Sudan University of Science and Technology

College of Engineering

School of Electrical and Nuclear Engineering

Substation Protection System

(Case study Khartoum Refinery Substation)

نظام حماية المحطات الكهربية

(دراسة حالة محطة مصفاة الخرطوم)

A Project Submitted in Partial Fulfillment for the Requirements of the Degree of B.Sc. (Honor) in Electrical Engineering

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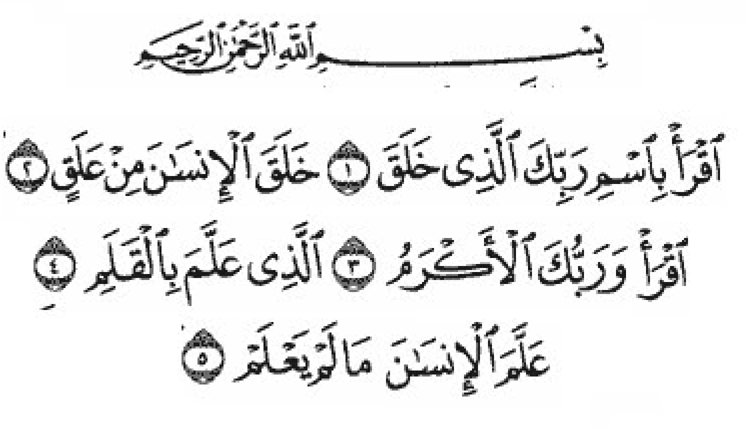
الآيـــه



بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

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صدق الله العظيم

سورة العلق

DEDICATION

We dedicate this project to our families, who have been patient
and measured until we reach what we have come to now
We also dedicate this work to our professors and teachers at
all educational levels
And also We dedicate this project to our comrades in batch 31
who if God then they would not have reached this stage
We dedicate this project to everyone who motivated us to
continue and not give up

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Finally,
we thank everyone who has contributed with us in this work,
asking God to accept for them and us

ABSTRACT

The objectives of this project is to identify the components of the protections used in the electrical substations and their effectiveness. The methodology of this project is visit the Khartoum Refinery substation as a case study to obtain data on the digital protection system. and as the result of project founded that the digital rely make system is more s efficient and up to date.

المستخلص

يهدف هذا المشروع إلى دراسة مكونات الحماية المستخدمة في محطات الكهرباء الفرعية ومدى فعاليتها. منهجية هذا المشروع هي زيارة محطة مصفاة الخرطوم كدراسة حالة للحصول على بيانات حول نظام الحماية الرقمية. والنتائج المتحصل عليها من المشروع ان مرحل الحماية الرقمي يجعل النظام فعال وحديث

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INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 General Concept

The electrical technology is one of steady and in recent years, rapid progress which has made it possible to design and construct economic and reliable power station capable of satisfying the continuing growth in the demand for electrical energy. Substation protection and control play a significant part and progress in design and development in these fields has necessary had to keep pace with advances in the design of primary plant such as generator indeed progress in the field of protection and control is avital prerequisite for efficient operation and continuing development of substation

1.2 Research problem

System protection has evolved over the year from relatively primitive device with limited capability which the operation of protection equipment must be accurate fast and reliability standard required that systems survive sever fault condition without collapse which was problem in conventional system

1.3 Research Objectives

The objectives of this research is Study the main components of the substation petroleum protection System, Study the main part of the substation system, and protection system in Khartoum substation petroleum and study the activation of protection system in petroleum substation.

1.4 Methodology

Khartoum refinery company represents petroleum factory that produce crude oil for fabrication. The substation including in the refinery company need to protected against electrical failures to operate in a good manner

1.5 Project Layout

This research is compromised from an abstract and five chapters, where chapter one represents an introduction deals overview, research problem, research objective, methodology and layout. Chapter two represents protection relays, chapter three represents substation component and faults, chapter four represents application of protection and chapter five about conclusions and recommendation.

CHAPTER TWO

PROTECTION RELAYS

CHAPTER TWO

PROTECTION RELAYS

2.1 Introduction

In electrical engineering, a protective relay is a relay device designed to trip a circuit breaker when a fault is detected. The first protective relays were electromagnetic devices, relying on coils operating on moving parts to provide detection of abnormal operating conditions such as over-current, over-voltage, reverse power flow, over-frequency, and under-frequency.

Microprocessor-based digital protection relays now emulate the original devices, as well as providing types of protection and supervision impractical with electromechanical relays. Electromechanical relays provide only rudimentary indication of the location and origin of a fault. In many cases a single microprocessor relay provides functions that would take two or more electromechanical devices. By combining several functions in one case, numerical relays also save capital cost and maintenance cost over electromechanical relays. However, due to their very long life span, tens of thousands of these "silent sentinels are still protecting transmission lines and electrical apparatus all over the world. Important transmission lines and generators have cubicles dedicated to protection, with many individual electromechanical devices, or one or two microprocessor relays.

The theory and application of these protective devices is an important part of the education of a power engineer who specializes in power system protection. The need to act quickly to protect circuits and equipment often requires protective relays to respond and trip a breaker within a few thousandths of a second. In some instances, these clearance times are prescribed in legislation or operating rules.

A maintenance or testing program is used to determine the performance and availability of protection systems.

2.2 Functional Diagram of Relaying

Relay function diagram can be represented in block diagram of figure 2.1.

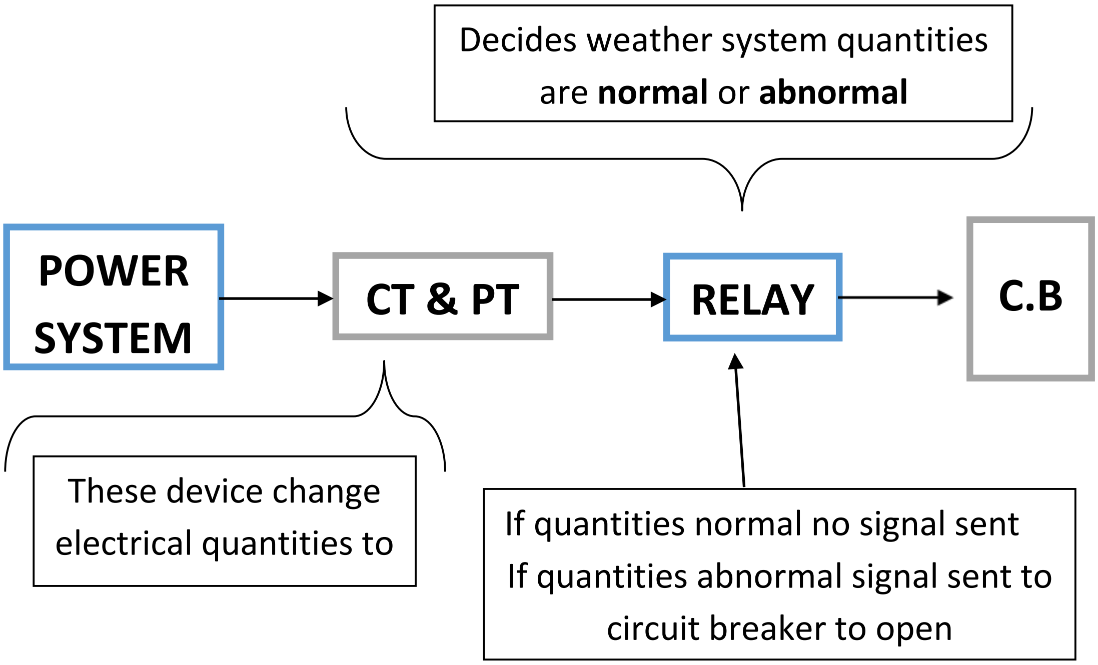


Figure :2.1: Relay function diagram

2.3 Operation Principles

Electromechanical protective relays operate by either magnetic attraction, or magnetic induction. Unlike switching type electromechanical relays with fixed and usually ill-defined operating voltage thresholds and operating times, protective relays have well-established, selectable, and adjustable time and current (or other operating parameter) operating characteristics. Protection relays may use arrays of induction disks, shaded-pole, magnets, operating and restraint coils, solenoid-type operators, telephone-relay contacts,[clarification needed] and phase-shifting networks.

Protective relays can also be classified by the type of measurement they make. A protective relay may respond to the magnitude of a quantity such as voltage or current. Induction relays can respond to the product of two quantities in two field coils, which could for example represent the power in a circuit.

"It is not practical to make a relay that develops a torque equal to the quotient of two ac. quantities. This, however is not important; the only significant condition for a relay is its setting and the setting can be made to correspond to a ratio regardless of the component values over a wide range."

Several operating coils can be used to provide "bias" to the relay, allowing the sensitivity of response in one circuit to be controlled by another. Various combinations of "operate torque" and "restraint torque" can be produced in the relay. By use of a permanent magnet in the magnetic circuit, a relay can be made to respond to current in one direction differently from in another. Such polarized relays are used on direct-current circuits to detect, for example, reverse current into a generator. These relays can be made bistable, maintaining a contact closed with no coil current and requiring reverse current to reset. For AC circuits, the principle is extended with a polarizing winding connected to a reference voltage source. Lightweight contacts make for sensitive relays that operate quickly, but small contacts can't carry or break heavy currents. Often the measuring relay will trigger auxiliary telephone-type armature relays.

In a large installation of electromechanical relays, it would be difficult to determine which device originated the signal that tripped the circuit. This information is useful to operating personnel to determine the likely cause of the fault and to prevent its re-occurrence. Relays may be fitted with a "target" or "flag" unit, which is released when the relay operates, to display a distinctive colored signal when the relay has tripped. [6]

2.4 Relay Characteristics

The characteristics of protection relays are: [6]

- Speed

Minimizes damage from current

Maximizes power transfer during normal conditions, stability

- Security

Relay should not cause circuit breaker to open during normal conditions.

- Sensitivity

Ability of a relay to detect all faults for the expected limiting system and fault conditions.

- Dependability

Relay should cause circuit breaker to open during abnormal conditions.

- Selectivity

Ability of a relay system to discriminate between faults internal and external to its intended protective zones.

2.5 Classification of Relays

Protection relays can be classified in accordance with the function which they carry out, their construction, the incoming signal and the type of protection. [6]

- General function:

Auxiliary.
Protection.
Monitoring.
Control.

- Incoming signal:

Current.
Voltage.
Frequency.
Temperature.

Pressure.
Velocity.
Others.

- Construction:

Electromagnetic.
Solid state.
Microprocessor.
Computerized.
Nonelectric (thermal, pressure…. etc.).

- Type of protection:

Over current.
Directional over current.
Distance.
Over voltage.
Differential.
Reverse power.
Other.

2.6 Types of Relays

The main types of protective relays are summaries in diagram shown in figure 2.2.

- Electromechanical relays

Electromechanical relays can be classified into several different types as follows:

- attracted armature
- induction
- mechanical

- moving coil
- motor operated
- Thermal

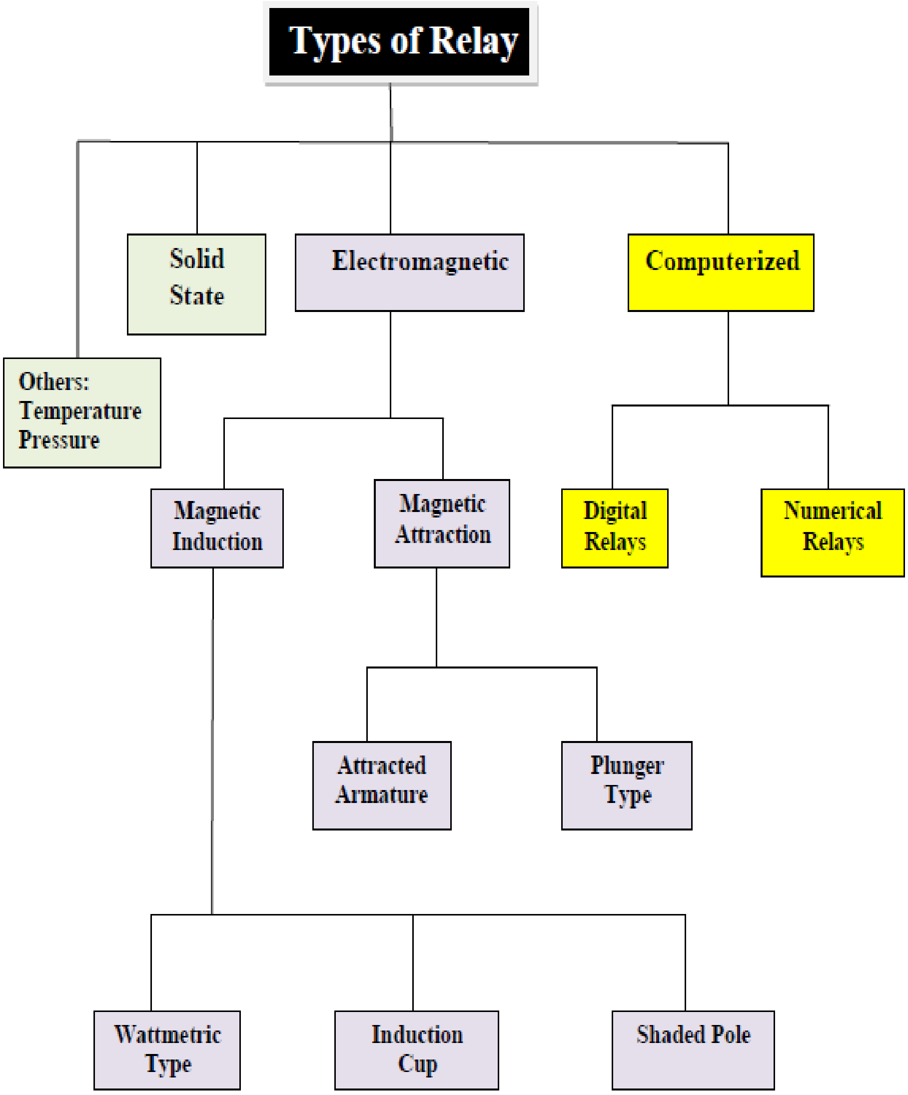


Figure. 2.2: type of protective relays

"Armature"-type relays have a pivoted lever supported on a hinge or knife-edge pivot, which carries a moving contact. These relays may work on either alternating or direct current, but for alternating current, a shading coil on the poleis used to maintain contact force throughout the alternating current cycle. Because the air gap between the fixed coil and the moving armature becomes much smaller when the relay has operated, the current required to maintain the relay closed is much smaller than the current to first operate it.

The "returning ratio" or "differential" is the measure of how much the current must be reduced to reset the relay. A variant application of the attraction principle is the plunger-type or solenoid operator. A reed relay is another example of the attraction principle. "Moving coil" meters use a loop of wire turns in a stationary magnet, similar to a galvanometer but with a contact lever instead of a pointer. These can be made with very high sensitivity. Another type of moving coil suspends the coil from two conductive ligaments, allowing very long travel of the coil. [6]

- Static Relays

Application of electronic amplifiers to protective relays was described as early as 1928, using vacuum tube amplifiers and continued up to 1956. Devices using electron tubes were studied but never applied as commercial products, because of the limitations of vacuum tube amplifiers. A relatively large standby current is required to maintain the tube filament temperature; inconvenient high voltages are required for the circuits, and vacuum tube amplifiers had difficulty with incorrect operation due to noise disturbances.

Static relays have no or few moving parts, and became practical with the introduction of the transistor. Measuring elements of static relays have been successfully and economically built up from diodes, zener diodes, avalanche diodes, unijunction transistors, p-n-p and n-p-n bipolar transistors, field effect transistors or their combinations. Static relays offer the advantage of higher sensitivity than purely electromechanical relays, because power to operate output contacts is derived from a separate supply, not from the signal circuits. Static relays eliminated or reduced contact bounce, and could provide fast operation, long life and low maintenance. [6]

- Digital Relays

Digital protective relays were in their infancy during the late 1960s. An experimental digital protection system was tested in the lab and in the field in the early 1970s. Unlike the relays mentioned above, digital protective relays have two main parts: hardware and software. The world's first commercially available digital protective relay was introduced to the power industry in 1984 by Schweitzer Engineering Laboratories (SEL) based in Pullman, Washington. In spite of the developments of complex algorithms for implementing protection functions the microprocessor based-relays marketed in the 1980s did not incorporate them.

A microprocessor-based digital protection relay can replace the functions of many discrete electromechanical instruments. These relays convert voltage and currents to digital form and process the resulting measurements using a microprocessor. The digital relay can emulate functions of many discrete electromechanical relays in one device, simplifying protection design and maintenance. Each digital relay can run self-test routines to confirm its readiness and alarm if a fault is detected.

Digital relays can also provide functions such as communications (SCADA) interface, monitoring of contact inputs, metering, waveform analysis, and other useful features. Digital relays can, for example, store multiple sets of protection parameters, which allows the behavior of the relay to be changed during maintenance of attached equipment. Digital relays also can provide protection strategies impossible to implement with electromechanical relays. This is particularly so in long-distance high voltage or multi-terminal circuits or in lines that are series or shunt compensated, they also offer benefits in self-testing and communication to supervisory control systems. Figure 2.3 show the Digital Relays [6]

Figure 2.3: digital relay

Numerical Relays

The distinction between digital and numerical protection relay rests on points of fine technical detail, and is rarely found in areas other than Protection, Numerical relays are the product of the advances in technology from digital relays. Generally, there are several different types of numerical protection relays. Each type, however, shares a similar architecture, thus enabling designers to build an entire system solution that is based on a relatively small number of flexible components, They use high speed processors executing appropriate algorithms Most numerical relays are also multifunctional and have multiple setting groups each often with tens or hundreds of settings. The numerical protection relay shown in figure 2.4.

figure 2.4: numerical protection relays

The table 2.1 show the comparison between relays (static, digital, numerical). [6]

Table 2.1: Compare between relays

Characteristic	Static Relay	Digital Relay	NUMERICAL Relay
Technology Standard	2nd generation relays.	Present generation relays.	Present generation relays
Operating Principle	In this relays transistors and IC’s been used	They use microprocessor. Within built software with predefined values	They use microprocessor. Within built software with predefined values
Measuring elements/ Hardware	R, L, C, transistors, analogue ICs comparators	Microprocessors, digital ICs, digital diagonal processors	Microprocessors, digital ICs, digital signal processors

Relay Size	Small	Small	Compact
Characteristics	Wide	Wide	Wide
Function	Single function	Multi-function	Single function
Speed of Response	Fast	Fast	Very fast
SCADA Compatibility	No	Possible	Yes

2.7 Basic Components of a Digital Relay

Any digital relay can be comprising of three fundamental subsystems. [1]

– A signal conditioning subsystem.

signal conditioning subsystem consisting of:

- Transducer.
- Surge protection circuits.
- Analog filtering.
- Analog multiplexers.

– A conversion subsystem.

A conversion subsystem consisting of:

- Sampling theorem.
- Signal aliasing error.
- Sample and hold circuit.
- Digital multiplexing.
- Digital – to – analogue conversion.
- Analog – to – digital conversion.

– A digital processing relay subsystem.

The digital relay subsystem comprises both of hardware and software. The hardware largely consists of a central processor unit, memory, data input and output.

CHAPTER THREE

SUBSTATION FAULT

CHAPTER THREE

SUBSTATION FAULT

3.1 Introduction

Substation is a part of an electrical generation, transmission and distribution system. Substation transform voltage from high to low or the reverse or perform any of several other important function

Fault calculation is the analysis of power system electrical behavior under fault condition, with particular reference to the effects of these condition on the power system current and voltage. Together with other aspects of system analysis. Fault calculation forms and indispensable part of the whole function and process of power system design.

The main part takes in details the fault calculation from type of fault to methods of fault calculation.[6]

3.2 Substation compound

The substation consists of:

- Power Transformer

Is an electrical operator designed to convert alternating current from one voltage to another and It can be design to step up or step down voltage and works on the magnetic induction principle. The transformer as shown in figure 3.1. **[6]**

- Potential Transformer

The potential transformer is instrument transformer used for the transformation of voltage from higher value to the lower value. This transformer steps down the voltage to a safe limit value which can be easily measured by ordinary low voltage instrument like voltmeter, wattmeter and watt-hour meter. The potential transformer also called voltage transformer and it shown as in figure 3.2. [6]

Figure 3.1: Power transformer

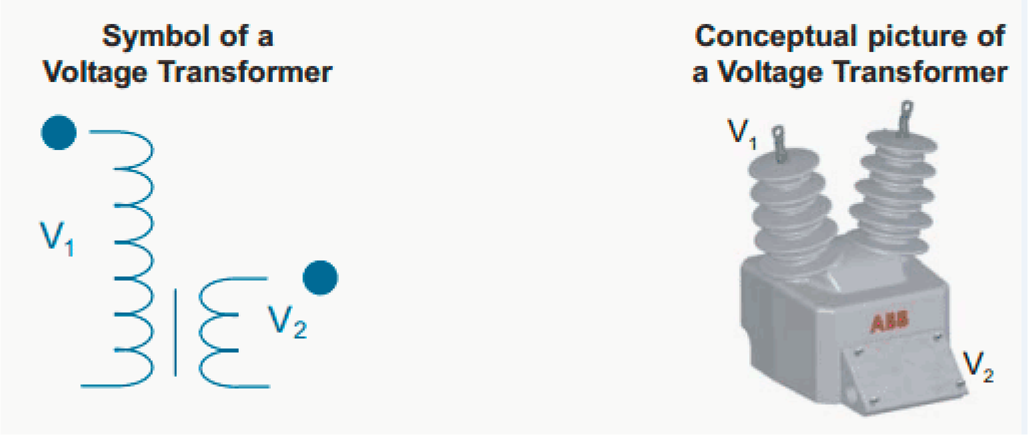


Figure 3.2: Voltage transformer

- Current Transformer

A current transformer is a type of instrument transformer that is designed to produce an alternating current in its secondary winding which is proportional to the current being measured in it's primary. Current transformer reduces high voltage current to a much lower value and provide a convenient way of safely monitoring the actual electrical current. The current transformer is shown in figure 3.3. [6]

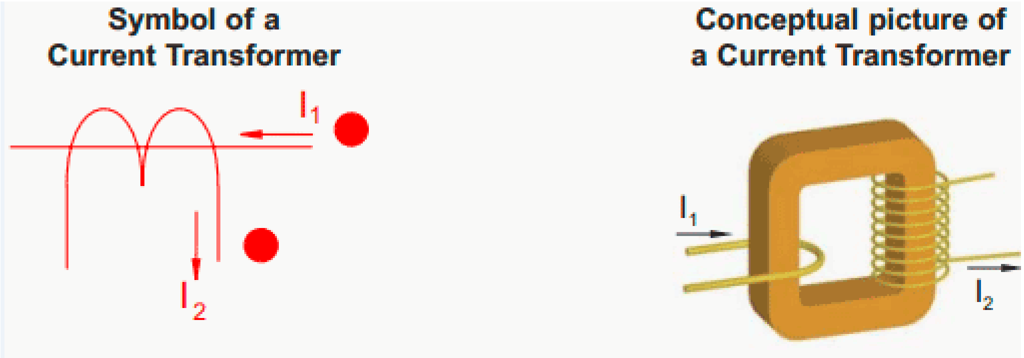


Figure 3.3: Current transformer

- Remote terminal unit

The remote terminal unit is an electronic devise that is control by microprocessor. the devise interfaces with physical object a distributed control system or supervisory control and data acquisition system by transmitting telemetry data to the system. the figure 3.4: illustrate the remote terminal unit (RTU). [6]

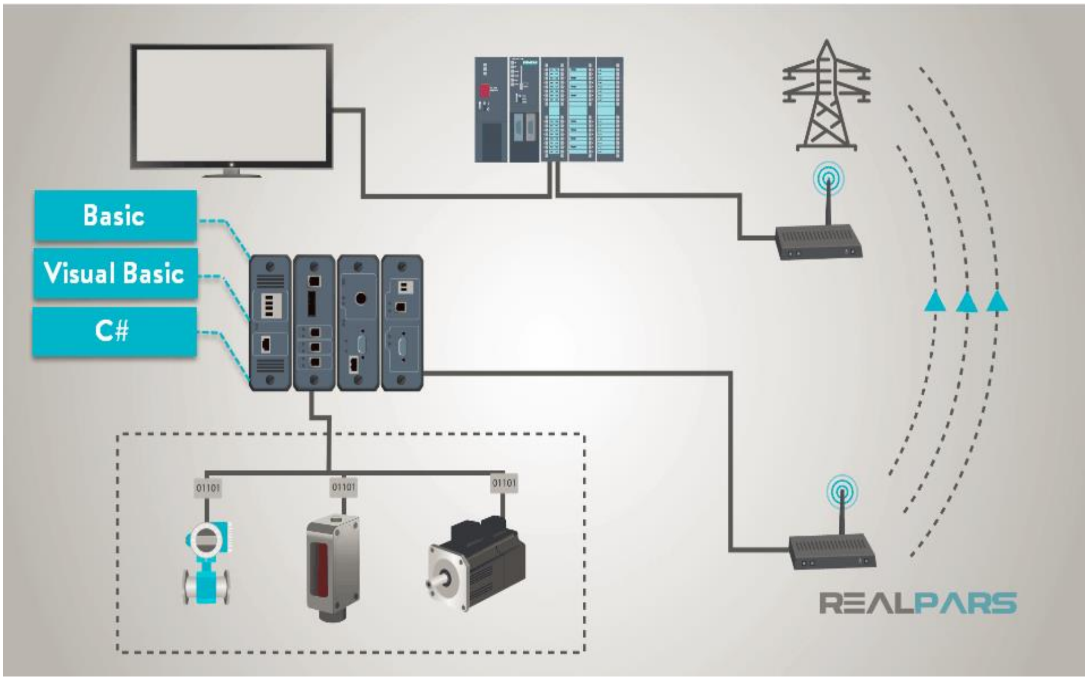


Figure 3.4: Remote terminal unit (RTU) system

- Uninterruptable power supply (UPS)

Is un electrical apparatus that provides emergency power to a load when the input power source or main power fails. UPS is probably warranted if you frequently do critical work on a computer and cannot risk it losing power even for a second. The UPS shown in figure 3.5. [6]

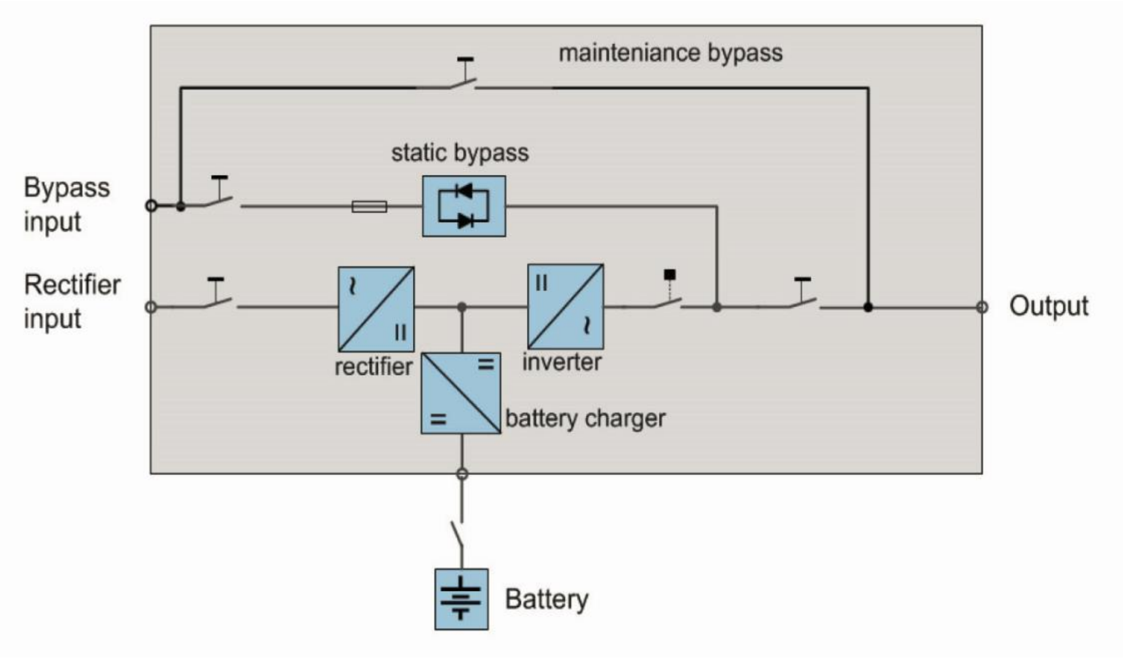


Figure 3.5: UPS system

- Circuit breaker

A circuit breaker is an automatically operated electrical designed to protected an electrical circuit from damage caused by excises current from an over load or short circuit. Its basic function is to interrupt current flow after fault is detected. The circuit breaker is switching device which also offers protection by tripping and cutting off the supply to load in case of fault. The circuit breaker as shown in figure 3.6. [6]

Figure 3.6: Circuit breaker

- Surge arrester

Is a device to protected electrical equipment from over voltage transients cause by external (lighting) or internal (switching). Surge arrester have many applications anywhere from protecting home to utility substation. The figure 3.7 shown the surge arrester

Figure 3.7: Surge arrester

3.3 Type of Fault

In the context of electrical fault calculating, a power system fault may be defined as any condition or abnormality of the system which involves the electrical failure of primary equipment the reference to primary las opposed to ancillary equipment implying equipment such as generators, transformers, bus bars, overhead lines and cables and all other items of plant which operate at power system voltage. The principal types of fault are listed and classified in table 3.1.

Table 3.1: types of fault

Types of fault	
Short-circuited phases	Three_ phase fault clear of earth. Three_ phase_ to_ earth fault. Phase_ to _phase fault. Single_ phase_ to_ earth fault. Two_ phase_ to_ earth fault. Phase_ to_ phase plus single_ phase_ to earth. fault
Open_ circuit phase	Single_ phase open_ circuit. Two_ phase open_ circuit. Three_ phase open_ circuit.
Simultaneous fault	A combination of two or more faults at the same time, the faults being of similar or dissimilar type and occurring at the same or different locations. Typical examples are the cross- country earth_ fault condition.
Winding faults	Winding_ to_ earth short_ circuit. Winding_ to_ winding short_ circuit. Short_ circuited turns. Open_ circuited winding.

3.4 Purpose of Fault Calculation

Fault calculation is the analysis of power system electrical behavior under fault conditions, with particular reference to effects of these conditions on the power system current and voltage values. Together with other aspects of system analysis, fault calculation forms an indispensable part of the whole function and process of power.

3.5 Methods of Faults Calculation

The information normally required from a fault calculation is that which gives the values of the current and voltages at stated points in the power system when the latter is subjected to a given fault condition, the fault location and system operating conditions being specified. Fault calculation is therefore essentially a matter of network analysis and can be achieved by a number of alternative methods, namely:

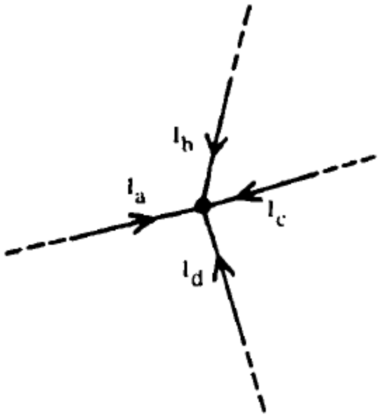
(i) direct solution of the network equations obtained from the mesh-current or nodal_ voltage methods
(ii) solution by network reduction and back-substitution
(iii) solution by simulation using a fault calculator or network analyzer

-Ohm's Law: ohms law states that the vector voltage drops V produced by vector current flowing through a complex impedance Z is given by the vector equation

$$V=I * Z \tag{3.1}$$

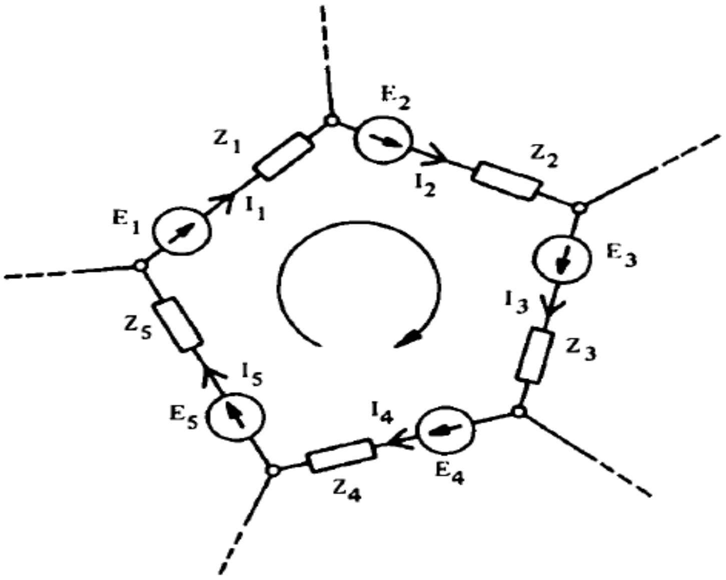
- Kirchhoff's First Law: Kirchhoff s first law states that the vector sum of all the current entering any junction or node in a network is zero, stated in equation form

- Kirchhoff's Second Law: Kirchhoff second law states that the vector sum of all the driving voltages (that is source voltages) acting round any closed path or mesh in a network is equal to the vector sum of the voltage drops in the impedances of the component branches of the path. Thus, in equation form



$$I_a + I_b + I_c + I_d = 0$$

Figure 3.7: Kirchhoff's Frist law



$$E_1 + E_2 + E_3 + E_4 + E_5 = I_1Z_1 + I_2Z_2 + I_3Z_3 + I_4Z_4 + I_5Z_5$$

Figure 3.8: Kirchhoff s second law

- Mesh Current Analysis: This methods of analysis can be understood by considering the simple network shown in figure 3.9. It will be noted that each mesh of the network is assumed to carry circulating current and it is these so called mesh currents.The current in any branch is the vector sum (taking due account of direction) of the mesh currents flowing in that branch, obtain the following equations for meshes 1,2 and 3 respectively

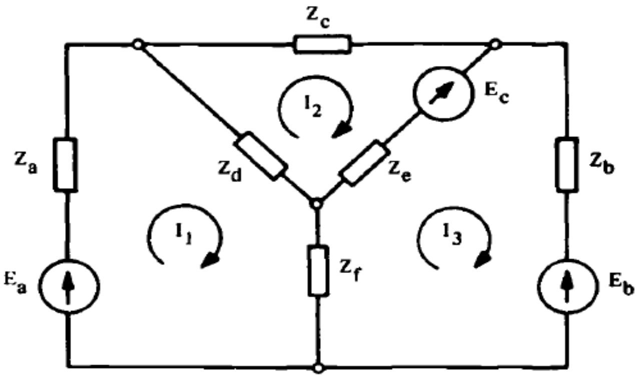


Figure 3.9: mesh current

$Z_aI_1 + Z_d(I_1 - I_2) + Z_f(I_1 - I_3) = E_a$ (3.2)

$Z_d(I_2 - I_1) + Z_cI_2 + Z_e(I_2 - I_3) = -E_c$ (3.3)

$Z_f(I_3 - I_1) + Z_e(I_3 - I_2) + Z_bI_3 = E_c - E_b$ (3.4)

- Nodal_ Voltage Analysis: In this method of analysis one of the network nodes is chosen as the reference node and the voltages of the remaining nodes, measured with respect to the reference node, are traded as the unknown in the problem. The voltage across any branch of a given mesh is equal to the difference between the node voltage at the two ends of the branch in question. It is seen therefore, that the summation of the component branch voltages round the mesh must be zero because the node voltages, whose difference constitutes any given branch voltage will be cancelled out in the summation by the contributions which the same node voltages, but reversed in sign, make to the voltage across the adjacent branches of the mesh, The simple network shown in Figure 3.10 we obtain the following equations for nodes 1,2 and 3 respectively.

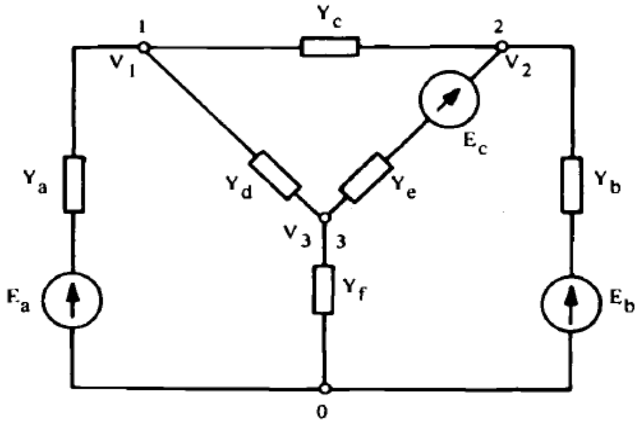


Figure 3.10: Network analysis by Nodal

$$(0 + E_a - V_1)Y_a + (V_2 - V_1)Y_c + (V_3 - V_1)Y_d = 0 \qquad (3.5)$$

$$(0 + E_b - V_2)Y_b + (V_1 - V_2)Y_c + (V_3 + E_c - V_2)Y_e = 0 \qquad (3.6)$$

$$(0 - V_3)Y_f + (V_1 - V_3)Y_d + (V_2 - E_c - V_3)Y_e = 0 \qquad (3.7)$$

3.6 Calculation of Balanced Fault Conditions

- Single_ Phase Representation:

The component items of electrical plant which together form a three_ phase power system, namely generators, transformers, over a head_ line and cable circuits, etc. can all be regarded, for most practical purposes. as having electrical characteristics which are balanced or symmetrical with respect to the three phases. Thus, the plant impedance characteristics are usually such that the phase self-impedance values can be regarded as the same for all three phases and the phase_ to_ phase mutual- impedance values regarded as symmetrical with respect to the three phases. The mathematical relationship between balanced positive –sequence) phase values at any given point in the power system are the same for both current and voltage, namely.

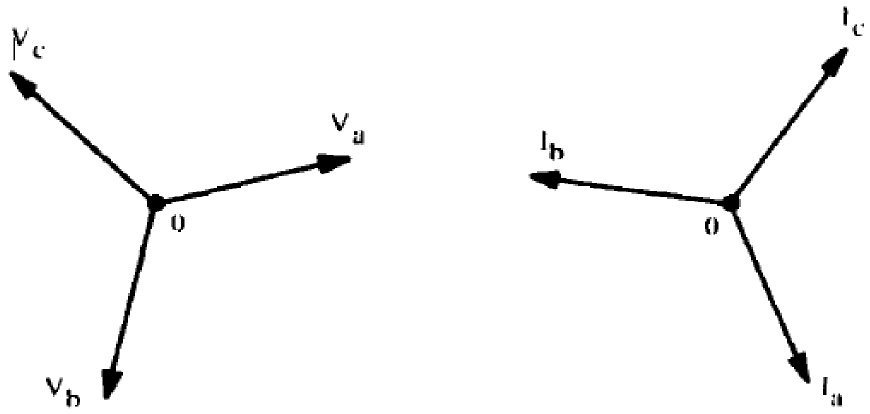


Figure 3.11: Phasor_ diagram representation possible of positive sequence voltages and currents

3.7 Calculation of Unbalanced Fault Conditions

- Symmetrical Components

A full and proper analysis of unbalanced conditions in three phase network is made possible by the fact that any given set of un balanced three_ phase vectors, which may be voltages or currents, can be represented by the sum of three sets of balanced or symmetrical vectors, namely: the positive_ sequence set, consisting of three vectors all equal in magnitude and symmetrically spaced at 120 in intervals, in time_ phase with a stated phase order (termed the positive- sequence phase order) equal to the phase order of the system generated voltage; The negative_ sequence set, consisting of three vectors all equal in magnitude and symmetrically spaced, at 120, all intervals, in time_ phase, their phase_ order being the reverse of the positive_ sequence phase order and finally, the zero sequence set, consisting of three vectors, all of which are equal in both magnitude and phase, and figure 2.12 represent the manner vector

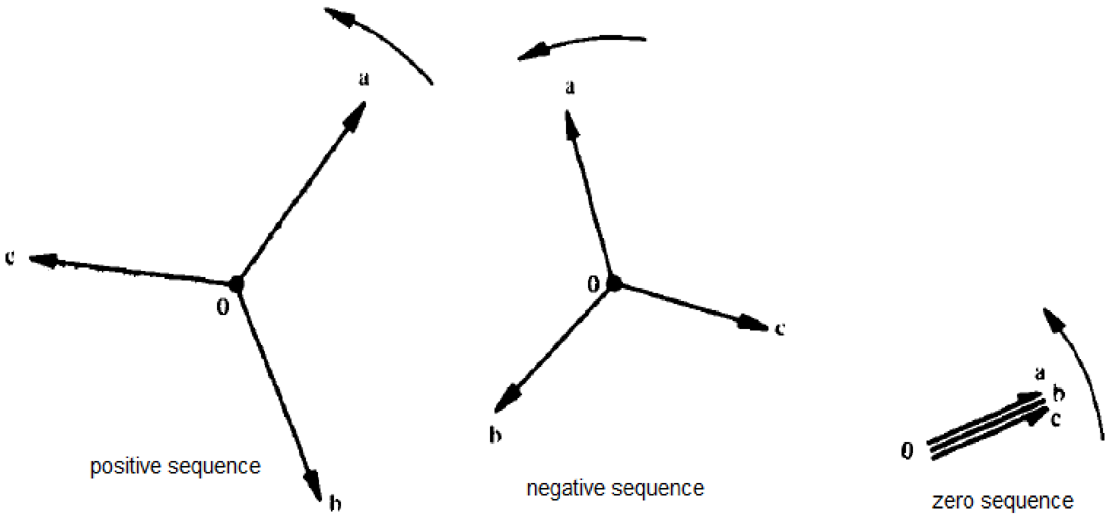


Figure 3.12: Phase- diagram representation of phase sequence components

Relations between phase vectors and their sequence components: let IA, IB and IC be any set of unbalanced three phase vectors, where the subscripts a, b and c demote the three phase in positive_ sequence phase- order. Then demoting the positive, negative and zero phase_ sequence by the second subscripts 1,2 and 0, respectively, the three sets of component vectors are the positive_ sequence set

Ia , $Ib = a^2 Ia_1$ and $Ic_1 = a Ia_1$

The negative_ sequence set

Ia_2 , $Ib_2 =a Ia_2$ and $Ic_2\ a^2 Ia_2$

And finally, the zero sequence set

Ia_0 , $Ib_2 = a Ia_0$ and $Ic_0 = I_0$

From what has already been said, therefore,

$Ia = Ia_1 + Ia_2 + Ia_0$ (3.8)

$Ib = Ib_1 + Ib_2 + Ib_0$ (3.9)

$Ic = Ic_1 + Ic_2 + Ic_0$ (3.10)

And rewriting these equations in terms of reference_ phase (phase-a) sequence components only, we get

$Ia = I_1 + I_2 + I_0$ (3.11)

$Ib = a^2I_1 + aI_2 + I_0$ (3.12)

$Ic = aI_1 + a^2 I_2 + I_0$ (3.13)

The sequence components of the three reference phase (phase a) can be obtained in terms of the three currents, the resulting equations being

$I_1 = 1/3(Ia + aIb + a^2Ic)$ (3.14)

$I_2 = 1/3(Ia + a^2 Ib + aIc)$ (3.15)

$I_0 = 1/3 (Ia + Ib + Ic)$ (3.16)

The voltage vectors, the resulting equation being

$Va = V_1 + V_2 + V_0$ (3.17)

$Vb = a^2V1 + aV_2 + V_0$ (3.18)

$Vc = aV_1 + a^2Vc + V_0$ (3.19)

For the phase values in terms of the reference-phase (phase_ a) sequence components

$V_1 = 1/3(Va + aVb + a^2Vc)$ (3.20)

$V_2 = 1/3(Va + a^2Vb + aVb)$ (3.21)

$V_0 = 1/3(Va + Vb + Vc)$ (3.22)

Because the symmetrical components of current and voltage in each of the three phases can be expressed in terms of those of the chosen reference phase (phase_ a).

- Phase_ Sequence Networks and Impedance

In any balanced-impedance circuit, the voltage drops produced in the three phase by phase currents of any given phase-sequence will themselves be of that same phase-sequence. Thus, the flow of positive sequence currents through such a circuit will produce positive_ sequence voltage drops in the three phases and no others negative-sequence currents will produce only negative-sequence voltage drops and zero- sequence currents only zero_ sequence voltage_ drops.

$Va_1 = Z_1\, Ia_1 \quad Va_2 = Z_2\, Ia_2 \quad va_0 = Z_0\, Ia_0$ (3.23)

$Vb_1 = Z_1\, Ib_1 \quad Vb_2 = Z_2\, Ib_2 \quad Vb_0 = Z_0\, Ib_0$ (3.24)

$Vc_1 = Z_1\, Ic_1 \quad Vc_2 = Z_2\, Ic_2 \quad Vc_0 = Z_0\, Ic_0$ (3.25)

The voltage_ drops equations are:

$V_1 = Z_1\, I_1$ (3.26)

$V_2 = Z_2\, I_2$ (3.27)

$V_0 = Z_0\, I_0$ (3.28)

The resulting total voltage_ drops in the three phases are therefore

$Va = I_1\, Z_1 + I_2\, Z_2 + I_0\, Z_0$ (3.29)

$Vb = a^2\, I_1\, Z_1 + aI_2\, Z_2 + I_0\, Z_0$ (3.30)

$Vc = a\, I_1\, Z_1 + a^2\, I_2\, Z_2 + I_0\, Z_0$ (3.31)

CHAPTER FOUR

APLICATION OF PROTECTION

CHAPTER FOUR

APLICATION OF PROTECTION

4.1 Introduction

The Sudan Khartoum Refinery Company is a petroleum company in Sudan, the company its name is abbreviated to KRC the company was founded on 1st march 1997 and began operations in 2000

4.2 substation components

Khartoum refinery company have many medium substations (work at 6 KV) and more than ten low voltages (work at 380 V) all this medium substation are same. The single line diagram of substation represent the first unit of refinery is shown in figure 4.1 consist of two section (section I, section II) each of them supplied by separated feeder. The bus section designed to supplied each section from other when the feeder of the section is DE energized. Each of sections has one potential transformer (PT) this potential transformer supplied all protection relay in their section by value of voltage in own section. Also the main part of substation which play important role is digital protection relay, the figure 4.2 shown the way of digital protection relay connection, one of important relay is MICOM P220 and the mostly enabled protections are (earth fault – short circuit – thermal overload – unbalance – locked rotor - excessive long start).

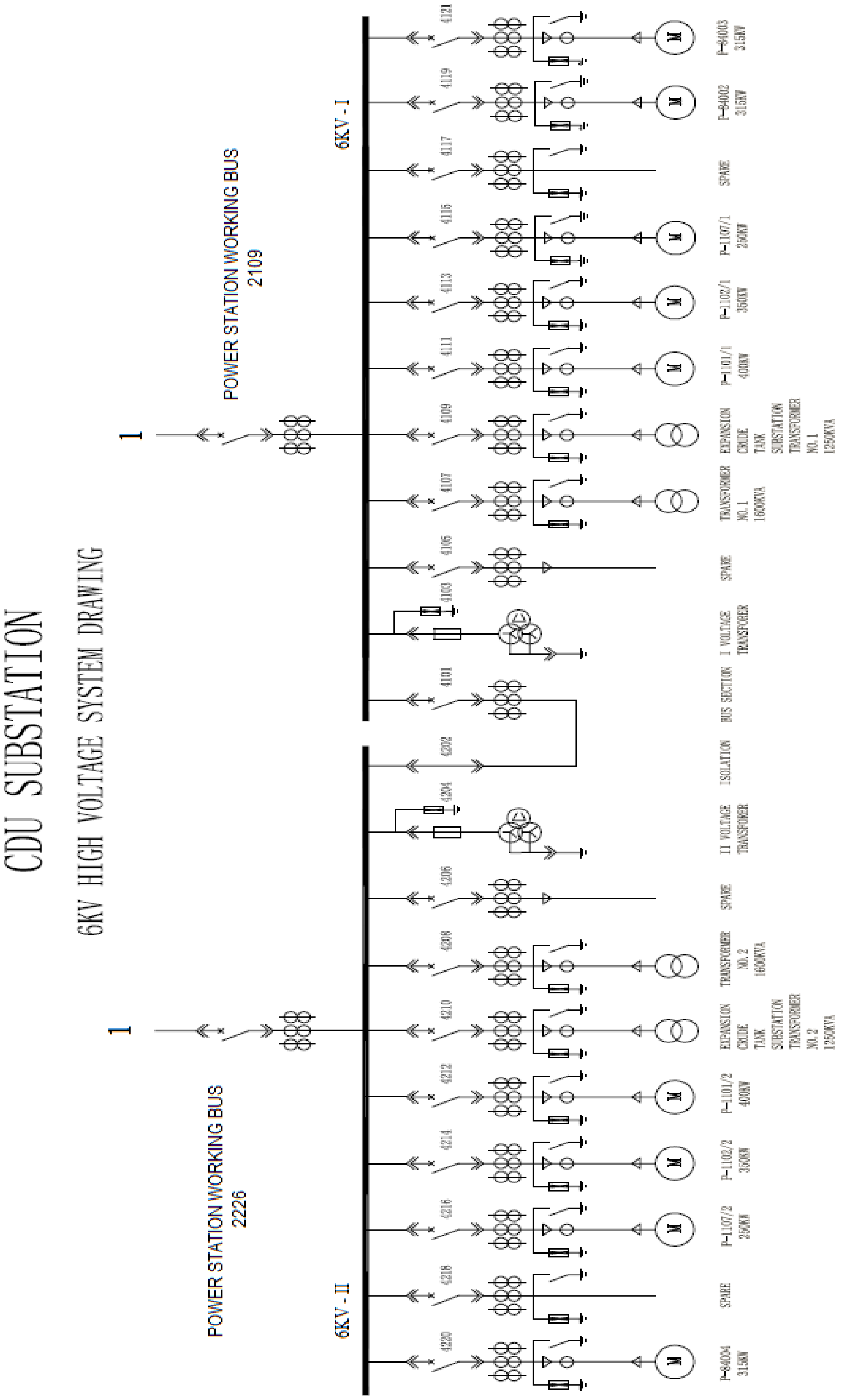


Figure (4.1) Single line diagram

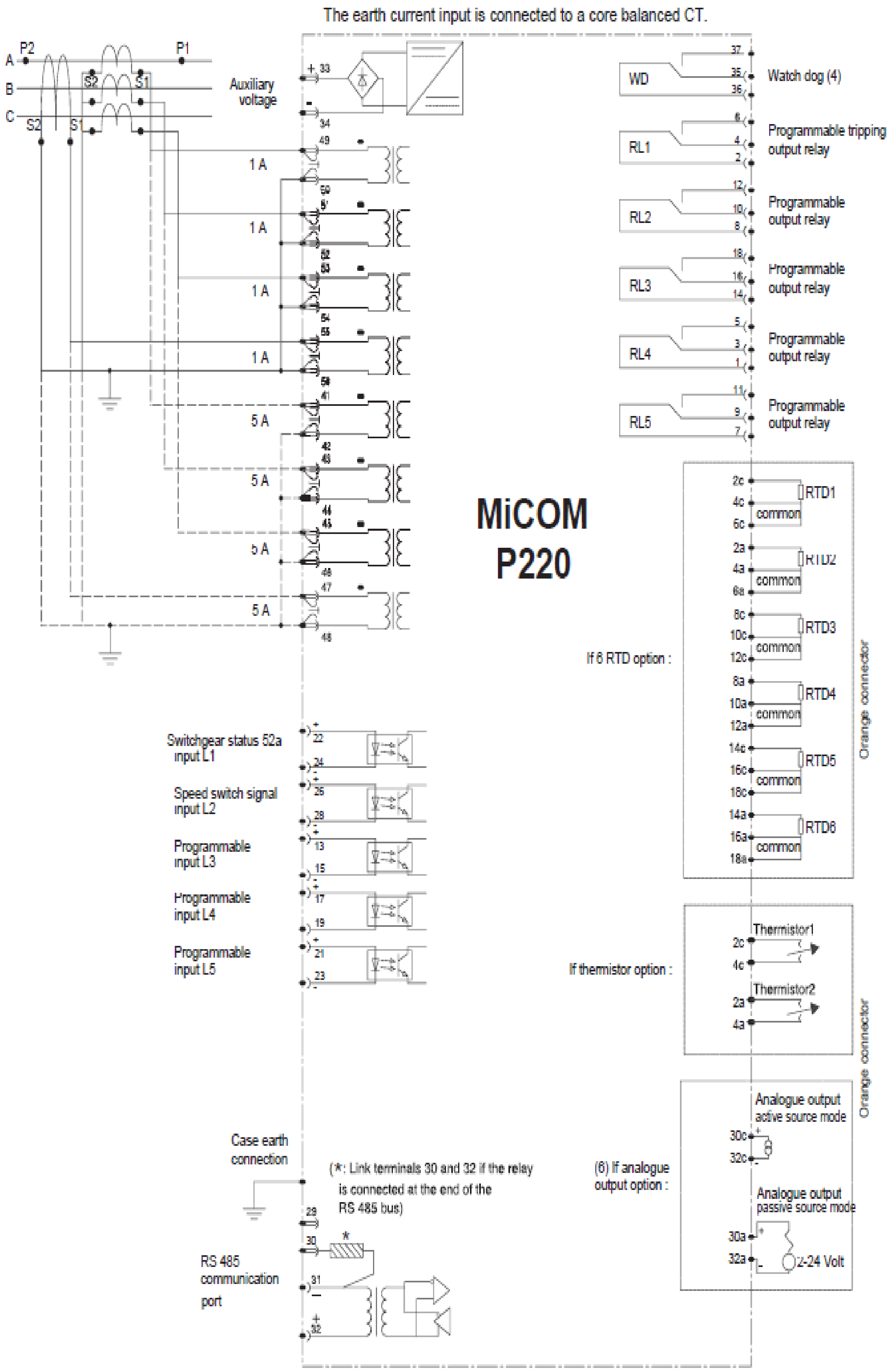


Figure 4.2: the protection relay connection

4.3 Earth fault (50N/51N)

Overheating of the stator windings is likely to lead to insulation deterioration. Since the windings are surrounded by an earthed metal case, stator faults usually manifest themselves as earth faults.

To protect against this, the P220 relay is provided with two independent earth fault overcurrent elements with settable definite time delays. This function reacts only to the fundamental component of the earth fault current, and thus remains insensitive to the disturbances of the higher-order harmonics (equal to or higher than 2). The earth fault protection function may be provided either by residual connection of the 3 phase current transformers (CTs), or by the use of a core-balance current transformer. It is preferable to use a core balance current transformer as this is more stable and is more sensitive. If residually connected CTs are used, the tripping setting would have to be increased by as much as 10 % higher than the rated current of the CT. This is highly undesirable because of the resulting increase in the earth fault current setting. Incorrect tripping can result from the saturation of one or more CTs during motor starting. Increased stability can be achieved in two ways:

- increasing the current threshold,
- insertion of a stabilising resistance in series with the P220 relay.

The value of stabilising resistor can be found from the following equation. [7]

$$R_{stab} > (I_d / I_s) * (R_{CT} + 2*R_f + R_{RE}). \tag{4.1}$$

where:

Id = start-up current magnitude brought to the secondary

Is = earth fault setting in Amps (threshold Io> or Io>>)

RCT = dc resistance of CT secondary windings.

Rf = resistance of single lead from CT to relay

RRE = other resistances connected in series to the CT (relays etc.).

The following earthing systems may be employed. [7]

Neutral earthed through an impedance:

The earth fault current is mainly comprising active current component resulting from the resistance of neutral point, the capacitive zero sequence (residual) contribution from the cables being of much lower value, even negligible

Insulated neutral:

A core balanced transformer is used as the fault current is due to the cable capacitive leakage current. A single earth fault will not cause the relay to trip but the fault should be localised.

Solidly earthed neutral:

The earth fault current is mainly inductive current, with magnitude being close to that of the three-phase short-circuit fault currents. The contribution of capacitive residual current from the cables is negligible.

The following table 4.1 shown the earth fault setting [7]

Table 4.1: Earth Fault Setting Protection

Submenu (50/51) EARTH FAULT	Primary Setting	Secondary Setting	Comments
Earth fault function enabled? threshold Io>		No	Only one earth fault current threshold can be programmed
Thresholds Io>		0.002Ion	
tIo>		0s	
Earth fault function enabled? threshold Io>>		Yes	
Threshold Io>>	2A	0.08Ion	Setting to 6,7 % of maximum earth fault current
tIo>>		0.1s	

4.4 Excessive Long Start (48)

The start-up current is specific to each motor and depends on the start-up method used (direct on-line, autotransformer, rotor resistance insertion, etc.). As for the startup time, it is dependent of the load connected to the motor. During the start-up period, this current surge imposes a thermal strain on the rotor. This is exaggerated as the rotor will have lost all of its ventilation because it does not rotate at the full speed. Consequently, a long start-up causes a rapid heating of the motor. For this reason, this protection is complementary to the thermal overload protection, and makes it possible to check that the start-up sequence does not exceed the parameters given by the manufacturer

The user can configure either option using the CONFIGURATION menu. Method 1 is recommended. This detects the start sequence on the circuit breaker closure. The function " Excessive long start " is initiated either by the detection of a start-up sequence, or (under normal operation) by the detection of a phase of re-acceleration. If at the end of delay time [tI_{start}] the current remains higher than the threshold [I_{start}], then a trip takes place. [7]

Typical settings are:

- [Istart] is equal to:
  - 1.5*[Iθ>] if the motor start-up current is lower than 4 times the rated current.
  - 2*[I_θ>] if the motor start-up current is equal to or higher than 4 times the rated current and lower than 8 times the rated current.
  - 3*[I_θ>] if the motor start-up current is equal to or higher than 8 times the rated current.
- [tI_{start}] = 120 % of the time of start-up and shorter than withstand time for the motor.

The following table 4.2 shown the excess long start setting. [7]

Table 4.2: Excess Long Start Setting Protection

Submenu (48) EXCESS LONG START	Primary Setting	Secondary Setting	Comments
Excess long start function enabled ?		Yes	
Threshold I start	540A	2Iθ	Id = 5.4*In motor → I start = 2*I θ
tIstart		5s	1.2 * td = 4.8s

4.5 Short Circuit (50/51)

A phase to phase short-circuit at the terminals of the motor or in the feeder cables, draws very large currents capable of damaging the motor and its feeder cable This also poses the threat of fire within the motor room. In this case, it is essential to detect the fault and to send the tripping command rapidly to the breaking device. To attain these objectives, the P220 relay is provided with an overcurrent element operating on fundamental component, with a settable definite time delay. The current threshold must be set as low as possible, without tripping due to:

- the start-up current of the motor
- the contribution of the motor to an external fault as well as
- the re-acceleration current due to voltage drops

In order to achieve this, the direct on-line start-up current must always be taken into account in the calculation of the setting even if the motor started under reduced voltage (soft start). Thus the short-circuit current threshold must be set higher than the direct on-line start-up current value. [7]

Taking into account aperiodic current components, the typical settings are:

- [I>>] = 130% * k_{start} * In_{motor} and [tI>>] = 100ms
- [I>>] = 180% * k_{start} * In_{motor} and [tI>>] = 0 ms

where k_{start} = start-up current of the motor in per unit.

In_{motor} = rated current of the motor.

It should then be checked that the threshold [I>>] is lower than:

- 90% of the limiting saturation current of the CTs used, and
- 1/3 of the minimum three-phase fault current at the motor terminals.

The following table 4.3 shows the short circuit setting. [7]

Table 4.3: Short Circuit Setting Protection

Submenu (50/51) SHORT-CIRCUIT	Primary Setting	Secondary Setting	Comments
Short-circuit function enabled ?		Yes	
Threshold I>>	1800A	6In	130% of motor start-up current
tI>>		0.1s	

4.6 Thermal overload (49)

Overloads can result in excessive stator temperature rises in excess of the thermal limit of the winding insulation. Whilst this may not cause the motor to burn out immediately, it has been shown that the life of the motor can be shortened if these overloads persist. The life of the motor is not purely dependent on the temperature of the windings but on the time that it is exposed to these temperatures. Due to the relatively high thermal storage capacity of induction motors, infrequent overloads of a short duration may be tolerated without damage. Sustained overloads of a small percentage may result in premature ageing and insulation failure. [7]

However, it should be noted that the overload protection includes the monitoring of both the stator and the rotor. This protection can be realised in various ways:

- Direct measurement through the use of temperature sensors.
- Indirect measurement by the means of current measurement.
- by a combination of the two preceding principles.

The thermal protection described above makes use of current measurement to protect the motor. Hence it will monitor balanced and unbalanced overloads. The thermal time-constant is adjustable in order to match any type of motor. The positive (I1) and negative (I2) components of the current are composed together in order to result in a equivalent thermal current replica of the temperature of the motor. [7]

This equivalent thermal current is given by the equation:

$$I_{eq} = \sqrt{(I_1^2 + Ke * I_2^2)}, \qquad (4.2)$$

where Ke is an adjustable parameter used to account for the effects of heating produced by the negative component of the current when developing the thermal image. From this equivalent thermal current, the thermal state θ of the motor is calculated every 5 cycles (every 100ms for a network of 50 Hz or 83.3ms for 60 Hz) by the relay in accordance with the following formula. [7]

$$\theta\ i+1 = (Ieq/I\theta>)^2 . [1- e(-t/T)] + \theta i \ . \ e(-t/T) \qquad (4.3)$$

θi = is the initial thermal state.

$I\theta$ = thermal current threshold setting

If the absorbed current is less than the thermal overload threshold [$I\theta>$], thus typically less than the nominal current or the full load current, then the thermal state θ will be less than 100%, so no tripping occurs. In the thermal model selected, the time of tripping depends on the initial state of the motor. The equation used to calculate the tripping time for a thermal state of the motor at 100 % is:

$$t = T * \ln [(K^2 - \theta i) / (K^2-1)] \quad (4.4)$$

The equation is valid for currents whose value is constant over a certain period of time, where:

− the value of T, thermal time-constant which depends on the value of the ratio $I_{eq} / I\theta$:

T = Te1 if $0 < I_{eq} \leq 2 * I\theta$ (overload curve)

T = Te2 if $I_{eq} > 2 * I\theta$ (start-up curve)

T = Tr if $I_{eq} = 0$ (cooling curve-motor stopped)

NOTE: $I_{eq} = 0$ is obtained through the logic input No.1 of the relay which recovers the information « contactor position open »

− $I\theta$ = thermal current threshold setting

− $K = I_{eq}/ I\theta$

− θi = initial thermal state of the motor

(ex.: thermal state of 50% → $\theta i=0.5$)

The heating time-constant Te1 can be estimated from the motor heating curve as shown in figure 4.3 below. [7]

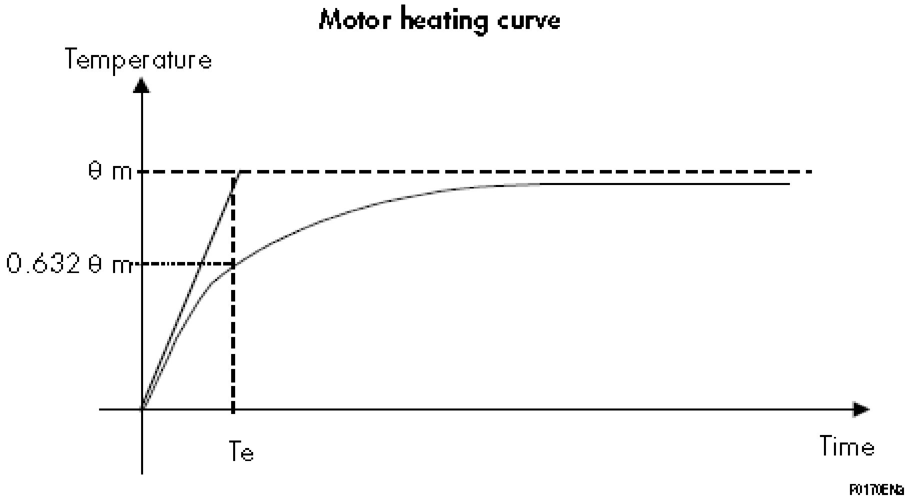


Figure 4.3: motor heating curve

This curve corresponds to the following law:

$\theta(t) = \theta m * (1 * e^{-t/Te})$, (4.5)

Where:

θm = maximum temperature after stabilisation of heat exchange, in degrees °C

Te = heating time-constant

t = time elapsed

The heating time-constant can be clearly defined. When a motor is absorbing its rated current indefinitely, it reaches 63.2% of its steady-state temperature ($\theta T = 63.2\%\ \theta m$) after one time-constant Te.

The cold curve of the motor is thus given by:

$t = Tr * \ln [\, K^2 / (K^2-1)]$ (4.6)

Where the equation for the motor cooling temperature is given by.

$\theta = K^2 (1 - e^{-t/Tr})$. (4.7)

When the motor is stopped, the rotor fan cooling is stopped also, hence the motor cooling down is few efficient. This causes the cooling time-constant to increase considerably This constant is generally much longer than the heating time-constant. In order to compensate for this phenomenon and to obtain a correct thermal replica, the cooling time constant is used by the relay.

An adjustable cooling time-constant (Tr) is provided in order to take into account the various modes of cooling. The cooling time-constant Tr can be estimated from the motor cooling curve in figure 4.4. [7]

The table 4.4: shown the thermal overload setting protection in MICON P220[7].

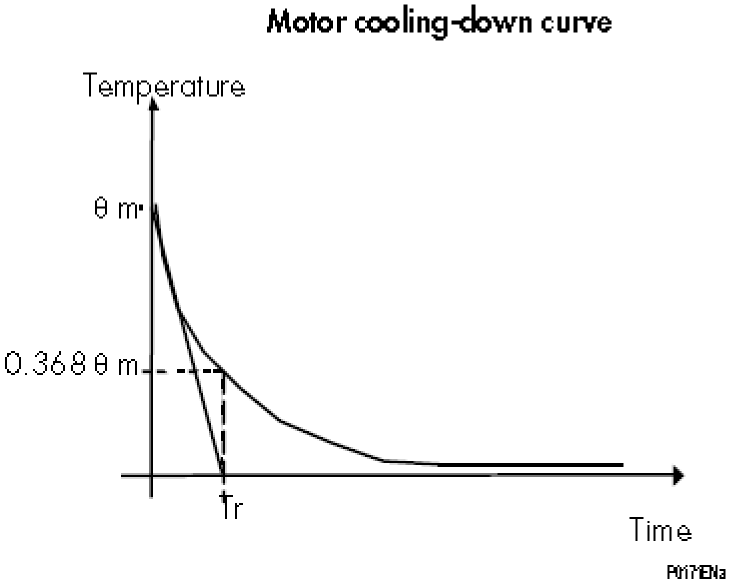


Figure 4.4: motor cooling down curve

This curve corresponds to the following law:

$\theta(t) = \theta m * e^{-t/Tr}$ (4.8)

Where:

θm = maximum temperature when motor is stopped

Tr = cooling time-constant

t = time elapsed

The cooling time-constant can be clearly defined. When a motor is stopped, its internal temperature decreases with time. This internal temperature reaches 36,8% of the initial temperature (temperature at the time when the motor was turned off) at the end of the period, which is equal to its time-constant Tr. [7]

Table 4.4: Therm. Overload Setting Protection

THERM.OVERLOAD(49) Submenu	Primary Setting	Secondary Setting	Comments
Thermal overload function enabled ?		Yes	

Thermal inhibition on start enabled ?		No	
Threshold Iθ >	270 A	0.9In (CT)	5.5% of overload authorised = 1.055 x In(motor)
Ke		3	
Te1		14 min	See motor characteristics
Te2		10 min	See motor characteristics
Tr		28 min	See motor characteristics
Influence RTD (optional)		No	
Θ ALARM enabled?		Yes	
Thermal alarm threshold θ ALARM		92%	0,92 > (256 / 270)2
θ FORBID START enabled ?		Yes	
FORBID START		78%	0,78 < (1382 / 270)2 * (1- exp (4/10*60)) + exp(5 / 10*60))

4.7 Unbalance Protection (46)

Under normal motor running conditions only positive sequence current components flow. The presence of a negative sequence component produces a field revolving in an opposite direction to that of the rotor. It induces rotor winding currents at double the supply network frequency. The skin effect in the rotor winding bars at this frequency can cause a significant increase in the resistance of the rotor. The rotor will overheat leading to deformation of the rotor bars and damage to them. This imposes additional heating of the stator that is in excess of the manufacturers rating.

Even if the thermal protection provided by this relay takes into account negative sequence component of the current, it will not account for the additional heating due to high unbalance rate. In the event of the motor losing one phase of its supply, considerable overheating would occur, hence protection for negative sequence is employed separately. [7]

Typical settings are

- alarm threshold: [I_i >] = 15% of the motor rated current, with a delay time of about 8 to 10s,
- tripping threshold: [I_i >>] = 20% of the motor rated current.

The following table 4.5 shown the unbalance setting protection. [7]

Table 4.5: Unbalance Setting Protection

Submenu (46) UNBALANCE	Primary Setting	Secondary Setting	Comments
Function Unbalance enabled? threshold Ii>		Yes	Alarm threshold enabled
Threshold Ii>	25.6 A	0.085 In (CT)	Setting to 10% of In motor
tli>		10s	
Function Unbalance enabled? threshold Ii>>		Yes	Tripping threshold enabled
Threshold Ii>>	51.2A	0.171 In (CT)	Setting to 20% of In motor

4.8 Locked rotor (51LR/50S)

There are two possible conditions for the rotor becoming locked at motor start-up or during normal run. Whatever the case, a locked rotor produces an input current equivalent to the direct on-line starting current.

The most frequent cause of a locked rotor is to a phase break (e.g. melting of a fuse protecting the motor, or one pole of a contactor remaining open.). A stationary motor cannot start and remains stationary with two phases feeding the stator. In the same way, a locked rotor can take place after the loss of a phase after the motor has been working normally.

The appearance and the importance of a locked rotor depend on the motor load at the time when the loss of phase occurs. In both cases the result is likely to be a thermal overloading of the rotor windings.

Under healthy conditions, a revolving flux is induced in the rotor, which generates balanced rotor current in the windings which produce symmetrical rotor heating. In the event of the loss of one phase of the supply, a heterogeneous flux is induced in the rotor as a result of the positive component and the negative components of the current. This causes uneven heating of the rotor windings which depend on the position of the rotor bars. This can lead to the damage of the rotor bars. For these reasons, it is important to eliminate the fault as quickly as possible. [7]

- Locked rotor during the start-up stage [50S]

This function is enabled only during the motor start-up stage. In order to take advantage of this function, the motor has to be equipped with a tachometric control, which indicates if the motor turns. This information is carried to a digital input of the relay so that the relay can detect whether the motor’s speed is or is not zero.

A locked rotor is detected if, after expiration of delay time [tI_{stall}], the digital input indicates zero speed (logic 0). Motors for which the real start-up time is shorter than their locked rotor withstand time can be protected against locked rotor condition at start-up without the help of a tachymetric control device (speed switch).

For such cases, the use of [tI_{start}] time setting (refer to « (48) Excessive long start » function) shorter than the motor locked rotor withstand time allows to provide efficient protection against both too long start-up sequence and locked rotor at start-up conditions. [7]

- Rotor stalled during normal run [51LR]

This function is valid only outside the re-acceleration and start-up stages. Tripping takes place if the current remains higher than [Istall] for a time period equal to or higher than delay time [stall].

Typical settings of the function [51LR/50S] are:

- **[I_{stall}] =:**

  -1.5*[I_θ>] if the motor start-up current is lower than 4 times the rated current.

  - 2*[I_θ>] if the motor start-up current is equal to or higher than 4 times the rated current and lower than 8 times the rated current.

  -3*[Iθ>] if the motor start-up current is equal to or higher than 8 times the rated current.
- **[tI_{stall}]** is 1 to 2 s for a pump and a fan, and 5 to 10 s for a crusher. In all the cases, this setting must be lower than the withstand time for the motor with the rotor stalled.

  The following table 4.6 shown the block rotor setting protection. [7]

Table 4.6: Block Rotor Setting Protection

[51LR/50S] BLOCK ROTOR submenu	PROTECTION G1	PROTECTION G2
Block rotor function enabled ?	No	No
TIstall	0,1 second	0,1 second

Stalled rotor while running function enabled ?	No	No
Threshold Istall	1 Iθ	1 Iθ
Locked rotor at start function enabled ?	No	No

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The Khartoum refinery substation contains on transformer, switchgear, busbars, current transformer, potential transformer. This component together comprises the substation system. this system is protected with digital relays, for feeders, busbars, motors, transformer.

5.2 Recommendations

Digital protection relay is latest technology used in protection system, therefor this digital protection can be used in many other electrical power substation, power plant and power transmission substation.

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