidays and the natural current In the case of using OC in the prevention of Phase Faults, the device passes through the natural current (Phase current) before any fault occurs, then the value rises to the value of the fault current after that, and perhaps in some cases Sometimes the difference between the two currents is not great, and therefore the discrimination between the natural state and the state of The failure is not as big as in the case of EF Protection

2.4 The different systems for placing the phase & EF relays

There are many ways to install OC Relays in networks, which is known as OC Protection Schemes. One of these systems is the use of a separate OC Relay for each phase separately, as shown in Figure 2.14. This method is characterized by the ability to detect faults in the three phases,

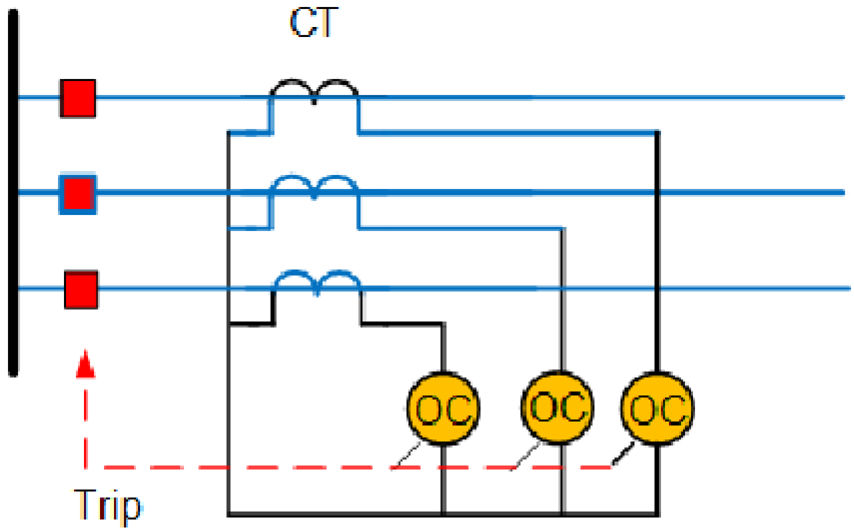

Figure 2.14 Use a separate OC relay in each phase

but sometimes in some networks it is difficult for the phase overcurrent relays to detect some ground faults due to the low value of the fault current, and in this case we use Earth Fault Relay With the previous group, as in Figure 2.15 , this EF Relay is actually nothing but a type of OC, but it is installed in the directional current return path, which is equal to zero in normal conditions, which makes it able to detect ground faults with great accuracy In many cases

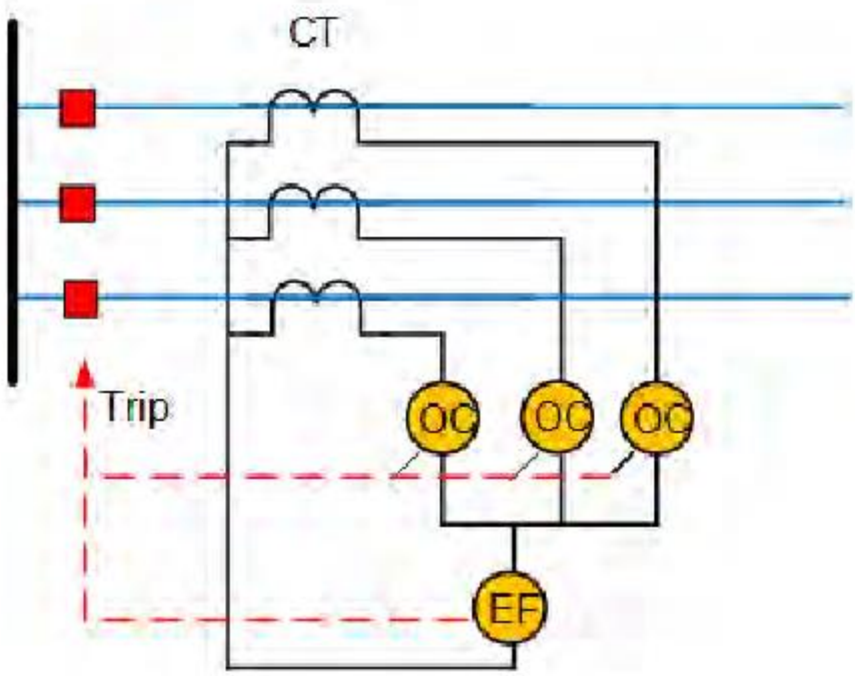

Figure 2.15 Using OC for each phase of using EF

only two OC Relays are installed on Two Phases, provided that an EF Relay is installed with them in the Third Phases, as in Figure 2.16. This method is economical as it uses three devices instead of four

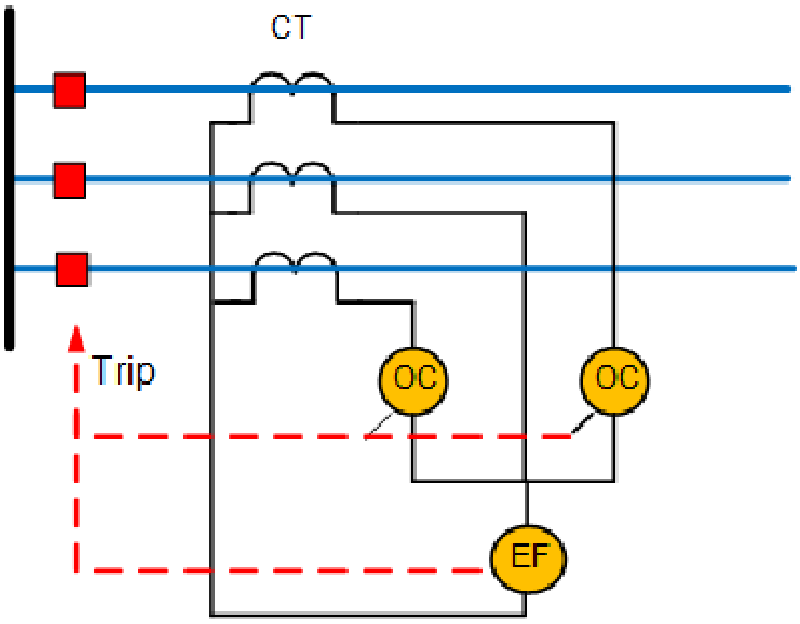

Figure 2.16 Uses three devices instead of four

2-5 Testing overcurrent relays

The requirements for testing the protective device usually differ according to its type, and whether it is, for example, digital or electromechanical.

In this part of the chapter, we present a method for testing protection (Digital Overcurrent), because Its requirements are more comprehensive than any other type. Usually, there are at least ten tests that an Overcurrent Relay must pass, namely:

1- Protective Functions tests, which are the most important types of tests.

2- Measurement accuracy tests.

3- Testing its tolerance to the maximum electrical limits (the maximum current that it passes through for a certain period, the maximum voltage - the maximum

Frequency...etc.

4- Testing the output contacts and their tolerance to the passage of current, for example, 5 amps for 200 hours Again, to ensure that it will bear the current that will feed the CB disconnect circuit later. And the previous two tests 4 & 3 are used when examining a specific device and using it for the first time on the network, and it is not a routine test.

5- Testing the Power Supply, meaning that it continues to perform its function with a change in the value of the supply voltage, such as from 110 volts to 220 volts, or according to its specifications.

6- Examination of control limits as will come in detail.

7- A test affected by the inrush current, if it was designed for that, and we will explain later about it.

8- Testing its effect on the surrounding magnetic fields, and this requires special treatment.

9- The Man Machine Interface MMI test, which means ease of dealing with it, with the password change test for changing the setting values and making sure that the device only works when there is a password one.

10- Testing his ability to record events with a specific number (Event Recording). These accidents include opening, closing, and malfunctions...

The last two tests, 10 & 9, are for digital protection devices only, while the other tests are general for all types.

2-5-1 Test requirements

To conduct the test, we must have a suitable test device available. The role of this device is to feed the protection device with a high current that represents the fault current. Usually, the Tester can be programmed so that it gives various and gradual values for the current that represents the fault current. The Tester is also equipped with a timer to measure the time it took for the protection device to be disconnected. Before conducting all tests, it is necessary to determine the following:

1- Determine the value of the normal current that is allowed to pass, whether it is 1A or 5A

2- Determine the starting current value Pickup Current

3- Determine the operating time, which is the period from the current reaching the Pickup value until the disconnection signal is issued.

After recording the required test values inside the Tester, and as soon as the test start indicator is pressed, the Tester starts feeding the relay with a gradual current until it reaches the value set by the Tester, and if this value is higher than the Pickup current that the Relay to be tested is set to, then we expect the relay to issue a Trip signal After the operating time set by the protection device, which is measured by the timer in the tester.

Accordingly, the relay passes the test if it issues a Trip Signal after the current entering it exceeds the value of the Pickup current during a period equal to the operating time for which it was set.

The efficiency of the protective devices varies in the ability to adhere to the specified values of operation, so if it is disconnected, for example, after a time more or less than the operating time on which it was set, then this means that the efficiency of the relay is low, and it may come to recalibration or even its removal from service if the excess is large.

2.5.2 Test steps

1- The relay is set to a specific value for the Pickup current, as well as a specific operating time, as in the second and third columns, respectively, of the previous table.

2- The relay is injected with a current from the Tester less than the Pickup for a long time to test the stability of the device and its tolerance of natural currents without disconnecting.

3- The value of the current is measured as seen by the relay. Digital protection devices. This value appears on the device screen (in order to ensure the accuracy of the measurement with the protection device).

4- The relay is injected with a current that increases gradually through the tester until the pickup signal is issued from the relay, and the current at which the pickup occurred is measured, and this current is the I_{pickup} that appears in the fourth column and is later compared to the values in the second column.

As long as the value injected by the Relay is higher than the Pickup current, we expect that the contact switches of the Contacts protection device touch after the operating time set for the protection device mentioned in the third column, and the tester measures the disconnection time that the Relay took, and this value appears in the column Fifth of the table. It is compared to the values mentioned in the third column. As for the rest of the columns in the table, they are calculated based on the values that were measured in the previous columns, and we explain that as follows:

2.5.3 Reset factor

In order to understand the meaning of this coefficient, we imagine that a malfunction occurs and the current rises to a value higher than the Pickup current, which results in the protection device starting to count down the operating time in preparation for issuing the Trip signal, but supposing that the fault current has decreased again quickly before the relay works, we expect in this case that the protective device will quickly return from its first decision to disconnect the circuit due to the decrease in current and we say that it has a drop off, and to measure the ability of the relay to quickly respond to the change in the current it goes through, we try this test.

This is done by injecting the relay with a higher current than the pickup until it separates and its contact points are closed. Then we begin to gradually reduce the values of the current that was injected until the Contact Points of the Relay open. And we record the value of the current at which the relay "retracted" in the sixth column, while we record the Reset Factor in the seventh column.

The return coefficient is defined as:

$$\text{Reset Factor} = (I_{Reset}) / I_{pickup}$$

The closer this coefficient is to the correct one, the more sensitive the device will be. In theory, it should disconnect if the current exceeds the set value, even by a part of a thousand, and then return to its normal state if the current is less than the set value, even by a part of a thousand. Therefore, the measurement of this coefficient is one of the elements of testing the protective device, and one of the elements of comparison between the different protective devices. In practice, you will not find a device with this ability, but the closer the coefficient is to the correct one The better.

2.5.4 Error percentage

The error rate is also measured between the I_{pickup} from which the device was disconnected and the $I_{setting}$ on which it was set. This percentage appears in the eighth column. The ratio can also be measured between the actual operating time and the operating time on which the device was set, and this percentage appears in the ninth column. This percentage is supposed to not exceed about 3%, (or according to the percentage mentioned in the device $catalog$)

CHAPTER THREE
Inrush current

CHAPTER THREE

3 Inrush current

3.1 Dealing with the phenomenon of cold inrush

When the electrical supply to a city is cut off, people often leave most of the electrical appliances, such as lighting, refrigerators, and air conditioners, without being inadvertently turned off. If we assume that 50% of the air conditioners were not disconnected after the power outage, then this means that when the current returns, these devices will start working simultaneously at one moment, and this means that the high starting current that is drawn in such devices will be drawn from each devices at the same moment, which means that a very high current will pass through the feeders.

Although this high current will quickly decrease naturally within seconds because it represents most of the starting currents, some Overcurrent Relays may be affected by this high current and consider it Fault Current, and thus the feeders are disconnected again. Hence the name because the inrush current occurs at $startup$ after a long pause.

To solve this problem, the OC Relay can be operated on a curve that has a relatively long separation time, such as the tenth curve in Figure 2-5 , for a period of several seconds until the current returns to its normal value after the disappearance of the Starting Currents, or the Inrush Currents in the transformers, and then the relay can It reverts back to its original curve. This is better than some other solutions that completely disconnect the protective devices at the beginning of the electricity return for a period of seconds in order to allow the inrush to pass without problems, because this method involves great risks, as it may happen that there is a real malfunction at the start of operation, and the value of the current rises without the presence of protection.

The problem of the inrush current in power transformers: It is important that while we are talking about prevention problems in transformers, we present an important problem that exists in all transformers, which is the problem of the inrush current, which is one of the most important problems that can cause a faulty disconnect.

The causes of the problem can be summarized as follows:

1- When any Power Transformer is separated, part of the flux remains inside the iron core, called Residual Flux ϕR

2- When the transformer returns to service, and since it is impossible to control the moment of its return to be the same as the moment at which it came out, and therefore the overflow that is supposed to begin to appear with the return of the current needs sometimes to be high to compensate for the value arising from the remaining overflow, and this requires drawing a high current It is the Inrush Current to generate this compensating flux in this case, the transformer came back at an instant equivalent to an overflow of ϕ_{max}−, while the remaining overflow is equivalent to a positive value ϕ_R, and to compensate for this difference, the inrush current is withdrawn at a high value This is the first case.

In the second case, the moment of return coincides with the moment of disconnection, and here the transformer does not need any additional overflow, as it will pull up the normal Magnetization current without any increase.

the impulse current has no specific value, as it may be very high, as in the first case. However, it is sometimes very close to the normal stream, if two conditions are met:

1- There should be no residual overflow inside the transformer.

2- If the moment of entry coincides with the moment of the greatest voltage, V_{max} , in which the flux is as low as possible, as it is known that the flux is always 90° behind the voltage according to Faraday's law V$\propto(d\phi/dt)$.

Between these two cases, there are many cases that make, as we said, the value of the inrush current indefinite, neither in form nor in value, because it depends mainly on two random variable values: the first is the value of the residual overflow, and the second is the moment the transformer enters into service, and therefore the value of this varies The current is even between the three faces This current, then, appears only at the start of operation, and its value may reach five or six times the normal current, or even twenty times the normal current, depending on the capacity of the transformer, but this is not the basis of the problem, especially since the impulse current takes only a second or a little more, just as Its value decreases rapidly during this short period, but the major problem is that this current does not pass except in the primary side of the transformer only, which is the side that is connected to the source, and it does not pass in the secondary side, because it passes through what is called the magnetic circuit of the transformer. It is known that the overcurrent relays - which we studied in the second chapter - can be suitable as a protection for the transformer because of its inability to distinguish the location of the fault, as a device will remain unable to distinguish the location of the fault, and whether it is inside the one to be protected, because the increase in the current is the value of sleep these faults. This phenomenon is the main motive for the basic thinking of thinking about the differential protection method. The unit is the generator itself, and it may be the transformer, and it may be one of the short transmission lines.

3.2 Differential protection

The goal of any protection system is to maintain the stability of the electrical system and to mitigate damage The effects of the malfunction, by isolating the equipment that is prone to malfunction quickly, while leaving a larger one as much of the network as possible is in service, which leads to limiting faults in specific area and within a small time through coordination between the elements of the system. Transformers are considered one of the most important elements of the electrical system .Modern power systems make progress in transformer design. Electrical transformers are among the most advanced .The elements are widespread and diverse in their shapes, sizes, and functions within the electrical system .It is possible to find dozens of electric generators in the electrical network, but it contains tens of thousands of transformers, and only cables and lines can match them in this wide spread antennas, as this diversity and wide spread makes the study and protection of power transformers an issue .Very important and necessary as differential protection is used to protect the important components within the electrical system such as generators, motors, power transformers, *busbars* and cables and transmission lines, and is considered the main protection for the protection of electrical power transformers for what it has of sensitivity, selectivity, speed and reliability.

Differential protection is characterized by its high sensitivity as it operates at a low current threshold, as it can detect a fault current several times smaller than the nominal current of the protected equipment. This protection works in an instantaneous manner as soon as the current passing through the differential measurement circuit exceeds the value of an operating current to protect, and therefore it is always used as a major protection for the electrical system elements from short circuits with very harmful effects on these elements

3.3 Working principle of differential protection:

The principle of differential protection depends on Kirchhoff's first law, which states that the sum of the currents entering a node is equal to the sum of the currents leaving it. Differential protection works only when a fault occurs in the area between the two current transformers, and on the other hand, it must not work when a fault occurs outside this region even if it is very close to its borders.

The following figure shows a schematic diagram of differential protection

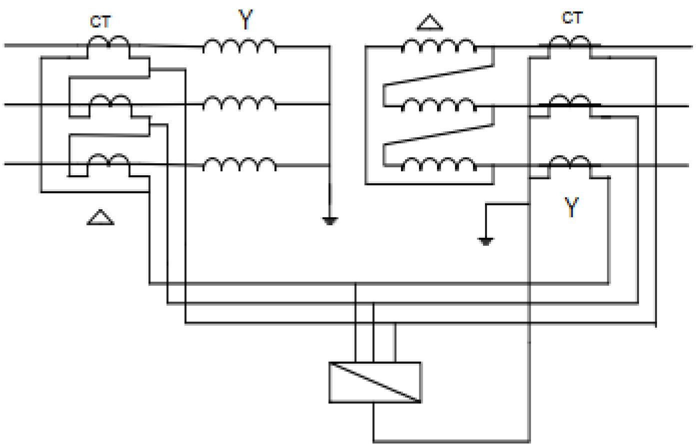

Figure 3.1 A schematic diagram of differential protection

In the case of normal work, the current entering the protection work area is equal to the current outside of it, and therefore the differential current is equal to zero, when a fault occurs within In the protection work area, the current entering this area is not equal to the current leaving it the difference between these two currents is the differential current which causes the protection to work being greater than the calibration current $I_d = l_{in} - l_{out}$

I_d: measured fault current or differential current

I_{in}: The current measured at the beginning of the protection zone (the current entering the protection zone).

I_{out}: the current measured at the end of the protection zone (the current out of the protection zone).

The principle of differential protection makes it selective in isolating faults, that is, it does not need to coordinate its work with other protections used, which are supportive of them, such as surge protectors $I_d = l_{in} - l_{out} \neq 0$ and $I_d \geq I_{set}$

3.4 The negative effects of rush currents:

3.4.1 Mechanical and electrical stresses

The amplitude of the inrush current can be equal to the short circuit current and last for a longer period without sufficient damping in the system circuit and thus can have serious effects on the transformer windings due to large mechanical stresses. The axial forces due to the inrush current are greater than those caused by the short circuit current, and the radial forces resulting from the inrush current are greater than the radial forces caused by the inrush current the palace is about 3 times larger.

3.4.2 Harmonics:

The impulse current contains harmonics of different orders, but only harmonics are considered second and third. there is also the continuous DC compound, which is important during the first cycles, depending on the magnetic flux:

1- DC vehicle: This component can always be present in the inrush current at different values. For each phase of a three-phase system, this component mainly follows the residual flux in the core.

2- The second harmonic: The inrush current contains the second harmonic component. The value of this harmonic follows the degree of saturation in the transformer.

3- The third harmonic: This component is also related to saturation in the magnetic core.

4- Harmonics of higher order: These harmonics exist in different orders, but the values of these harmonics are sufficiently small for her neglect.

3.4.3 Malfunctioning of protection devices:

The surge current causes the protection devices to malfunction, as when the transformer is activated, the surge current passes through the primary coil of the transformer and does not pass through the secondary coil of the transformer, and this may cause incorrect work of the differential protection and may cause wrong disconnection of the automatic circuit breaker when the transformer is energized without load, the inrush current may cause excessive saturation of the transformer core, which negatively affects the safety of the transformer.

3.4.4 Voltage drop:

Because of the impedance between the power source and the transformer, the inrush current may lead to a temporary drop in the voltage of the electrical system. These dips vary in length between the three phases and take a long time to return to a stable state. Figure (3-2) shows by analogy the value of the voltage drop for the three phases of a 11kv electric network due to the activation of the transformer without load, where these dips are not synchronized in the three phases (the voltage drop of each phase is different from the other phases due to the different degrees of saturation), where we note that the value of the voltage drop is about 0.17 pu and that it needs a long period of time about 100ms to return to 50% of its value. This slow recovery of voltage is attributed to the ratio L / R in the circuit and this ratio is known as a constant the time delay of the impulse current.

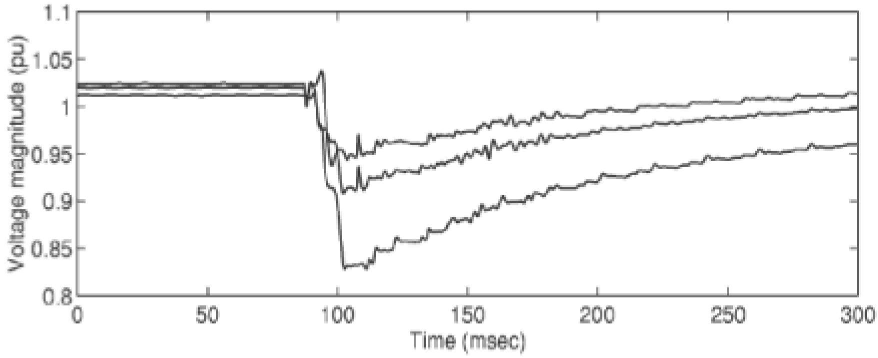

Figure 3.2 the voltage drop for the three phases of a 11kv

3.4.5 Sympathetic impulse:

A transformer connected to a power system may experience unexpected saturation events due to current passing A friendly rush in another converter.

This sudden saturation is attributed to the voltage drop in the electrical system due to the activation of another transformer. This phenomenon is known as the sympathetic impulse phenomenon.

3.5 Factors affecting impulsivity

1- The effect of the difference in the initial phase angle of the voltage: The switch is connected to the network at random and is often connected at the moment that passes It has a voltage wave of zero, and this will lead to a magnetic flux equal to twice the maximum value of the flux in the steady state, and thus the passage of a large current that may reach ten times the nominal value of the current, and therefore choosing the optimal moment to connect the transformer to the network is very important.

2- Effect of residual flux in the nucleus: The higher the value of residual flux in the core, the greater the value of the inrush current

3- The effect of impedance of the supply source: The higher the value of the impedance of the feeding source, the value of the impulse current decreases, but there are limits to increasing the value of the source impedance, because the higher the source impedance, the greater the copper losses.

4- The effect of the resistance of the primary winding of the transformer: The higher the value of the resistance of the primary coil of the transformer, the value of the inrush current decreases, but there are limits to increasing this value because the higher the resistance of the coils, the greater the copper losses in the transformer.

5- transformer power effect: The capacity of the transformer reflects the internal value of the impedance of the transformer, as the greater the capacity of the transformer, the greater the value of the internal impedance of the transformer, and the lower the value of the amplitude of the inrush current

CHAPTER FOUR

CHAPTER FOUR

4.1 Conclusion:

a-These electrical protection devices play a crucial role in preventing electrical hazards, reducing the risk of electrical fires, equipment damage, and electrical injuries to individuals. It is essential to use the appropriate protection devices based on the specific requirements and potential risks associated with an electrical system or equipment.

b-Studying inrush current provides valuable insights into the behavior of electrical systems during startup or energization. This knowledge aids in equipment selection, design, protection, power quality analysis, energy efficiency, and safety considerations, ultimately leading to improved performance and reliability of electrical systems

c-The phenomenon of inrush current leads to incorrect operation of differential protection unless the protection system is able to distinguish it from fault current.

d- Factors influencing inrush currents:

1-The value of inrush current increases with the increase in residual flux in the core.

2-The value of inrush current decreases with the increase in the source impedance.

3-The value of inrush current decreases with the increase in the primary winding resistance of the transformer.

4-The value of inrush current decreases with the increase in the transformer's capacity.

4.2 future work:

1- Study the overvoltage

2-Comparison of methods that enable differential protection and overcurrent protection to distinguish between inrush current and fault current and studying the possibility of obtaining new methods.

3- Studying problems other than the inrush current to troubleshooting the problems of the electrical system

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