**Sudan University of Science and Technology**

**College of Engineering**

**Electrical Engineering**

# Simulation of Electrical Power Plant Protection Using ETAP

# محاكاة حماية محطة توليد كهربائية باستخدام ETAP

*A project Submitted in partial fulfillment for the requirement*
*of the degree of B.Sc. (honor) in electrical engineering*

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# الآية

قال تعالي:

بسم الله الرحمن الرحيم

" يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ "

صدق الله العظيم

سوره المجادلة الآية رقْم 11

# Dedication

*To who give our lifes meaning*

*To our fathers and mothers*

*To our sisters and brothers*

*To all researchers who are working to improve the quality of life*

*To all of them we dedicate this work*

# ACKNOWLEDGEMENTS

We own our deepest gratitude to our advisor, Dr.Al fadil Zakria , for his invaluable support in getting us started on this project, his constant generosity in providing the necessary advices to do the work.

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# Abstract

The main goal of this thesis is to simulate Electric power generation network because this network faced by blackouts several times this led to severe lack of production during blackout times specially when great amount of load from substations trip or one or more of on service generators stop suddenly this thesis find the best generators protection setting specially for over and under voltage fault protection setting and over and under frequency faults protection setting by using ETAP (Electrical Transient and Analysis Program) software as an analysis tool to perform generators protection setting for three different type of generators using for Sudan Nuclear Plant and draw the power network and simulate successfully many faults cases and find best generators protection setting. The new relay setting coordination had been applied to all relays in the five main substations as a result from this study.

The sequence of operation is improved and as a result the total black outs frequency is significantly decreased.

# المستخلص

الهدف الرئيسي من هذا المشروع هو محاكاة حماية شبكة توليد الطاقة الكهربية لأن هذه الشبكة واجهت انقطاع التيار الكهربائي عدة مرات مما قد يؤدي إلى نقص شديد في الإنتاج أثناء أوقات التعتيم خاصة عندما يتوقف عدد كبير من المحطات الفرعية ذات الحمولة الواحدة أو أكثر من مولدات الخدمة التي تتوقف فجأة. يبحث هذا المشروع على أفضل إعداد لحماية المولدات خصوصًا لإعداد الحماية من أعطال الجهد الزائد وأعطال الجهد المنخفض وأعطال التردد الزائد وأعطال التردد المنخفض باستخدام برنامج ETAP (برنامج التحليل الكهربائي العابر) كأداة تحليل لأداء ضبط حماية المولدات لثلاثة أنواع مختلفة من المولدات سوف تستخدم لمحطة السودان النووية ورسم شبكة الكهرباء ومحاكاة العديد من حالات الأعطال وإعداد أفضل الطرق لحماية المولدات. تم تطبيق تنسيق إعداد المرحلات على جميع المرحلات في المحطات الفرعية الخمسة الرئيسية نتيجة لهذه الدراسة. تم تحسين تسلسل العملية ، ونتيجة لذلك ، انخفض إجمالي عدد مرات التعتيم بشكل ملحوظ.

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# CHAPTER ONE

# INTRODUCTION

## 1.1 Overview

Sudan Nuclear power plant which located in PortSudan in west Red Sea State this power plant used Nuclear generators to produce electrical power, total capacity around 30MW,, so the stability of electrical power supply is very important and any interrupt will cost a lot

Power system protection is a branch of electrical power engineering that deals with the protection of electrical power systems from faults through the isolation of faulted parts from electrical network. Protection scheme in a power system is designed to continuously monitor the power system to ensure maximum continuity of electrical supply with minimum damage life, equipment, and property.

A generator has to be protected not only from electrical faults (stator and rotor faults) and mechanical problems, but it also has to be protected from adverse system interaction arising if generator going out of step with the rest of system, loss of field winding etc. Under certain situations like internal faults, the generator has to be quickly isolated (tripped), while problems like loss of field problem require an ‘alarm’ to alert the operator.

ETAP is the most comprehensive analysis platform for the design, simulation, operation, and automation of generation, distribution, and industrial power systems. ETAP is developed under an established quality assurance program and is used worldwide as high impact software. As a fully integrated enterprise solution, ETAP extends to real-time intelligent power management systems to monitor, control, automate, simulate, and optimize the operation of power systems.

## 1.2 Problem Statement

The main purpose of this project is to find best generator setting parameters due to unstable voltage and frequency on the power grid caused by high amount of load trip or one or group of generators within parallel generators trip and simulating protection system of generators using Electrical power plant generator protection data to help in analyzing the protection system and find out the best way to protect generators from damage.

## 1.3 Objectives

The main objective of this thesis is to use ETAP Package in order to study the effect of disturbances on the generators and describe the form of protection fitting each disturbance especially voltage and frequency interrupt on the plant and the implementation of this protection.

## 1.4 Methodology

The methodology of this thesis under taken as follows:

a) Understanding the previous studies.
b) Read and understanding the generator system and its protection methods
c) Understanding the ETAP software program.
d) Build the proposed system using ETAP software.
e) Evaluate the performance of the proposed system under different operation condition based on the simulation results.

## 1.5 Thesis layout

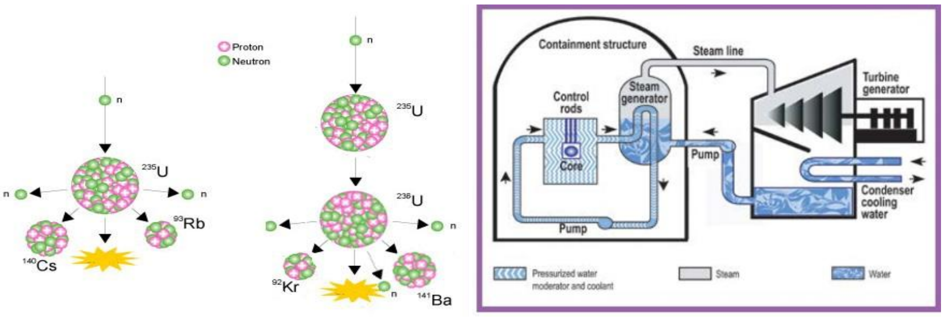
This thesis consists of five chapters. Chapter one include overview, problem statement, objectives and methodology. chapter two will discuss protection system in general way, Chapter three contains electrical circuit of generator, various faults, abnormal operating conditions and backup protection of generator. Chapter four consists simulation results and discussion. Finally Chapter five includes conclusion and recommendations.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

A nuclear reactor produces and controls the release of energy from splitting the atoms of uranium. Uranium-fuelled nuclear power is a clean and efficient way of boiling water to make steam which drives turbine generators. Except for the reactor itself, a nuclear power station works like most coal or gas-fired power stations.

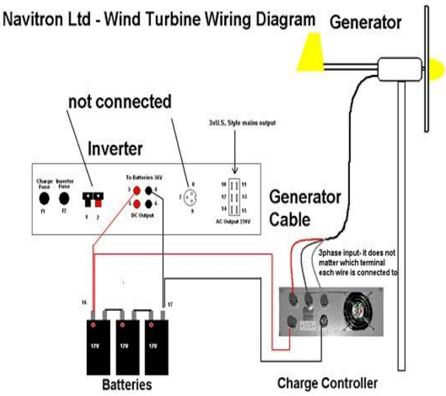


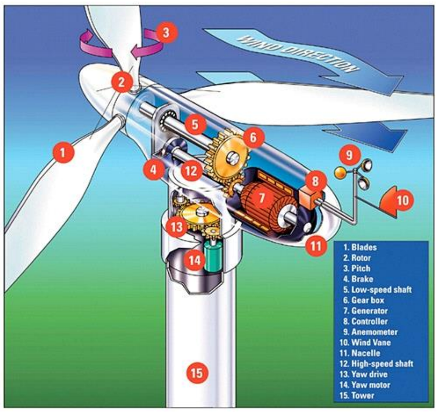
2.1 Nuclear Power Generation

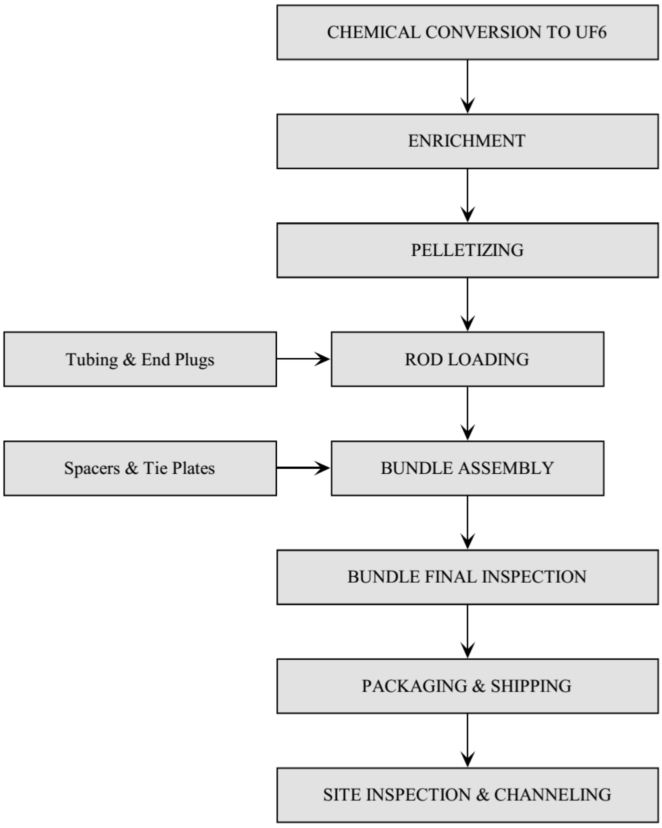
In a nuclear power plant, many of the components are similar to those in a fossil-fueled plant, except that the steam boiler is replaced by a Nuclear Steam Supply System (NSSS). The NSSS consists of a nuclear reactor and all of the components necessary to produce high pressure steam, which will be used to turn the turbine for the electrical generator.

Like a fossil-fueled plant, a nuclear power plant boils water to produce electricity. Unlike a fossil-fueled plant, the nuclear plant’s energy does not come from the combustion of fuel, but from the splitting of fuel atoms.

The uranium starts out as ore, and contains a very low percentage (or low enrichment) of the desired atoms (U-235). The U-235 is a more desirable atom for fuel, because it is easier to cause the U-235 atoms to fission (split) than the much more abundant U-238 atoms. Therefore, the fuel fabrication process includes steps to increase the number of U-235 atoms in relation to the number of U-238 atoms (enrichment process).







2.2 Enrichment Process

Once the fuel has been enriched, it is fabricated into ceramic pellets. The pellets are stacked into 12-foot long, slender metal tubes, generally made of a zirconium alloy. The tube is called the “fuel cladding.” When a tube is filled with the uranium pellets, it is pressurized with helium gas, and plugs are installed and welded to seal the tube. The filled rod is called a “fuel rod.” The fuel rods are bundled together into “fuel assemblies” or “fuel elements.” The completed assemblies are now ready to be shipped to the plant for installation into the reactor vessel.

## 2.2 Overview of electrical fault

Electrical faults usually occur due to breakdown of the insulating media between live conductors or between a live conductor and earth. This breakdown may be caused by any one or more of several factors, for example, mechanical damage, overheating, voltage surges (caused by lightning or switching), ingress of a conducting medium, ionization of air, and deterioration of the insulating media due to an unfriendly environment or old age, or misuse of equipment.

Fault currents release an enormous amount of thermal energy, and if not cleared quickly, may cause fire hazards, extensive damage to equipment and risk to human life. Faults are classified into two major groups: symmetrical and unbalanced (asymmetrical). Symmetrical faults involve all three phases and cause extremely severe fault currents and system disturbances. Unbalanced faults include phase-to-phase, phase-to-ground, and phase-to-phase-to-ground faults. They are not as severe as symmetrical faults because not all three phases are involved. The least severe fault condition is a single phase-to-ground fault with the transformer neutral earthed through a resistor or reactor. However, if not cleared quickly, unbalanced faults will usually develop into symmetrical faults.

### 2.2.1 Electrical three phase System Fault Types:

- Single phase to ground fault
- Phase to Phase fault
- Double Phase to earth fault
- Three phase fault
- Three phase to ground fault

Figure 2.3 represent the types of electrical faults.

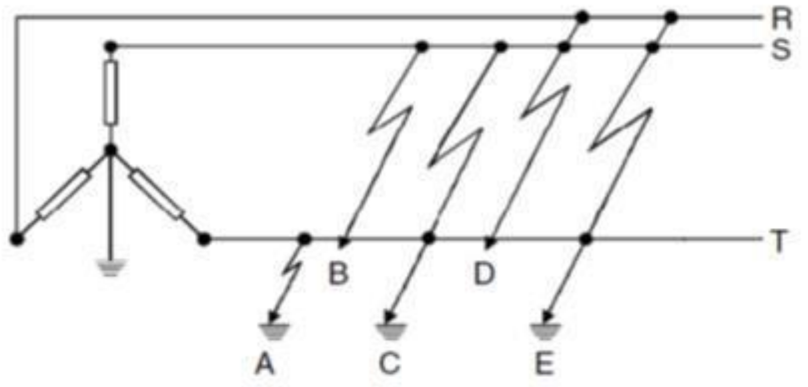


Figure 2.3 Type of faults on a three phase system.

## 2.3 Protection component

A collection of protection devices (relays, fuses, etc.). Excluded are devices such as CT’s, CB’s, Contactors, etc**.**

### 2.3.1 Fuses

Probably the oldest, simplest, cheapest, and most-often used type of protection device is the fuse. The operation of a fuse is very straightforward: The thermal energy of the excessive current causes the fuse-element to melt and the current path is interrupted. Technological developments have made fuses more predictable, faster, and safer (not to explode) Fuses are very inexpensive and they can operate totally independently, that is, they do not need a relay with instrument transformers to tell them when to blow. This makes them especially suitable in applications like remote ring main units, etc. [1]

### 2.3.2 Relays

The most versatile and sophisticated type of protection available today, is undoubtedly the relay/circuit-breaker combination. The relay receives information regarding the network mainly from the instrument transformers (voltage and current transformers), detects an abnormal condition by comparing this information to pre-set values, and gives a tripping command to the circuit-breaker when such an abnormal condition has been detected. The relay may also be operated by an external tripping signal, either from other instruments, from a

SCADA master, or By human intervention. Relays may be classified according to the technology used into:

## - ELECTROMECHANICAL RELAYS

These relays were the earliest forms of relay used for the protection of power systems, and they date back nearly 100 years. They work on the principle of a mechanical force causing operation of a relay contact in response to a stimulus. The mechanical force is generated through current flow in one or more windings on a magnetic core or cores, hence the term electromechanical relay. The principle advantage of such relays is that they provide galvanic isolation between the inputs and outputs in a simple, cheap and reliable form therefore for simple on/off switching functions where the output contacts have to carry substantial currents, they are still used. Electromechanical relays can be classified into several different types as follows:

- Attracted armature
- Moving coil
- Induction
- Thermal
- Motor operated
- Mechanical

## - STATIC RELAYS

Introduction of static relays began in the early 1960’s. Their design is based on the use of analogue electronic devices instead of coils and magnets to create the relay characteristic. Early versions used discrete devices such as transistors and diodes in conjunction with resistors, capacitors, inductors, etc., but advances in electronics enabled the use of linear and digital integrated circuits in later versions for signal processing and implementation of logic functions. While basic circuits may be common to a number of relays, the packaging was still essentially restricted to a single protection function per case, while complex functions required several cases of hardware suitably interconnected. User programming was restricted to the basic functions of adjustment of relay characteristic curves. They therefore can be viewed in simple terms as an analogue electronic replacement for electromechanical relays, with some additional flexibility in settings and some saving in space requirements. In some cases, relay burden is reduced, making for reduced CT/VT output requirements.

## - Digital Relays

Digital protection relays introduced a step change in technology. Microprocessors and microcontrollers replaced analogue circuits used in static relays to implement relay functions. Early examples began to be introduced into service around 1980, and, with improvements in processing capacity, can still be regarded as current technology for many relay applications. However, such technology will be completely superseded within the next five years by numerical relays. Compared to static relays, digital relays introduce A/D conversion of all measured analogue quantities and use a microprocessor to implement the protection algorithm. The microprocessor may use some kind of counting technique, or use the Discrete Fourier Transform (DFT) to implement the algorithm. However, the typical microprocessors used have limited processing capacity and memory compared to that provided in numerical relays. The functionality tends therefore to be limited and restricted largely to the protection function itself. Additional functionality compared to that provided by an electromechanical or static relay is usually available, typically taking the form of a wider range of settings, and greater accuracy. A communications link to a remote computer may also be provided.

## - Numerical Relays

The distinction between digital and numerical relay rests on points of fie technical detail, and is rarely found in areas other than Protection. They can be viewed as natural developments of digital relays as a result of advances in technology. Typically, they use a specialized digital signal processor (DSP) as the computational hardware, together with the associated software tools. The input analogue signals are converted into a digital representation and processed according to the appropriate mathematical algorithm. Processing is carried out using a specialized microprocessor that is optimized for signal processing applications, known as a digital signal processor or DSP for short.

Digital processing of signals in real time requires a very high power microprocessor. In addition, the continuing reduction in the cost of microprocessors and related digital devices (memory, I/O, etc.) naturally leads to an approach where a single item of hardware is used to provide a range of functions („one-box solution" approach). By using multiple microprocessors to provide the necessary computational performance, a large number of functions previously implemented in separate items of hardware can now be included within a single item.

### 2.3.3 Instrument transformers (CT\VT)

Relays need information from the power network in order to detect an abnormal condition. This information is obtained via voltage and current transformers (collectively called instrument transformers), as the normal system voltages and currents are too high for the relays to handle directly, and the instrument transformers protect the relay from system

'Spikes' to a certain extent.[1]

## 2.4 Zones of protection

To limit the extent of the power system that is disconnected when a fault occurs, protection is arranged in zones. The principle is shown in Figure 2.4

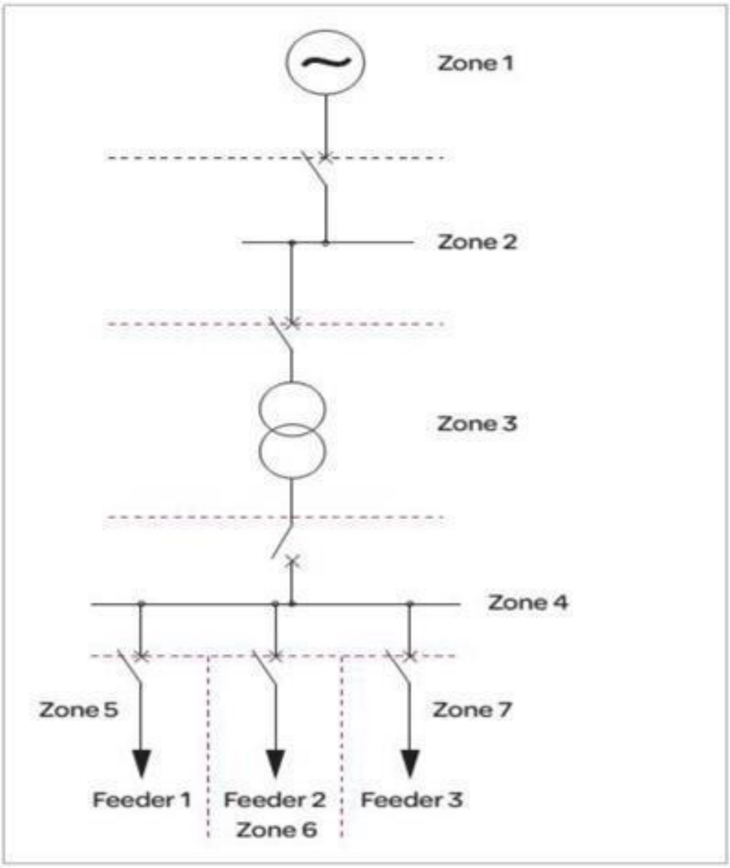


Figure 2.4 Division of Power System into Protection Zone

Ideally, the zones of protection should overlap, so that no part of the power system is left unprotected. The circuit breaker being included in both zones. For practical physical and economic reasons, this ideal is not always achieved, accommodation for current transformers being in some cases available only on one side of the circuit breakers. This leaves a section between the current transformers and the circuit breaker that is not completely protected against faults. In Figure 2. 5a fault at F would cause the bus bar protection to operate and open the circuit breaker but the fault may continue to be fed through the feeder. The feeder protection, if of the unit type, would not operate, since the fault is outside its zone. This problem is dealt with by inter-tripping or some form of zone extension, to ensure that the remote end of the feeder is tripped also.

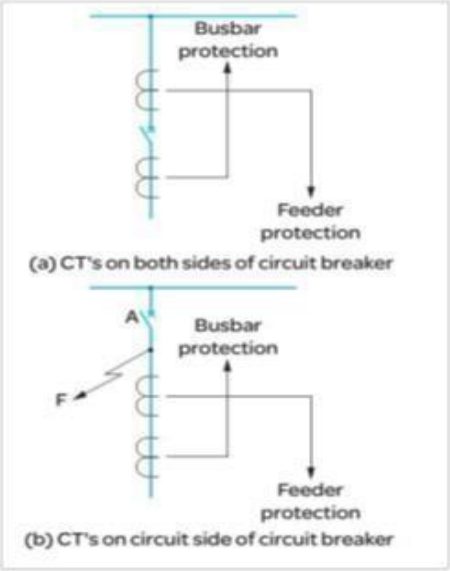


Figure2-5 CT locations

The point of connection of the protection with the power system usually defines the zone and corresponds to the location of the current transformers. Unit type protection will result in the boundary being a clearly defined closed loop. Figure 2. 6illustrates a typical arrangement of overlapping zones. [2]

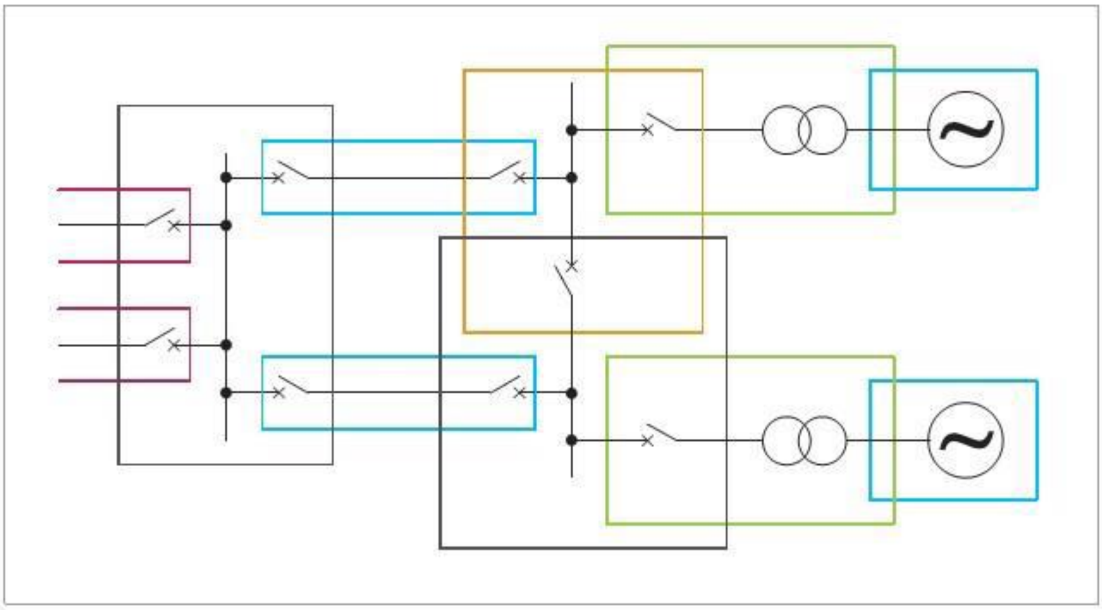


Figure 2.6 Overlapping Zones of Protection System

## 2.5 Protection quality

Protection quality represents: discrimination, stability, reliability, speed of operation and sensitivity.

### 2.5.1 Discrimination

Discrimination, or selectivity, is the ability of the protection to isolate only the faulted part of the system, minimizing the impact of the fault on the power network. Absolute discrimination is only obtained when the protection operates exclusively within a clearly defined zone. This type of protection is known as ‘unit protection’, as only one unit is exclusively protected for example, a transformer, or a specific feeder cable. The term ‘zone protection’ is also commonly used. Unit protection can only be achieved when the following essentials are satisfied:

• Sensing or measuring devices must be installed at each (Electrical) end of the protected equipment; and • There has to be a means of communication between the devices at each end, in order to compare electrical conditions and detect a fault when present.

**-The main advantages of unit protection are**:

- Only the faulted equipment or part of the network is disconnected, with minimum disruption to the power network.

- Unit protection operates very fast, limiting damages to equipment and danger to human life. Fast operation is possible because the presence or absence of a fault is a very clear-cut case.

- Unit protection is very stable.
- Unit protection is very reliable.
- Unit protection is very sensitive.

**-The major disadvantages of unit protection are the following**:

- It is very expensive.
- It relies on communication between the relays installed at either end

### 2.5.2 Stability

Stability, also called security, is the ability of the protection to remain inoperative for normal load conditions (including normal transients like motor starting). Most stability problems arise from incorrect application of relays and lack of maintenance.

### 2.5.3 Reliability

Reliability, or dependability, is the ability of the protection to operate correctly in case of a fault. Reliability is probably the most important quality of a protection system

### 2.5.4 Speed of operation

The longer the fault current is allowed to flow, the greater the damage to equipment and the higher the risk to personnel. Therefore, protection equipment has to operate as fast as possible, without compromising on stability. The best way to achieve this is by applying unit protection schemes. The phase shift between voltages at different bus bars on the system also increases, and therefore so does the probability that synchronism will be lost when the system is disturbed by a fault. The shorter the time a fault is allowed to remain in the system, the greater can be the loading of the system. Figure 2.7 shows typical relations between system loading and fault clearance times for various type of fault.

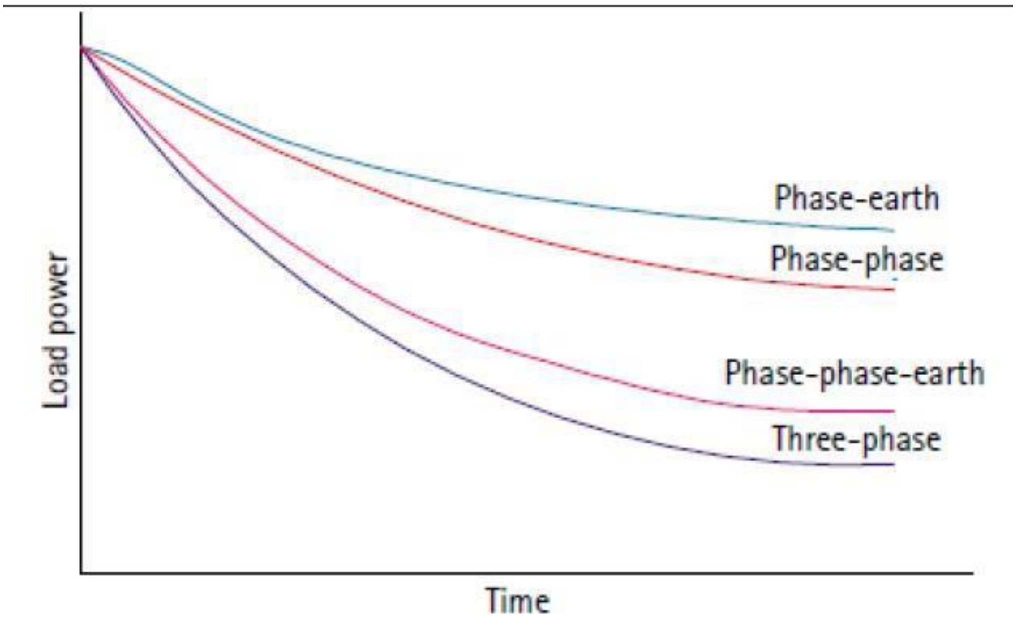


Figure 2.7 Typical Power / Time Relationship for Various Fault Types

### 2.5.5 Sensitivity

The term sensitivity refers to the magnitude of fault current at which protection operation occurs. A protection relay is said to be sensitive when the primary operating current is very low. Therefore, the term sensitivity is normally used in the context of electrical protection for expensive electronic equipment, or sensitive earth leakage equipment [2]

## 2.6 Generator protections Types:

-Over current protection

- Earth fault protection

-Differential protection

### 2.6.1 Over Current Protection

The term “overcurrent” refers to abnormal current flow higher than the normal value of current flow in an electrical circuit. Uncorrected “overcurrent” can cause serious safety hazards and costly damage to electrical equipment and property. The overcurrent relay typically displays the inverse definite minimum time (IDMT) characteristic as displayed in Figure 2.8

Traditionally, normally inverse (NI), very inverse (VI), and extremely inverse (EI) have been applied, with each type of curve characteristic to a specific type of relay. Multitudes of curves, up to 15 in one relay, user selectable, are available with modern relays.

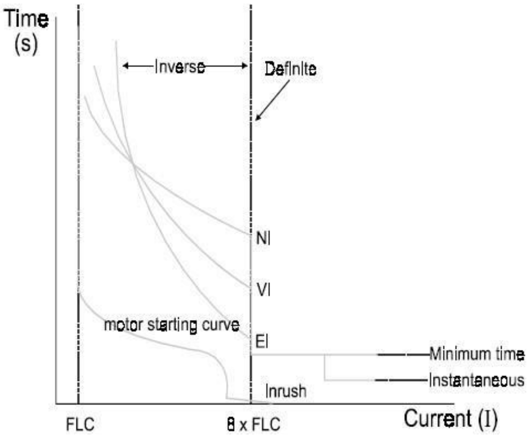


Figure 2.8 Traditional Over Current Curve

## 2.6.2 Earth fault protection

Phase-to-earth faults are covered by earth fault relays. The most common form of earth Fault protection operates on the principle that the vector sum of currents flowing in a balanced three-phase system equals zero. A very effective combination of overcurrent and earth fault protection has developed in the era of electromechanical relays, and the same principle is still used today in most protection schemes. This is illustrated in Figure 2.9

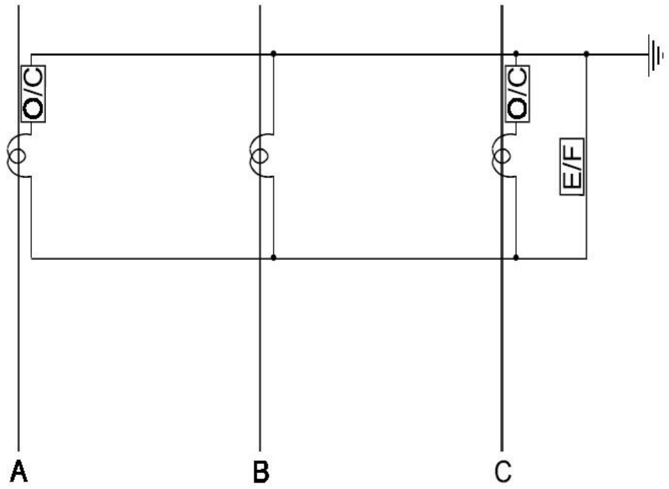


Figure 2.9 Economical CT Arrangement for O /C and E/ F

Only two phases need to be monitored by the overcurrent relay, the reason being that a fault on the third phase will be either to one of the other two phases, or to earth. A phase to-earth fault will cause an unbalance in the three phases, resulting in a current flowing in the earth fault element, tripping the earth fault relay. The same protection CTs are thus being used in this arrangement. [3]

## 2.6.3 Differential protection

Differential protection schemes vary according to the type of equipment to be protected, the most common being machine and feeder differential protection. The protection relays. Differ in their compensation methods for typical internal losses in the equipment to be protected, but operates on basically the same principle. The values of current going into and out of the equipment are measured and compared. The relay trips if the difference in Current exceeds a pre-set value, compensating For internal losses in the equipment and CT Inaccuracies. Figure 2.10 and figure 2. 11 illustrate the use of a differential protection scheme.

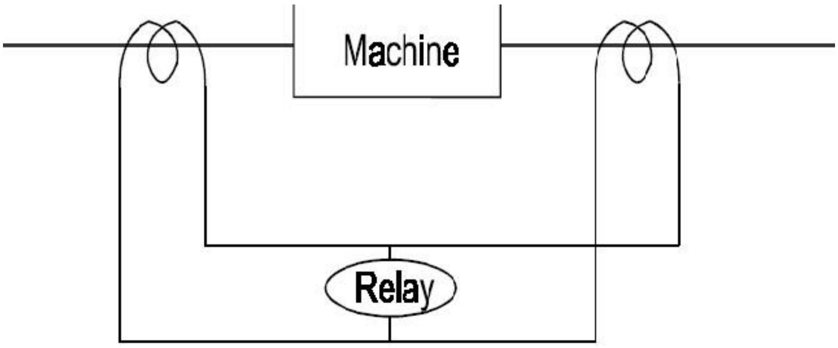


Figure 2.10 Machine Differential Protection

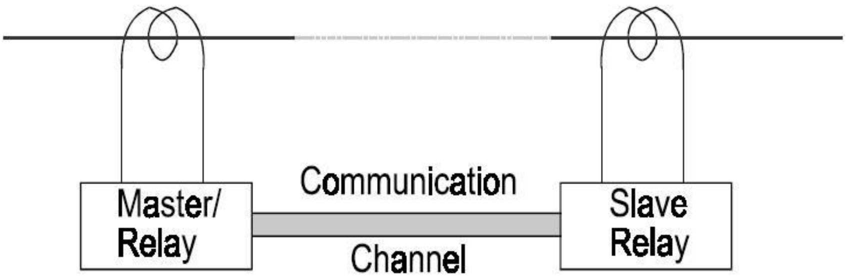


Figure 2.11 Feeder Differential Protection

With machine differential protection (motors or transformers), the sets of CTs are close to each other, and only relay needs to be used in most cases, with current flowing through the relay in case of a difference in current values. With feeder protection, the two sets CTs are far away from each other. Two relays are installed, one at both end of the equipment, one master and one slave. The slave relay measures the current at its end and sends it through to the master relay via the communication channel [1]

# CHAPTER THREE

# GENERATOR PROTECTION

## 3.1 Introduction

A generator is the heart of an electrical power system, as it converts mechanical energy into its electrical equivalent, which is further distributed at various voltages. It therefore requires a ‘prime mover’ to develop this mechanical power and this can take the form of steam, gas or water turbines or diesel and gas engines. Small and medium sized sets may be directly connected to a power distribution system. A larger set may be associated with an individual transformer, through which it is coupled to the EHV primary transmission system [2].

The protection of the generator presents a very challenging problem because of its system connections on three different sides as shown in Figure (3.1). On the one side, it is connected to the prime mover and on the other side it has to run in synchronism with the grid because of its connection to the power system. On yet another (third) side, it is connected to the source of DC excitation. It is thus obvious that generator protection is very complex compared to protection for other elements of the power system

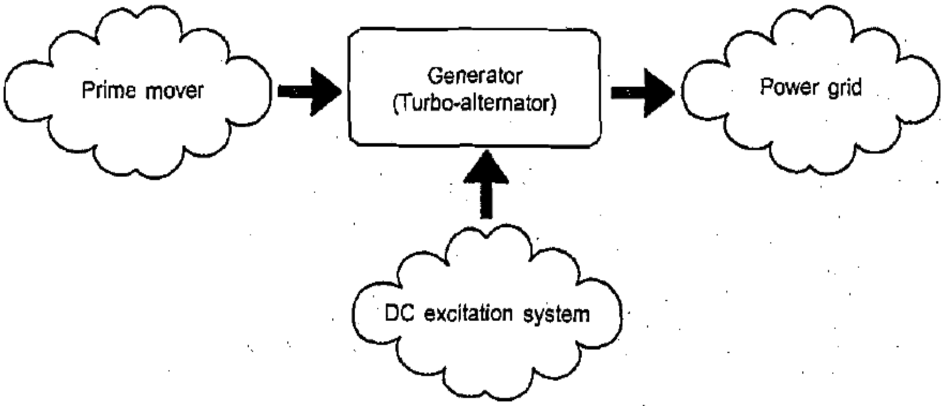


Figure 3.1 Generation system main connection.

In the case of a fault on alternator, it is not enough to open the main circuit breaker or connecting it to the power grid. The high costs associated with large generating and transforming plants accentuate the need for reliable, high speed schemes of protection to:

a. Minimize fault damage and so reduce the possible need to replace the plant (capital outlay).

b. Reduce repair outage time and so minimize the need to run lower merit (less cost-efficient) plant in order to meet the demand (revenue expenditure).

c. Assist in maintaining system stability.

The degree of protection to be provided for the plant is determined by protection engineers in consultation with plant designers and system operation engineers, the objective being to provide a minimum of protection consistent with adequate coverage of all conditions liable to cause damage or effect continuity of supply. Before considering in detail the many forms of protection fitted to generators and transformers, it is desirable to consider the origin and effects of faults and other system disturbance so that the significance of the protection arrangements may be appreciated.

## 3.2 Electrical Circuit of Generator

The electrical circuit of the generator is very simple in spite of the complexity of the overall system. It is to be noted that the generator is never solidly grounded. If it were solidly grounded, the single line-to-ground fault current would be dangerously high apart from the high value of fault current, the resulting asymmetry in the rotating magnetic field inside the generator would cause unacceptably large vibration and result mechanical damage to the rotor .Hence, in order to limit the short circuit, the neutral of the generator is grounded through a resistance. In order to get a practicable value of the grounding resistor connected through a step-down transformer, known as grounding transformer [3].

### 3.2.1 Unit auxiliary transformer

The power plant has a sizeable auxiliary electrical load of its own, of the order of 10% of the power rating of the generator, which is supplied through the Unit Auxiliary Transformer (UAT). It is to be noted that these auxiliaries require power even before the generator can be started, run up to speed and synchronized with the grid. Hence, there is the switching facility to energize the UAT directly from the grid [3]

Figure 3.2 show the alternator UAT and main circuit breaker.

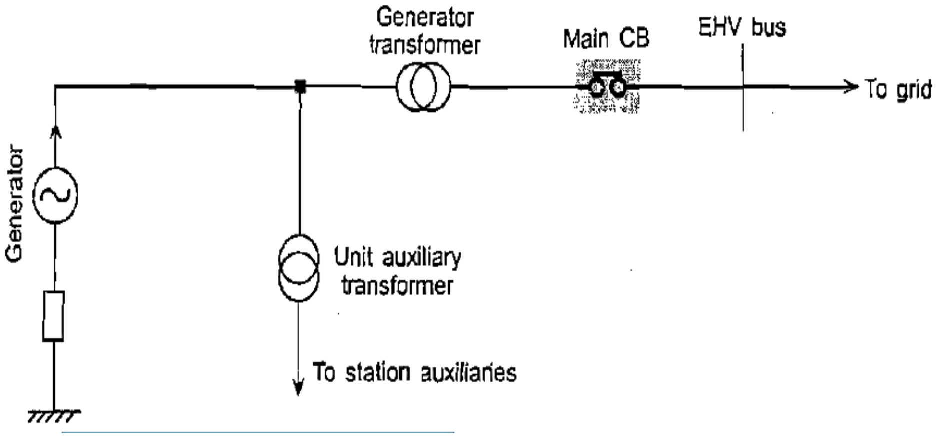


Figure 3.2 Alternator unit auxiliary transformer and main CB.

### 3.2.2 Generator grounding

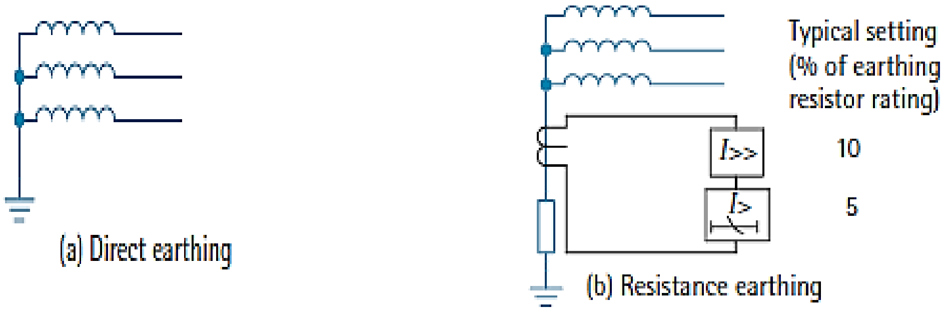
The neutral point of a generator is usually earthed to facilitate protection of the stator winding and associated system. Grounding also prevents damaging transient over-voltages in the event of an arcing earth fault or fero-resonance. For High Voltage (HV) generators, impedance is usually inserted in the stator grounding connection to limit the magnitude of earth fault current. There is a wide variation in the earth fault current chosen, common values being:

1. Rated current.
2. 200A-400A (low impedance grounding).

3. 10A-20A (high impedance grounding).

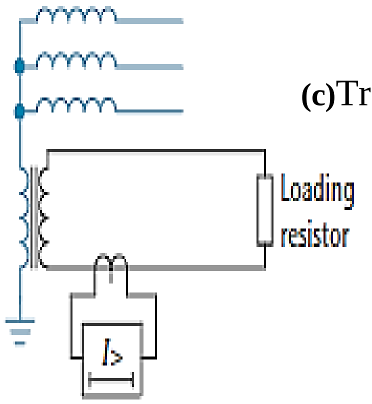
The main methods of impedance-grounding a generator are shown in Figure 3.3. Low values of earth fault current may limit the damage caused from a fault, but they simultaneously make detection of a fault towards the stator winding star point more difficult. Except for special applications, such as marine, Low Voltage LV generators are normally solidly earthed to comply with safety requirements. Where a step-up transformer is applied, the generator and the lower voltage winding of the transformer can be treated as an isolated system that is not influenced by the grounding requirements of the power system [1].The main methods of grounding are :

- Machine stator windings are surrounded by a mass of earthed metal.
- Most probable result of stator winding insulation failure is a phase-earth fault.
- Desirable to earth neutral point of generator to prevent dangerous transient over voltages during arcing earth fault.



(a) Direct earthing

(b) Resistance earthing



**(c)**Transformer grounding

Figure 3.3: Methods of generator grounding

### 3.2.3 Generator excitation

The rotor of the generator houses the field winding. A separate DC generator, which is mounted on the turbo-alternator shaft, feeds the field. The DC system is kept floating with respect to the AC ground, i.e. neither the +ve nor the -ve terminal is grounded. The field interrupter and the arrangement for field suppression is also shown in Figure 3.4[3].

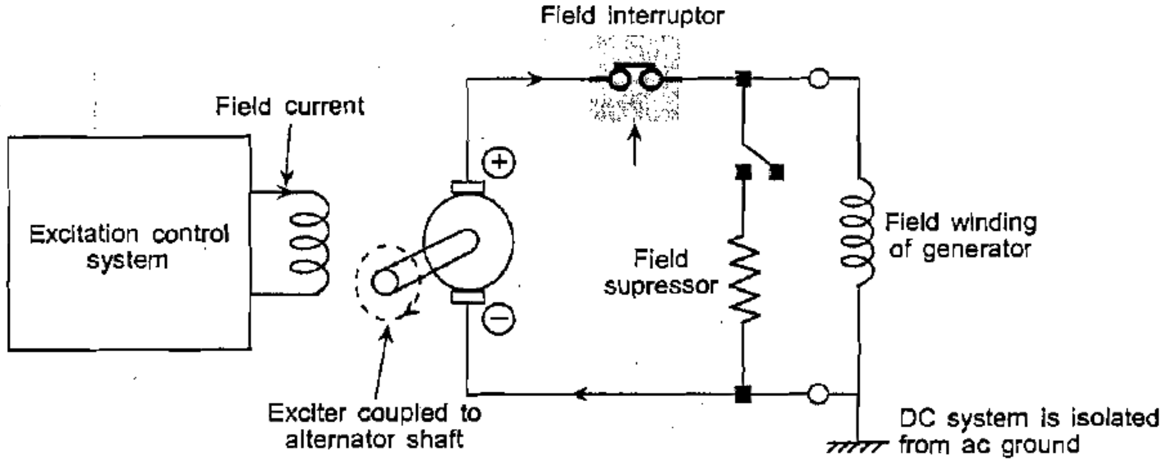


Figure 3.4: Electrical circuit of the exciter of the generator.

## 3.3 Various Faults and Abnormal Operating Conditions

In addition various electrical faults, a generator goes through many abnormal operating conditions, which need to be understood. Figure 3.5 and Figure 4.6 show the hierarchy of the electrical faults and abnormal operating conditions[3].

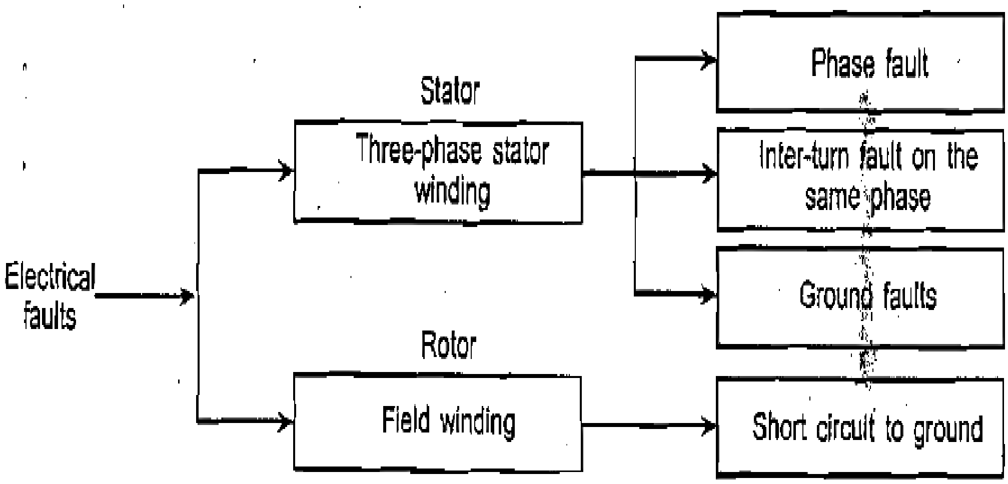


Figure 3.5:Various electrical faults on a turbo-alternator

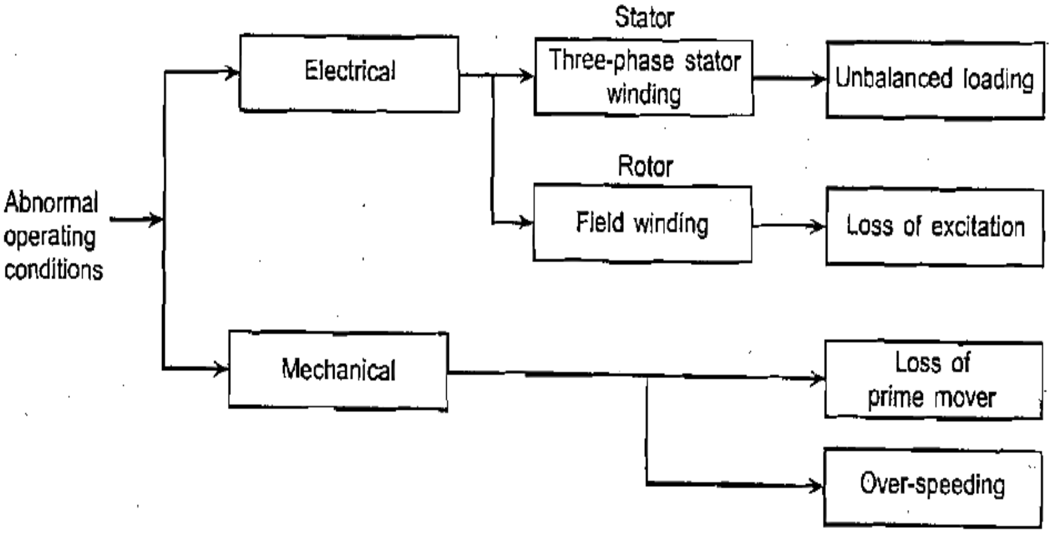


Figure 3.6: Various abnormal operating conditions of a turbo-alternator.

## 3.4 Stator Grounding and Earth Faults

The neutral point of the generator stator winding is normally earthed so that it can be protected, and impedance is generally used to limit earth fault current.

The stator insulation failure can lead to earth fault in the system. Severe arcing to the machine core could burn the iron at the point of fault and weld laminations together. In the worst case, it could be necessary to rebuild the core down to the fault necessitating a major strip-down. Practice, as to the degree of limitation of the earth fault current varies from rated load current to low values such as 5A.Fault caused by failure of stator winding insulation Leads to:

- Burning of machine core
- Welding of laminations

Rebuilding of machine core can be a very expensive process. Generators connected direct to the distribution network are usually earthed through a resistor. However, the larger generator–transformer unit (which can be regarded as isolated from the EHV transmission system) is normally earthed through the primary winding of a voltage transformer, the secondary winding being loaded with a low ohmic value resistor. Its reflected resistance is very high (proportional to the turns ratio squared) and it prevents high transient over-voltages being produced as a result of an arcing earth fault.

When connected directly through impedance, over-current relays of both instantaneous and time-delayed type are used. A setting of 10% of the maximum earth fault current is considered the safest setting, which normally is enough to avoid spurious operations due to the transient surge currents transmitted through the system capacitance. The time delay relay is applied a value of 5%[2].Earth fault protection can be applied by using a transformer and adopting a relay to measure the grounding transformer secondary current or by connecting a voltage-operated relay in parallel with the loading resistor (see Figure 3.7).

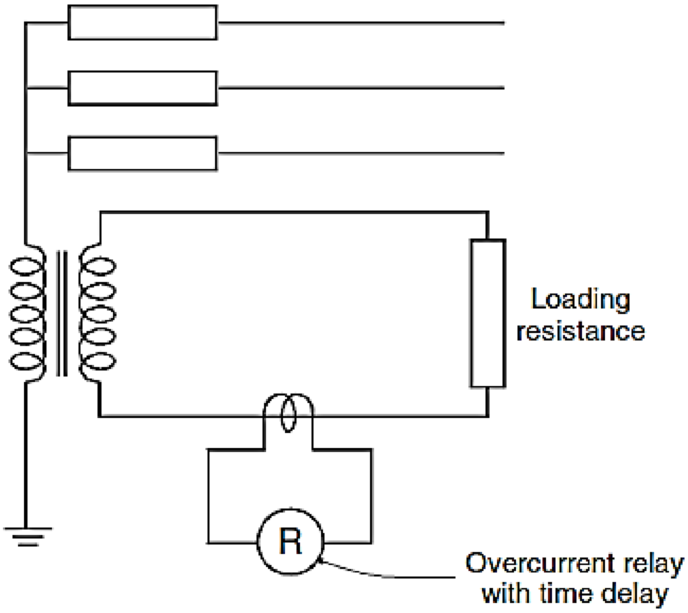


Figure 3.7: Earth fault protection using a relay to measure secondary current

The current operated relay should incorporate third harmonic filter and is normally set for about 5% of the maximum earth fault current. The third harmonic filter is required because of the low current of the grounding system, which may not be much different from the possible third harmonic current under normal conditions. The time delay is essential to avoid trips due to surges (see Figure 3.8).

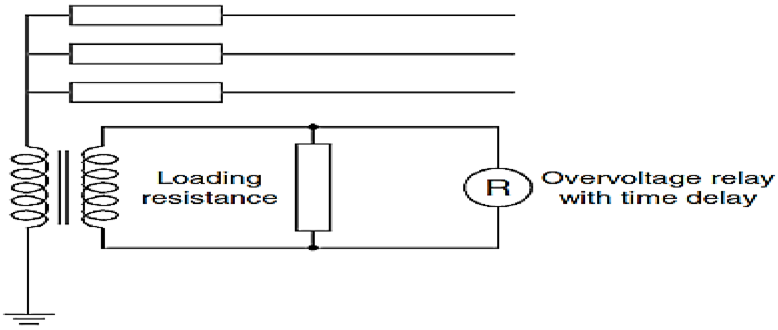


Figure 3.8 Earth fault protection using a relay in parallel with loading resistor

In the voltage-operated type, a standard induction disk type overvoltage relay is used. It is also to be noted that the relay is connected across the secondary winding of the transformer and the relay shall be suitably rated for the higher continuous operating voltage. Further, the relay is to be insensitive for third harmonic current.

Phase-to-phase faults clear of earth are less common. They may occur on the end coils or on adjacent conductors in the same slot. In the latter case, the fault would involve earth in a very short time [2].

## 3.5 Rotor faults

The rotor has a DC supply fed onto its winding which sets up a standing flux. When this flux is rotated by the prime mover, it cuts the stator winding to induce current and voltage therein. This DC supply from the exciter need not be earthed. If an earth fault occurs, no fault current will flow and the machine can continue to run indefinitely, however, one would be unaware of this condition. Danger then arises if a second earth fault occurs at another point in the winding, thereby shorting out portion of the winding. This causes the field current to increase and be diverted, burning out conductors.

In addition, the fluxes become distorted resulting in unbalanced mechanical forces on the rotor causing violent vibrations, which may damage the bearings and even displace the rotor by an amount, which would cause it to foul the stator. It is therefore important that rotor earth fault protection be installed. This can be done in a variety of ways[2].

### 3.5.1 Rotor earth fault protection methods

#### (a) potentiometer method

The field winding is connected with a resistance having center tap. The tap point is connected to the earth through a sensitive relay R. An earth fault in the field winding produces a voltage across the relay. The maximum voltage occurs for faults at end of the windings. However, there are chances that the faults at the center of the winding may get undetected. Hence, one lower tap is provided in the resistance. Though normally, the center tap is connected, a pushbutton or a bypass switch is used to check for the faults at the center of

Winding. A proper operating procedure shall be established to ensure that this changeover is done at least once in a day (see Figure 3.9)[2].

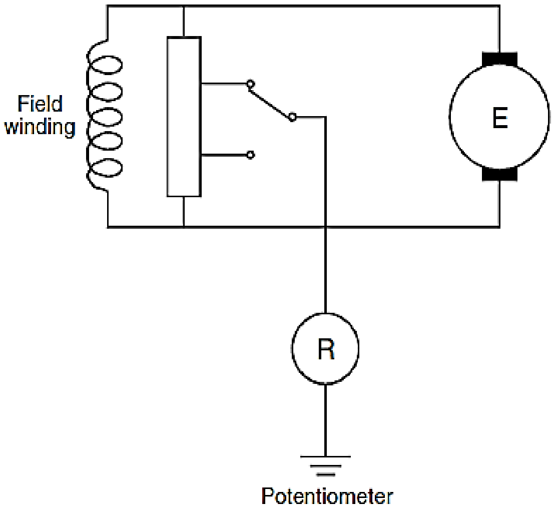


Figure 3.9 Potentiometer

## (b) AC injection method

This method requires an auxiliary supply, which is injected to the field circuit through a coupling capacitance. The capacitor prevents the chances of higher DC current passing through the transformer. An earth fault at any part of the winding gives rise to the field current, which is detected by the sensitive relay. Care should be taken to ensure that the bearings are insulated, since there is a constant current flowing to the earth through the capacitance(see Figure 3.10)[2].

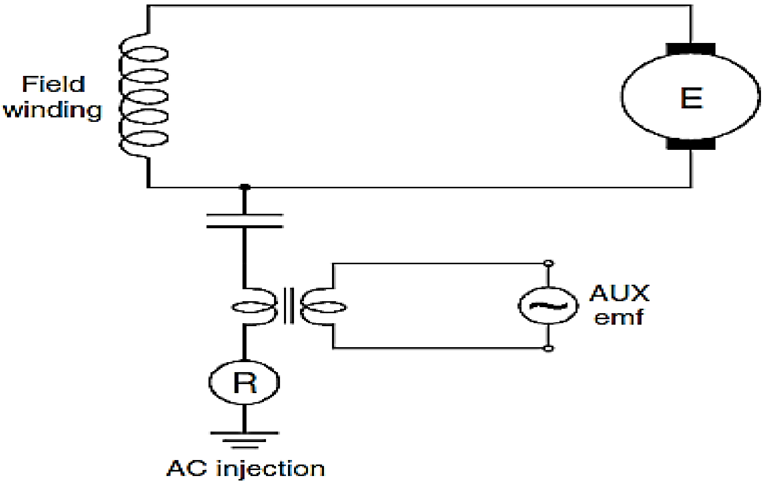


Figure 3.10 AC injection

### (c) DC injection method

This method avoids the capacitance currents by rectifying the injection voltage adopted in the previous method. The auxiliary voltage is used to bias the field voltage to be negative with respect to the earth. An earth fault causes the fault current to flow through the DC power unit causing the sensitive relay to operate under fault conditions (see Figure 3.11) [2].

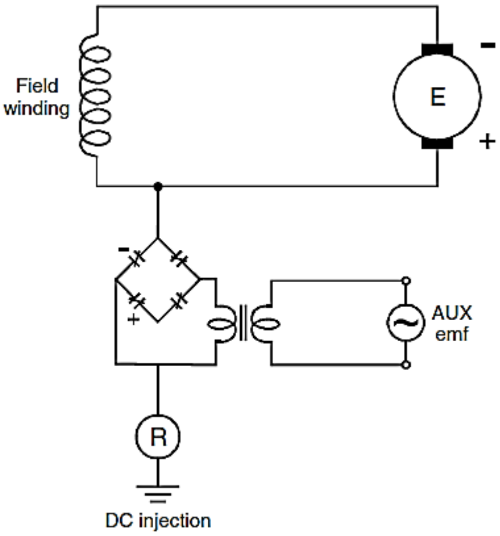


Figure 3.11 DC injection

### 3.5.2 Rotor shorted turn Protection

Shorted section of field winding will result in an unsymmetrical rotor flux pattern and in potentially damaging rotor vibration. Detection of such an electrical fault is possible using a probe consisting of a coil placed in the air gap. The flux pattern of the positive and negative poles is measured and any significant difference in flux pattern between the poles is indicative of a shorted turn or turns.

Automated waveform comparison techniques can be used to provide a protection scheme, or the waveform can be inspected visually at regular intervals. An immediate shutdown is not normally required unless the effects of the fault are severe. The fault can be kept under observation until a suitable shutdown for repair can be arranged. Repair will take some time, since it means unthreading the rotor and dismantling the winding. Since short-circuited turns on the rotor may cause damaging vibration and the detection of field faults for all degrees of abnormality is difficult, the provision of a vibration a detection scheme is desirable – this forms part of the mechanical protection of the generator [1].

## 3.6 Abnormal Operating Conditions

A generator cannot be considered in isolation because of a very large number of other equipment connected to it. Even though there is no electrical fault in the generator, if one of its associated equipment develops a fault, then it has serious implications for the generator. Every auxiliary equipment connected to the generator is a likely source of trouble. There are a large number of possible faults, as well as combinations of faults, on these equipment’s, that threaten the operation of the generator.

Instances where there is no direct electrical fault in the generator but one or more of its associated equipment develop a fault or an abnormality, may lead to an abnormal operating condition, which may or may not be serious. However, all abnormal operating conditions need to be detected as quickly and

As sensitively as possible so that the corrective action can be taken and a possible shutdown averted or anticipated. In the following sections, we consider some prominent abnormal operating conditions that need to be carefully considered while providing protection to the generator [3]

### 3.6.1UnbalancedLoading

A three-phase balanced load produces a reaction field that, to a first approximation, is constant and rotates synchronously with the rotor field system. Any unbalanced condition can be resolved into positive, negative and zero sequence components. The positive sequence component is similar to the normal balanced load. The zero sequence component produces no main armature reaction. If there is an unbalanced loading of the generator then the stator currents have a negative sequence component. The stator field due to these negative sequence currents rotates at synchronous speed but in a direction opposite to the direction of the field structure on the rotor.

Thus, if the stator carries unbalanced currents, then it is the rotor, which is overheated. How long the generator can be allowed to run under unbalanced loading, depends upon the thermal withstand capacity of the machine, which in turn depends upon the type of cooling system adopted. The rate of heat generation is proportional to $I_2^2 R$ while the heat energy is proportional to $I_2^2 Rt$, where t is the time and I, is negative sequence current. Since the capacity of a particular machine, to safely dissipate energy, is limited to a certain value k, we can write

$$I_2^2 Rt=k \qquad (3.1)$$

Assuming R to be a constant, and **K** = k/R, we get the thermal characteristics of the machine as

$$I_2^2\, t=\mathbf{K} \qquad (3.2)$$

In other words, the time t for which the offending current I can be allowed to flow should be less than or equal to $\mathbf{K}/I_2^2$

Thus, the current-time characteristic can be written as

$$T \quad \mathbf{K}/I_2^2 \qquad (3.4)$$

Where K is a constant proportion to the thermal capacity of the generator rotor [3].

### 3.6.2 Over voltages Protection

Over voltages on a generator may occur due to transient surges on the network, or prolonged power frequency over voltages may arise from a variety of conditions. Surge arrestors may be required to protect against transient over voltages, but relay protection may be used to protect against power frequency over voltages. A sustained overvoltage condition should not occur for a machine with a healthy voltage regulator, but it may be caused by the following contingencies:

a. Defective operation of the automatic voltage regulator when the machine is in isolated operation.

b. Operation under manual control with the voltage regulator out of service. A sudden variation of the load, in particular the reactive power component, will give rise to a substantial change in voltage because of the large voltage regulation inherent in a typical alternator.

c. Sudden loss of load (due to tripping of outgoing feeders, leaving the set isolated or feeding a very small load) may cause a sudden rise in terminal voltage due to the trapped field flux and/or over speed.

Sudden loss of load should only cause a transient overvoltage while the voltage regulator and governor act to correct the situation. A maladjusted voltage regulator may trip to manual, maintaining excitation at the value prior to load loss while the generator supplies little or no load. The terminal voltage will increase substantially, and in severe cases it would be limited only by the saturation characteristic of the generator. A rise in speed simply compounds the problem. If load that is sensitive to over voltages remains connected, the

Consequences in term of equipment damage and lost revenue can be severe. Prolonged over voltages may also occur on isolated networks, or ones with weak interconnections, due to the fault conditions listed earlier.

For these reasons, it is prudent to provide power frequency over voltage protection, in the form of a time delayed element, either IDMT or definite time. The time delay should be long enough to prevent operation during normal regulator action, and therefore should take account of the type of Automatic Voltage Regulator (AVR) fitted and its transient response. Sometimes a high-set element is provided as well, with a very short definite-time delay or instantaneous setting to provide a rapid trip in extreme circumstances. The usefulness of this is questionable for generators fitted with an excitation system other than a static type, because the excitation will decay in accordance with the open-circuit time constant of the field winding. This decay can last several seconds. The relay element is arranged to trip both the main circuit breaker (if not already open) and the excitation; tripping the main circuit breaker alone is not sufficient [1].

### 3.6.3Undervoltage Protection

Under voltage protection is rarely fitted to generators. It is sometimes used as an interlock element for another protection function or scheme, such as field failure protection or inadvertent energizing protection, where the abnormality to be detected leads directly or indirectly to an under voltage condition. A transmission system under voltage condition may arise when there is insufficient reactive power generation to maintain the system voltage profile and the condition must be addressed to avoid the possible phenomenon of system voltage collapse.

However, it should be addressed by the deployment of ’system protection’ schemes. The generation should not be tripped. The greatest case for under voltage protection being required would be for a generator supplying

An isolated power system or to meet Utility demands for connection of embedded generation. In the case of generators feeding an isolated system, under voltage may occur for several reasons, typically overloading or failure of the AVR. In some cases, the performance of generator auxiliary plant fed via a unit transformer from the generator terminals could be adversely affected by prolonged under voltage. Where under voltage protection is required, it should comprise an under voltage element and an associated time delay. Settings must be chosen to avoid mal-operation during the inevitable voltage dips during power system fault clearance or associated with motor starting. Transient reductions in voltage down to 80% or less may be encountered during motor starting [1].

### 3.6.4 Losses of excitation

There are several possible causes due to which field excitation may be lost, namely:

1- Loss of field to main exciter
2- Accidental tripping of the field breaker
3- Short circuit in the field winding
4- Poor brush contact in the exciter
5- Field circuit breaker latch failure
6- Loss of ac supply to excitation system

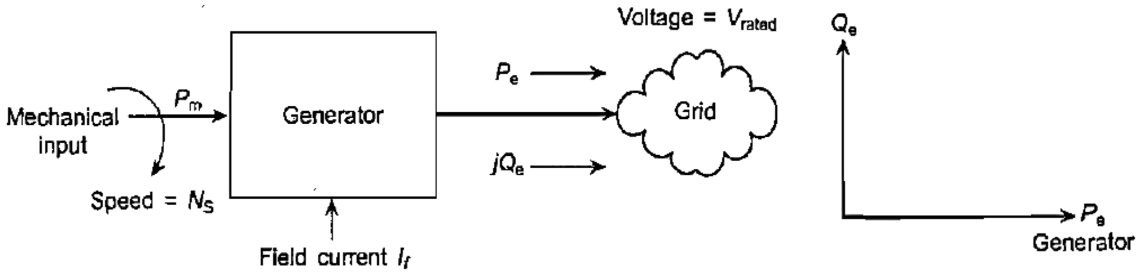
**Effects**

- ❖ Single generator:
  - Loses output volts and therefore load.
- ❖ Parallel generators:
  - Operate as induction generator (> synch speed).
  - Flux provided by reactive stator current drawn from system-leading PF.

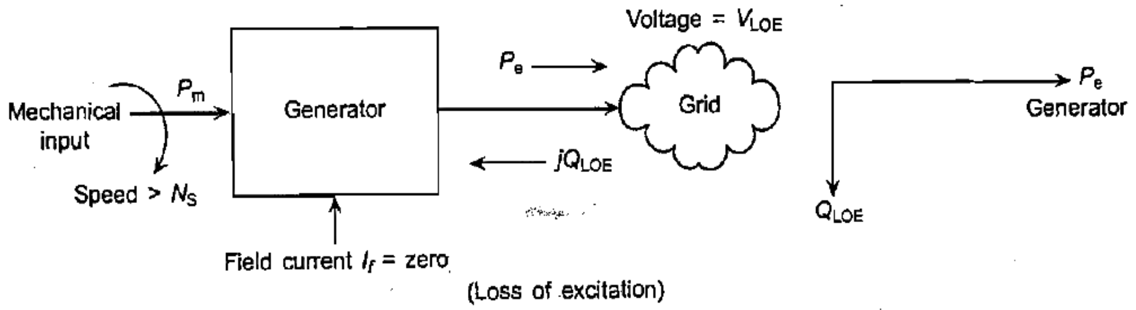
- Slip frequency current induced in rotor - abnormal heating.

The generator delivers both real as well as reactive power to the grid. The real power comes from the generator while the reactive power is due to the field excitation. Consider a generator delivering the complex power, S = P + j Q to the grid. Corresponding to real power $P_e$, there is the shaft mechanical power input Pm, and corresponding to reactive power $Q_e$, there is the field current If as shown in Figure 4.12 (a)and(b).

Consider that the field excitation is lost while the mechanical input remains intact. Since the generator is already synchronized with the grid, it would attempt to remain synchronized by running as an induction generator. As an induction generator, the machine speeds up slightly above the synchronous speed and draws its excitation from the grid. This is shown in Figure 3.12(b). Operation as an induction generator necessitates the flow of slip frequency current in the rotor, the current flowing in the damper winding and also in the slot wedges and the surface of the solid rotor body.



(a) Before loss of excitation



(b) After loss of excitation

Figure 3.12 Loss of excitation.

There are two possibilities. Either the grid is able to meet this reactive power demand fully or meet it partially. If the grid is able to fully satisfy this demand for reactive power, the machine continues to deliver active power of Pe, MW but draws reactive power of QLOE MVA and there is no risk of instability. However, the generator is not designed as an induction machine, so abnormal heating of the rotor and overloading of the stator winding will take place.

If the grid were able to meet the reactive power demand only partially then this would be reflected by a fall of the generator terminal voltage. The generator would be under excited. There are certain limits on the degree to which a generator can be operated within the under-excited mode. Therefore, the operation in case of loss of excitation must be quickly detected and checked to avert any shutdown of the generator. The simplest method by which loss of excitation can be detected is to monitor the field current of the generator. If the field current falls below a threshold, a loss of field signal can be raised.

A complicating factor in this protection is the slip frequency current induced in the event of loss of excitation and running. The quantity which changes most when a generator loses field excitation is the impedance measured at the stator terminals. On loss of excitation, the terminal voltage begins to decrease and the current begins to increase, resulting in a decrease of impedance and also a change of power factor as an induction generator [3].

### 3.6.5 Under / Over frequency

The governor fitted to the prime mover normally provides protection against over frequency. Under frequency may occur as a result of overload of generators operating on an isolated system, or a serious fault on the power system that results in a deficit of generation compared to load. This may occur if a grid system suffers a major fault on transmission lines linking two parts of

The system, and the system then splits into two. It is likely that one part will have an excess of generation over load, and the other will have a corresponding deficit.

Frequency will fall fairly rapidly in the latter part, and the normal response is load shedding, either by load shedding relays or operator action. However, prime movers may have to be protected against excessively low frequency by tripping of the generators concerned. With some prime movers, operation in narrow frequency bands that lie close to normal running speed (either above or below) may only be permitted for short periods, together with a cumulative lifetime duration of operation in such frequency bands. This typically occurs due to the presence of rotor torsional frequencies in such frequency bands. In such cases, monitoring of the period of time spent in these frequency bands is required. A special relay is fitted in such cases, arranged to provide alarm and trip facilities if either an individual or cumulative period exceeds a set time [1].

### 3.6.6Overfluxing

Over fluxing occurs when the ratio of voltage to frequency is too high. The iron saturates owing to the high flux density and results in stray flux occurring in components not designed to carry it. Overheating can then occur, resulting in damage. The problem affects both direct-and indirectly-connected generators. Either excessive voltage, or low frequency, or a combination of both can result in over fluxing, a voltage to frequency ratio in excess of transiently, which is not a problem for the generator. For example, a generator can be subjected to a transiently high power frequency voltage, at nominal frequency, immediately after full load rejection. Since the condition would not be sustained, it only presents a problem for the stability of the transformer differential protection schemes applied at the power station

Sustained over fluxing can arise during run up, if excitation is applied too early with the AVR in service, or if the generator is run down, with the excitation still applied. Other over fluxing instances have occurred from loss of the AVR voltage feedback signal, due to a reference VT problem. Such sustained conditions must be detected by a dedicated over fluxing protection function that will raise an alarm and possibly force an immediate reduction in excitation. Most AVRs' have an over fluxing protection facility included. This may only be operative when the generator is on open circuit, and hence fail to detect over fluxing conditions due to abnormally low system frequency. However, this facility is not engineered to protection relay standards, and should not be solely relied upon to provide over fluxing protection. A separate relay element is therefore desirable and provided in most modern relays.It is usual to provide a definite time-delayed alarm setting and an instantaneous or inverse time-delayed trip setting, to match the withstand characteristics of the protected generator and transformer. It is very important that the VT reference for over fluxing protection is not the same as that used for the AVR [1].

## 3.7 Back up Protection of Generator

Back up protection should always be given in highly rated machine like synchronous generator or alternator. If faults occurred had not been cleared by the appropriate protection scheme then back up protection relays should be operated to clear the fault. Over current relays are generally used for this purpose. Because the synchronous reactance of modern machine is often greater than hundred percent, the sustained fault current fed from the machine into an external fault is invariably below the normal full load current. The normal IDMTL relays would not prove satisfactory because they are current settings must be close to the full load and their time sitting short if operation is to be obtained, resulting in probable lack of discrimination with other over current relays in the system. Father, the over current relay would most

Probably operate for loss of field on the machine, disconnecting it prematurely. To overcome this problem is it has become customary to apply an over current relay in combination with under voltage relay, the letter relay controlling the fault settings of the former.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Introduction

Generator protection system was simulated using power system software called ETAP this program is used to apply on nuclear power plant generators protection and simulated the faults affect the power generating.

## 4.2 ETAP Software

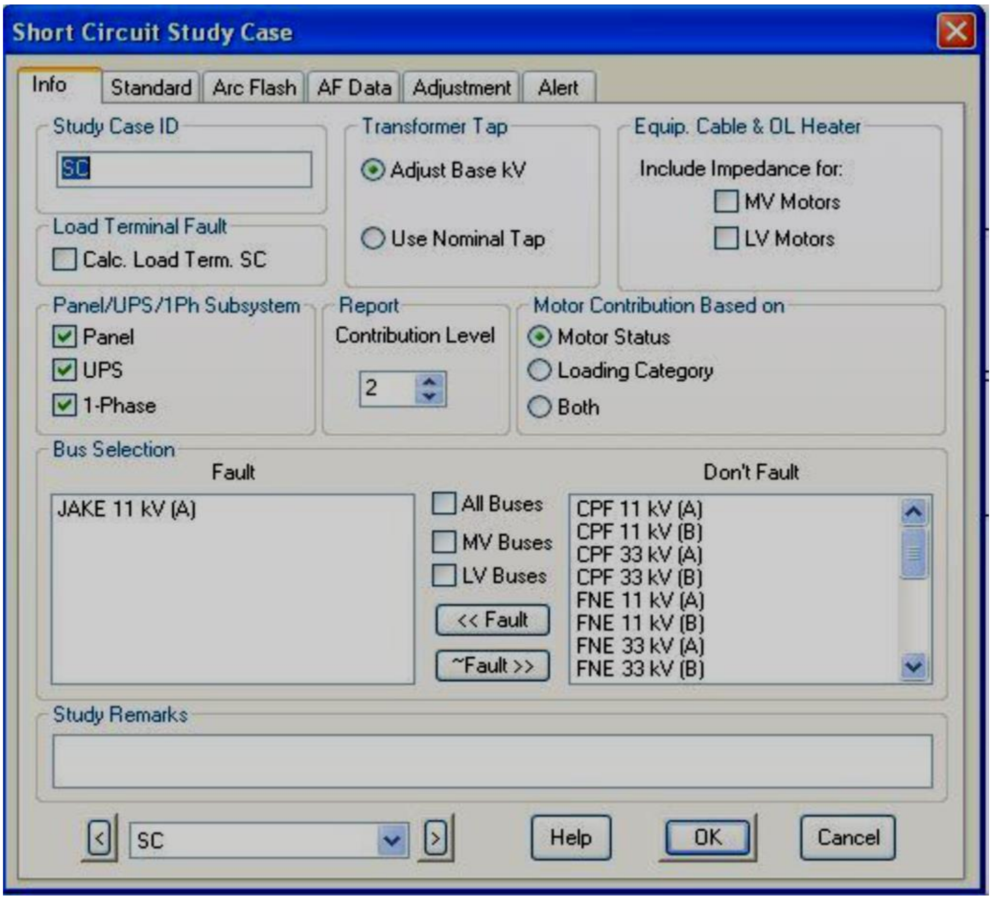
In a power system, one of the most critical aspects is the power system protection. Power system protection involves using protective devices to ensure that in the case of a short circuit or any electrical fault, system components are not damaged and as little of the system is such down as possible. In order to provide an adequate protection for the circuit, these fault conditions must be simulated and analyzed. This can be achieved using an appropriate software package such as ETAP software. ETAP is comprehensive software that allows the user to design and simulate power systems as well as automatic generation, transmission and distribution schemes.

ETAP generates and simulates software solution for electrical power systems. ETAP is the most comprehensive electrical engineering software solution for the design, simulation, operation, and automation of generation, transmission, distribution, and industrial power systems. ETAP is developed under an established quality assurance program and is used worldwide as high impact software. As a fully integrated enterprise solution, ETAP extends to a real-time power management System to monitor, control, automate, simulate, and optimize the operation of power systems.

## 4.3 Short-Circuit Analysis Module of ETAP

Short-circuit analysis module of ETAP provide instruction of how to run ANSI and IEC short- circuit calculations. In addition, there will be a brief look at study case editors and the alert view function. From the mode toolbar, the short circuit mode was selected by clicking on which represent the short-circuit analysis button, editing study case was performed by clicking on This opened the short-circuit study case editor shown on Figure 4.1, allows to change calculation criteria and options, and also to choose a bus or multiple buses to be faulted or to be un-faulted.

Short circuit was run after specifying the faulted and un-faulted buses by clicking on , the customized fault currents were appeared on the One Line View (OLV) buses and the contribution of all elements connected to each faulted bus-bar. Finally the short circuit report was generated after clicking on , the reports manager shown in Figure 4.2 was appeared to create different options of reports.



Study Case ID: SC

Load Terminal Fault: ☐ Calc. Load Term. SC

Transformer Tap: ● Adjust Base kV ○ Use Nominal Tap

Equip. Cable & OL Heater
Include Impedance for:
☐ MV Motors
☐ LV Motors

Panel/UPS/1Ph Subsystem
☑ Panel
☑ UPS
☑ 1-Phase

Report
Contribution Level: 2

Motor Contribution Based on
● Motor Status
○ Loading Category
○ Both

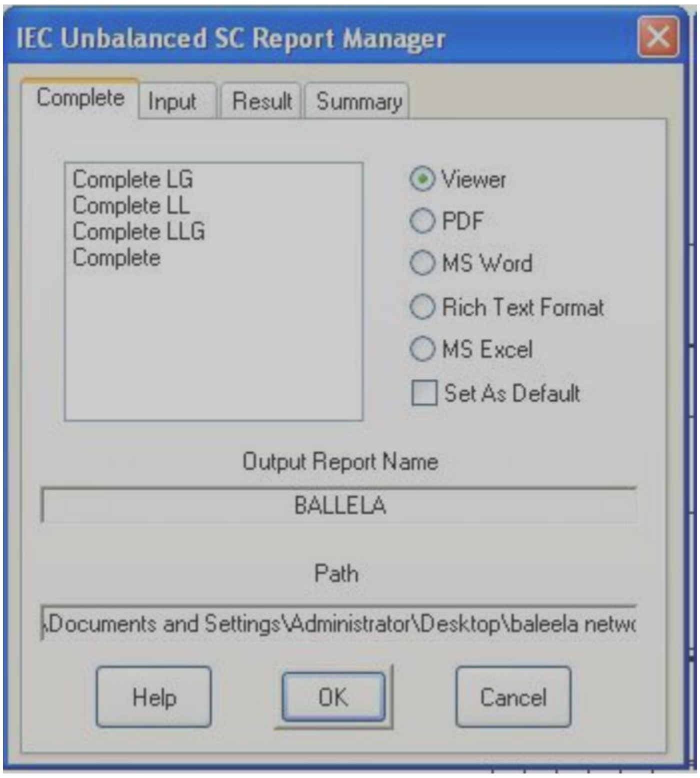
Bus Selection

| Fault | | Don't Fault |
|---|---|---|
| JAKE 11 kV (A) | ☐ All Buses<br>☐ MV Buses<br>☐ LV Buses | CPF 11 kV (A)<br>CPF 11 kV (B)<br>CPF 33 kV (A)<br>CPF 33 kV (B)<br>FNE 11 kV (A)<br>FNE 11 kV (B)<br>FNE 33 kV (A)<br>FNE 33 kV (B) |

Study Remarks

SC

Figure 4.1: Study Case Editor



Complete LG
Complete LL
Complete LLG
Complete

● Viewer
○ PDF
○ MS Word
○ Rich Text Format
○ MS Excel
☐ Set As Default

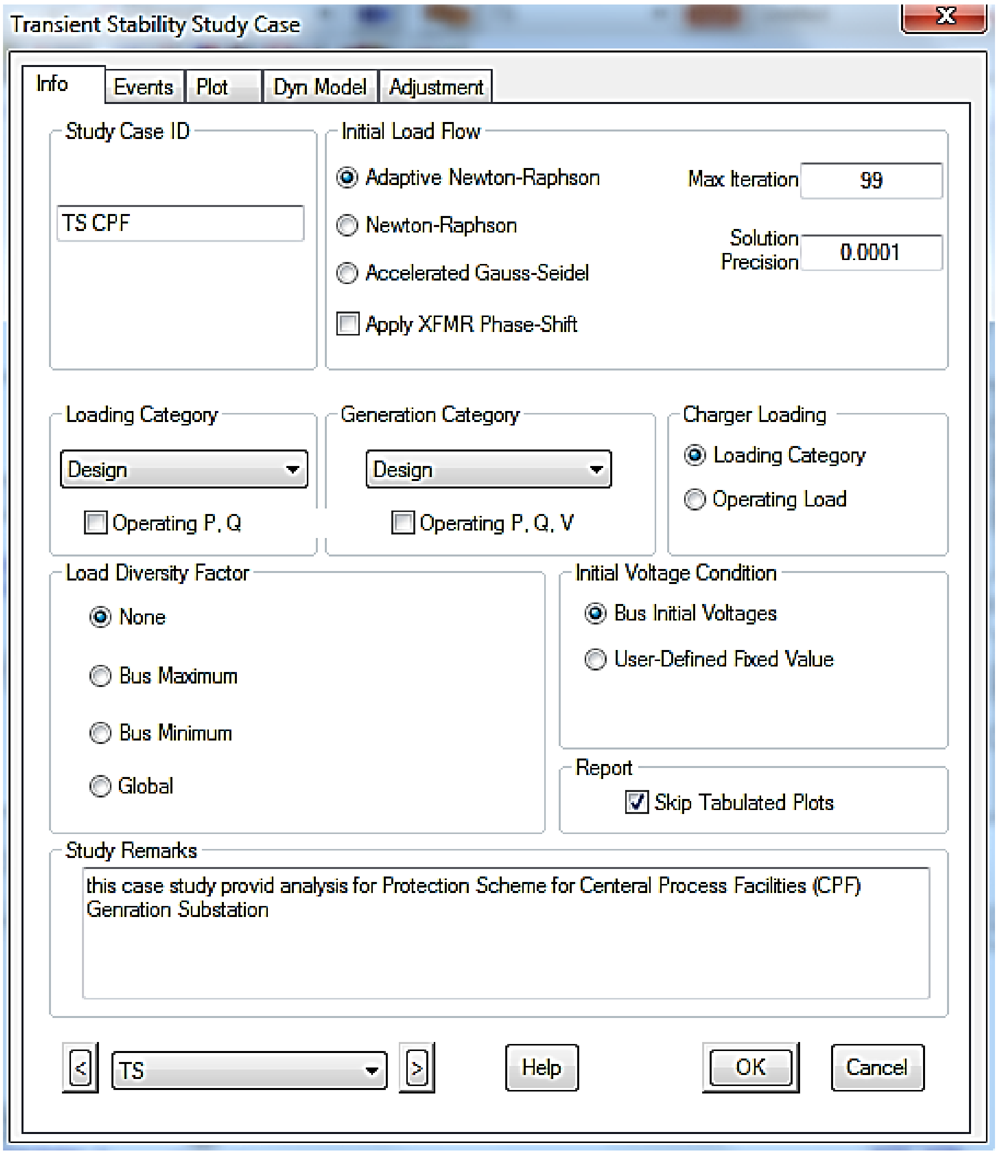
Output Report Name: BALLELA

Path: \Documents and Settings\Administrator\Desktop\baleela netw

Figure 4-2Short Circuit Report Manager

## 4.4 Transient stability analysis

The ETAP program is designed to investigate the system dynamic responses and stability limits of a power system before, during, and after system changes or disturbances. The program models dynamic characteristics of a power system, implements the user-defined events and actions, solves the system network equation and machine differential equations interactively to find out system and machine responses in time domain. You can use these responses can be used to determine the system transient behavior, make stability assessment, set protective device settings, and apply the necessary remedy or enhancement to improve the system stability. Transient stability study case editor is shown in Figure 4.3:



Study Case ID: TS CPF

Initial Load Flow
● Adaptive Newton-Raphson
○ Newton-Raphson
○ Accelerated Gauss-Seidel
☐ Apply XFMR Phase-Shift
Max Iteration: 99
Solution Precision: 0.0001

Loading Category: Design
☐ Operating P, Q

Generation Category: Design
☐ Operating P, Q, V

Charger Loading
● Loading Category
○ Operating Load

Load Diversity Factor
● None
○ Bus Maximum
○ Bus Minimum
○ Global

Initial Voltage Condition
● Bus Initial Voltages
○ User-Defined Fixed Value

Report
☑ Skip Tabulated Plots

Study Remarks: this case study provid analysis for Protection Scheme for Centeral Process Facilities (CPF) Genration Substation

TS

Figure 4.3: Transient stability case study editor

## 4.5 Sudan Nuclear Power Plant ETAP Circuit

The following diagram (figure 4.4) illustrates a single line diagram of the circuit used to simulate the generator protection system. This circuit is simulated using ETAP. The circuit consists of a lot of abbreviations defined in ETAP such as.

- CBs: Circuit breakers.
- T: Transformer.
- L1, L2, L3, L4, L5 and L6 which are basically lump load.
- Rolls-Royce generators (D, E, F, G) and Wartsila generator (1 and 2):
- OV: Voltage relay.
- Freq.: Frequency relay.
- Relay: Over-current relay.

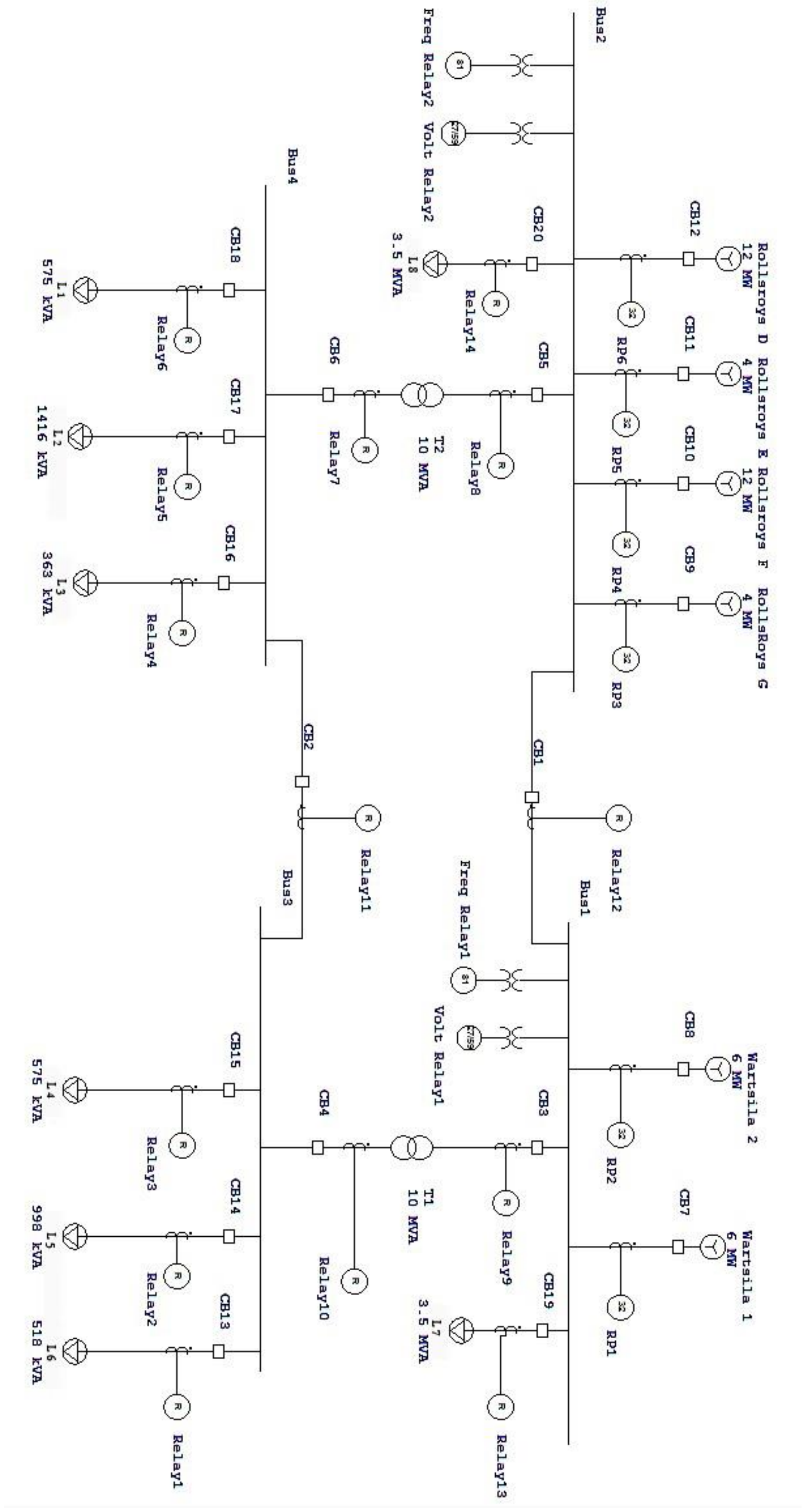
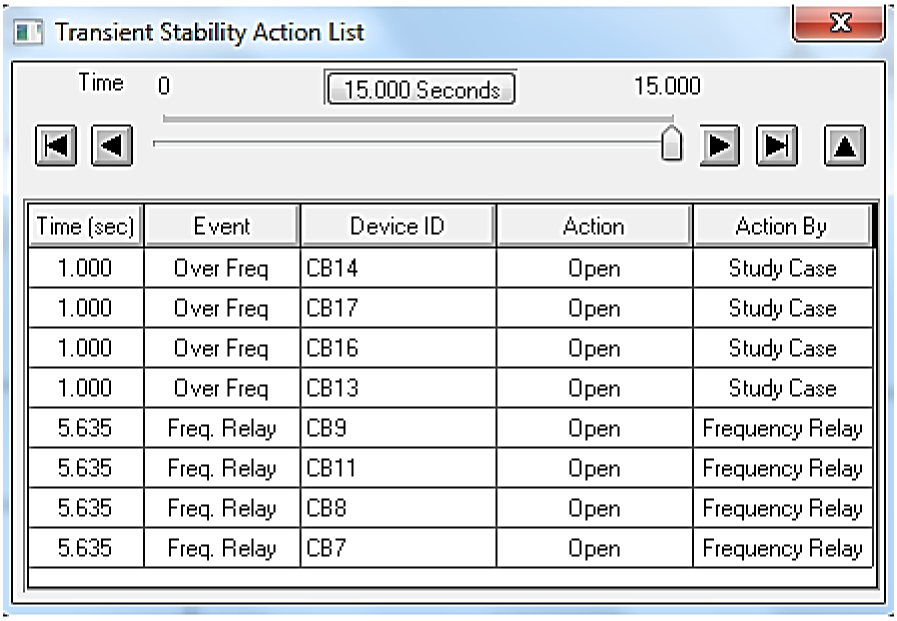


Figure 4.4 Single line diagram SNP CPF generation power plant

### 4.6.1 Over frequency test

To simulate over frequency condition ETAP Transient Stability Analysis is used, and by making a high load rejection event at the 1st second therefore the over frequency condition is met. Figure 4.5 below shows over-frequency condition event when the network is connected. Figure 4.6 shows over frequency condition frequency over time graph at Bus1 when the network is connected.



| Time (sec) | Event | Device ID | Action | Action By |
|---|---|---|---|---|
| 1.000 | Over Freq | CB14 | Open | Study Case |
| 1.000 | Over Freq | CB17 | Open | Study Case |
| 1.000 | Over Freq | CB16 | Open | Study Case |
| 1.000 | Over Freq | CB13 | Open | Study Case |
| 5.635 | Freq. Relay | CB9 | Open | Frequency Relay |
| 5.635 | Freq. Relay | CB11 | Open | Frequency Relay |
| 5.635 | Freq. Relay | CB8 | Open | Frequency Relay |
| 5.635 | Freq. Relay | CB7 | Open | Frequency Relay |

Figure 4.5: Over frequency condition event when feeders CB opened and over frequency protection activated

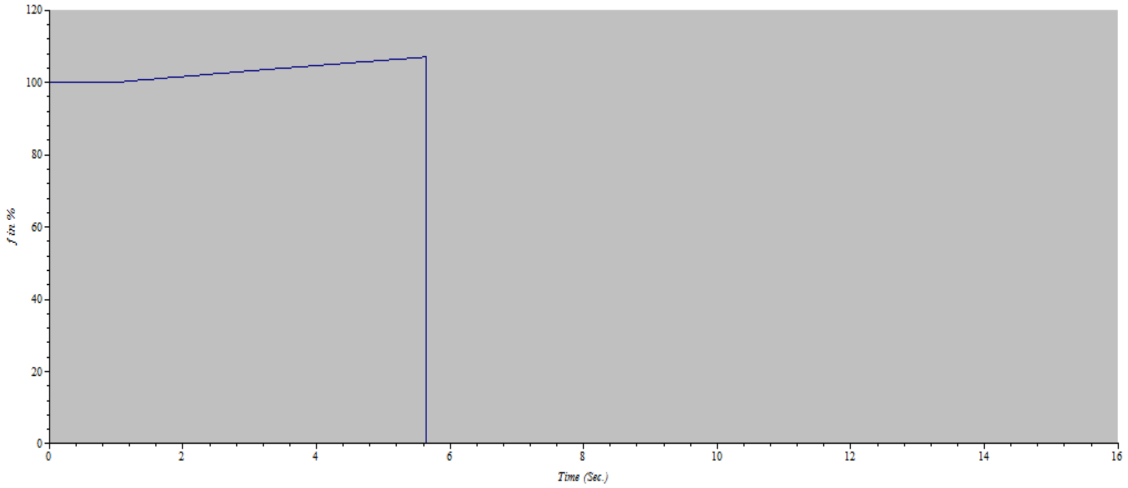


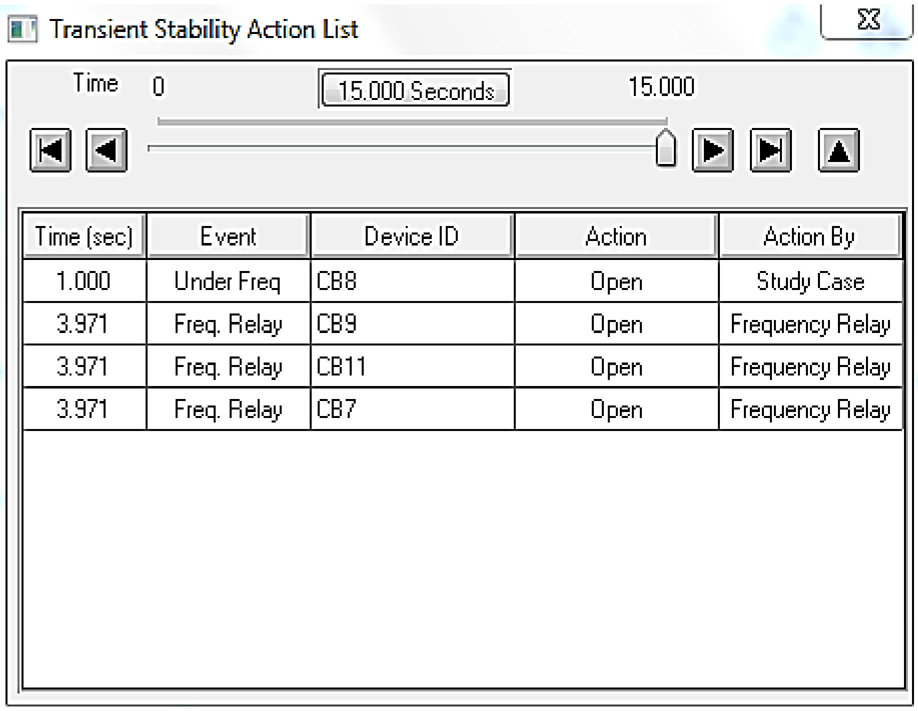
Figure 4.6: Over frequency condition frequency/time graph at Bus2

As an observation from above figure, frequency relay is used to trip the generator after when the frequency exceeds 106% of the rated frequency.

### 4.6.2. Under frequency test

To simulate under frequency condition ETAP transient stability analysis is used, and by trip wartsila 2 generator CB at the 1st second therefore the under frequency condition is met.

Figure 4.7 below shows under frequency condition event and frequency relay response. Figure 4.8shows under frequency condition frequency over time graph at Bus2.



| Time (sec) | Event | Device ID | Action | Action By |
|---|---|---|---|---|
| 1.000 | Under Freq | CB8 | Open | Study Case |
| 3.971 | Freq. Relay | CB9 | Open | Frequency Relay |
| 3.971 | Freq. Relay | CB11 | Open | Frequency Relay |
| 3.971 | Freq. Relay | CB7 | Open | Frequency Relay |

Figure 4.7 Under Frequency Condition event and Frequency Relay Response

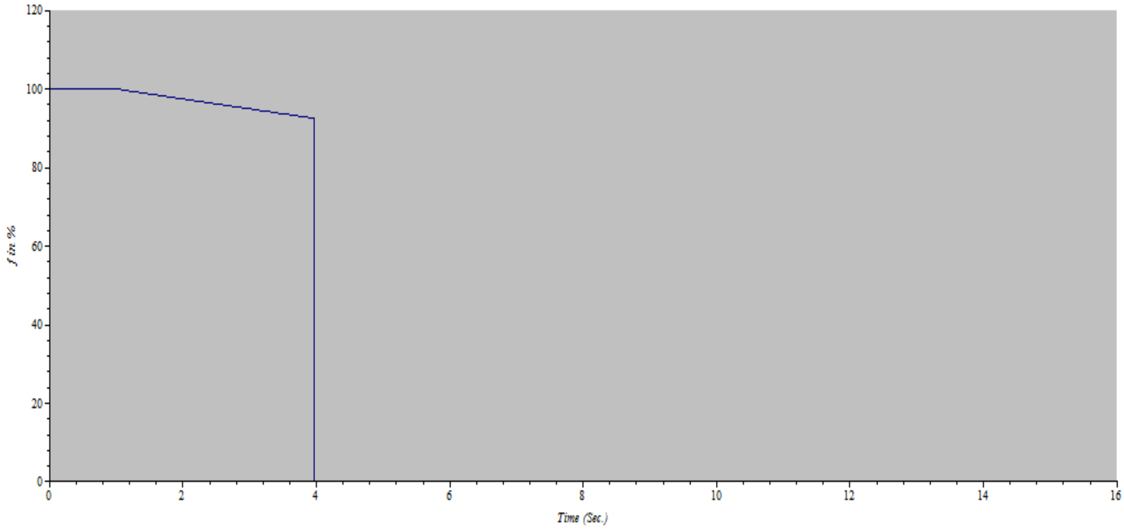
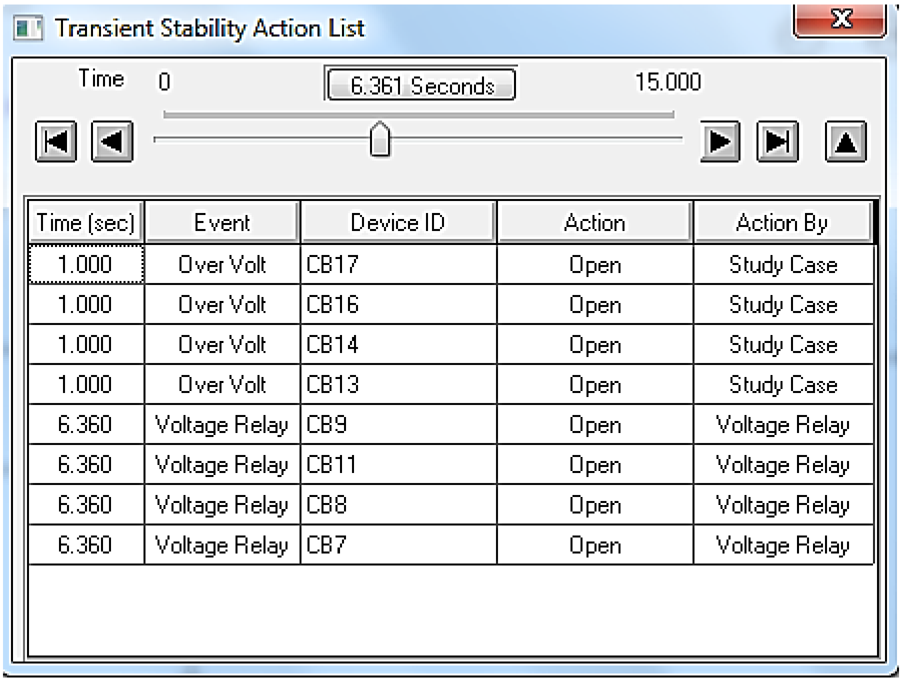


Figure 4.8: Under frequency condition frequency/time at Bus1 when the network is connected

Notice that the frequency relay trips the generator after 0.5sec when the frequency is less than the rated frequency by 94%.

### 4.6.3 Over voltage test

To simulate over-voltage condition ETAP transient stability analysis is used by, and by making a high load rejection event at the 1st second therefore the over voltage condition is met .Figure 4.9 below shows over voltage condition event when load was rejected and over voltage relay response to protect generators. Figure 4.10 shows over voltage condition voltage over time graph at Bus2.



| Time (sec) | Event | Device ID | Action | Action By |
|---|---|---|---|---|
| 1.000 | Over Volt | CB17 | Open | Study Case |
| 1.000 | Over Volt | CB16 | Open | Study Case |
| 1.000 | Over Volt | CB14 | Open | Study Case |
| 1.000 | Over Volt | CB13 | Open | Study Case |
| 6.360 | Voltage Relay | CB9 | Open | Voltage Relay |
| 6.360 | Voltage Relay | CB11 | Open | Voltage Relay |
| 6.360 | Voltage Relay | CB8 | Open | Voltage Relay |
| 6.360 | Voltage Relay | CB7 | Open | Voltage Relay |

Figure 4.9 over voltage condition event and over voltage relay response

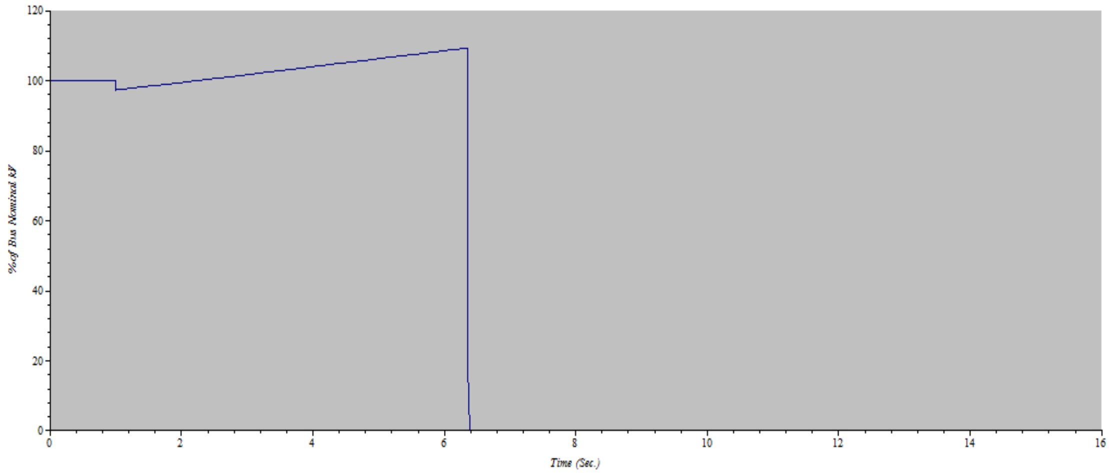


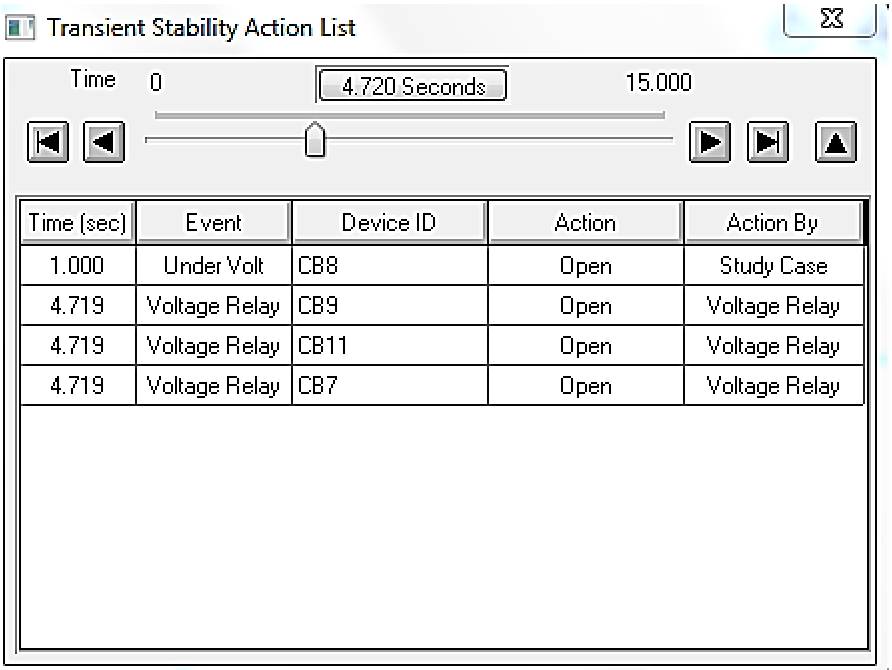
Figure 4.10Over voltage condition voltage/time graph at Bus2

Observe that due to load rejection overvoltage relay trips the generator to protect it.

### 4.6.4 Under voltage test

To simulate under voltage condition ETAP transient stability analysis is used and by trip wartsila 2 generator CB at the 1st second therefore the under frequency condition is met.

Figure 4.11 below shows over voltage condition event when load was rejected and over voltage relay response to protect generators. Figure 4.12 shows over voltage condition voltage over time graph at Bus2.



| Time (sec) | Event | Device ID | Action | Action By |
|---|---|---|---|---|
| 1.000 | Under Volt | CB8 | Open | Study Case |
| 4.719 | Voltage Relay | CB9 | Open | Voltage Relay |
| 4.719 | Voltage Relay | CB11 | Open | Voltage Relay |
| 4.719 | Voltage Relay | CB7 | Open | Voltage Relay |

Figure 4.11 Under voltage condition event and over voltage relay response

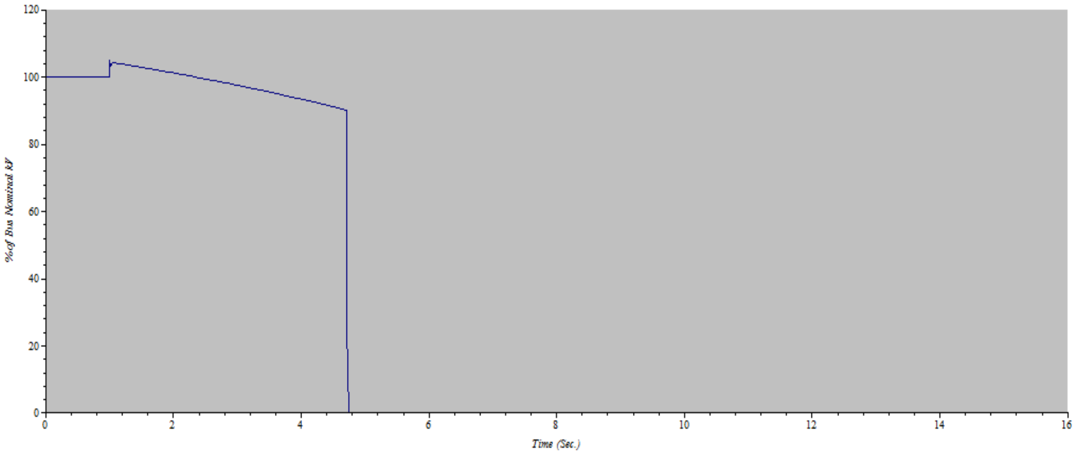
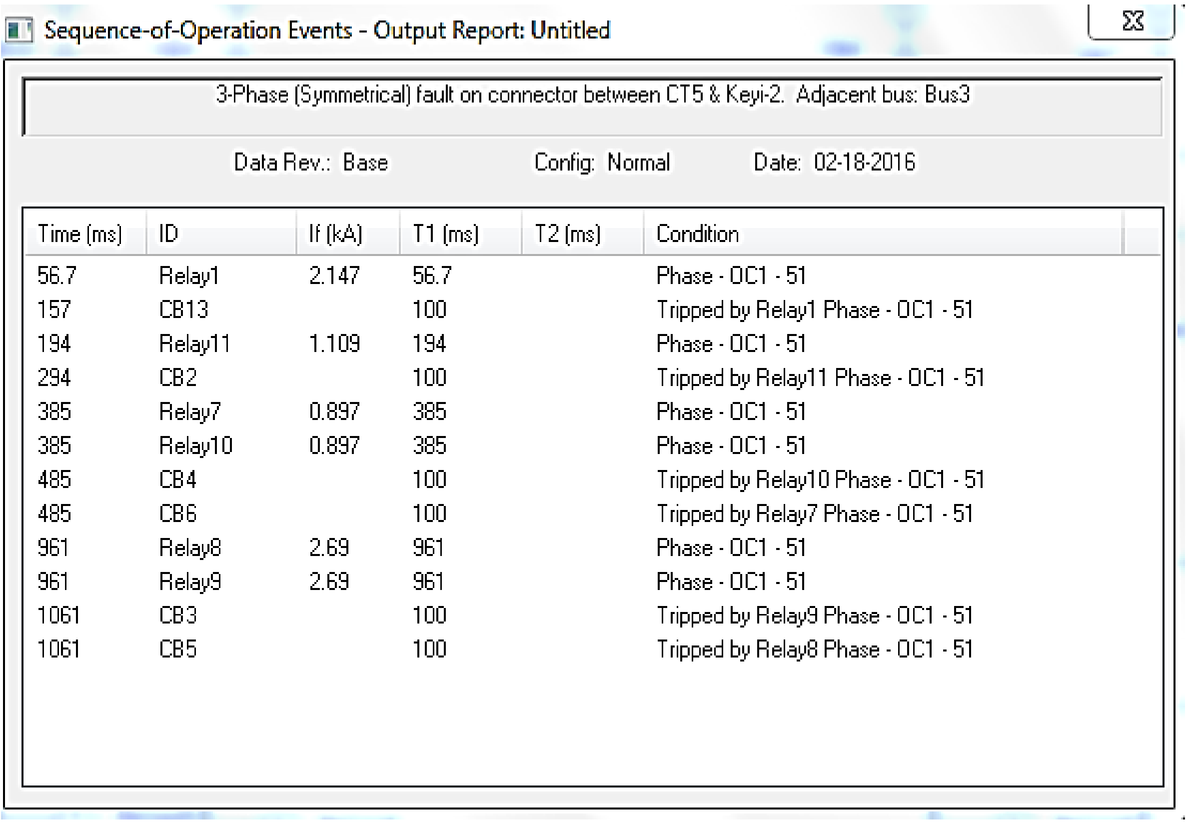


Figure 4.12 under voltage condition voltage/time graph at Bus2

Observe that due to generator rejection under-voltage relay trips the others generator to protect it.

### 4.6.5 Three phase fault test

ETAP star-protective device coordination mode is used. Three phase faults at outgoing to L6 is initiated to examine the response of substation phase protection. Figure 4.13 show Relay responses to 3phase fault at L6 outgoing feeder.



3-Phase (Symmetrical) fault on connector between CT5 & Keyi-2. Adjacent bus: Bus3

Data Rev.: Base Config: Normal Date: 02-18-2016

| Time (ms) | ID | If (kA) | T1 (ms) | T2 (ms) | Condition |
|---|---|---|---|---|---|
| 56.7 | Relay1 | 2.147 | 56.7 | | Phase - OC1 - 51 |
| 157 | CB13 | | 100 | | Tripped by Relay1 Phase - OC1 - 51 |
| 194 | Relay11 | 1.109 | 194 | | Phase - OC1 - 51 |
| 294 | CB2 | | 100 | | Tripped by Relay11 Phase - OC1 - 51 |
| 385 | Relay7 | 0.897 | 385 | | Phase - OC1 - 51 |
| 385 | Relay10 | 0.897 | 385 | | Phase - OC1 - 51 |
| 485 | CB4 | | 100 | | Tripped by Relay10 Phase - OC1 - 51 |
| 485 | CB6 | | 100 | | Tripped by Relay7 Phase - OC1 - 51 |
| 961 | Relay8 | 2.69 | 961 | | Phase - OC1 - 51 |
| 961 | Relay9 | 2.69 | 961 | | Phase - OC1 - 51 |
| 1061 | CB3 | | 100 | | Tripped by Relay9 Phase - OC1 - 51 |
| 1061 | CB5 | | 100 | | Tripped by Relay8 Phase - OC1 - 51 |

Figure 4.13: Relays responses to 3-phase fault at L-6 outgoing feeder.

- As a result of 3-phase (symmetrical) fault at L-6 outgoing feeder:

1. CB13 is tripped by relay1 in order to isolate bus 4 from the fault.
2. In case of failure in relay1 to trip CB13, CB2 must be tripped by relay11 in order to isolate bus 3 and protect it from under voltage.
3. In case of failure in tripping CB2 by relay11, then relay7 and relay 10 trip CB4 and CB6 simultaneously in order to protect transformer 1 and transformer 2 from fault current .

4. In case of failure in tripping CB4 and CB6 by Relay7 and Relay10 then relay 8 and Relay 9 trip CB3 and CB5 simultaneously in order to protect generators fault current .

Over frequency condition make an oscillation in the generator speed which may affect the generator life time if this oscillation continues. Without occurrence of any action of protection may let to mechanical damages a result of simulation increase of the frequency to 110% at 4.035 second after load rejection which is bad and effect in generator life time so that the frequency relay trip CB7,CB8, CB9 and CB11 and isolate the generators.

Under frequency is opposite of over frequency occurs as response of suddenly increasing in load or sudden loss of generation this suddenly make the voltage to decrease and result of high terminal current appear which makeover heat and damage stator winding. In loss of generation simulation the frequency decrease to 94% at time 3.971sec which is bad and effect in generator life time so that the frequency relay trip, CB8, CB9 and CB11 and isolate the generators.

Over voltage simulation result shows the voltage increase to108% at time 6.36sec which is bad and effect in generator life time so that the voltage relay trip ,CB8, CB9 and CB11 and isolate the generators.

Under voltage simulation result shows the voltage decrease to 94% at time 4.719 sec which is bad and effect in generator life time so that the voltage relay trip ,CB8, CB9 and CB11 and isolate the generators.

Generator faults are always considered to be serious since they can cause severe and costly damage to isolation, winding and the core of they can also produce severe mechanical torsional shock to shaft and coupling, Fault currents in generator do not cease to flow when generator is tripped from the system and the field disconnected fault current can continue to flow for many

Seconds because of trapped flux within the machine thereby increasing the amount of damage.

As a result of 3-phase (symmetrical) fault on L-6 outgoing feeder as example the sequence of over-current relays is correct in order to achieve discrimination, selectivity and fast response to fault condition. The settings of relays enable the Protection scheme of substation to Protect generators from all abnormal condition (over-frequency, under-frequency, over-voltage, under-voltage and over-current).All relays characteristic attached in Appendix.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATINS

## 5.1Conclusion

Generators require special protection for faults and abnormal operations. Generator protection is very important in power plant operation. The protection of generators involves the consideration of more possible abnormal operating conditions than the protection of any other system element. In unattended power stations, automatic protection against all harmful abnormal conditions should be provided.

To achieve the reliability of protection system backup protection should be installed according to fault type and abnormal condition type. In this thesis simulation results show that generator protection achieved to all types of faults and abnormal condition (over and under frequency, over voltage. Also the simulation results show the relays trip and pickup abnormal conditions to prevent generator from damage.

The result of simulation show that relay trip and pickup abnormal conditions to prevent generator from damage.

## 5.2 Recommendations

The main reason of the damage of power stations is caused due to damage of the generation units. To make a recommended scenario in protecting these generating units, the following recommendations must be taken into account for others researchers to develop an on-line generator monitoring System using Expert systems technology. This system will correlate generator diagnostic information from existing sensors to provide operations personnel with warning of developing generator problems and recommendations for corrective action. Developing the software presents many technical challenges associate with the requirement for a real-time expert system which can be readily customized and applied to generators of varying design, manufacture, and operating environments. A description of the software architecture better to be implement.

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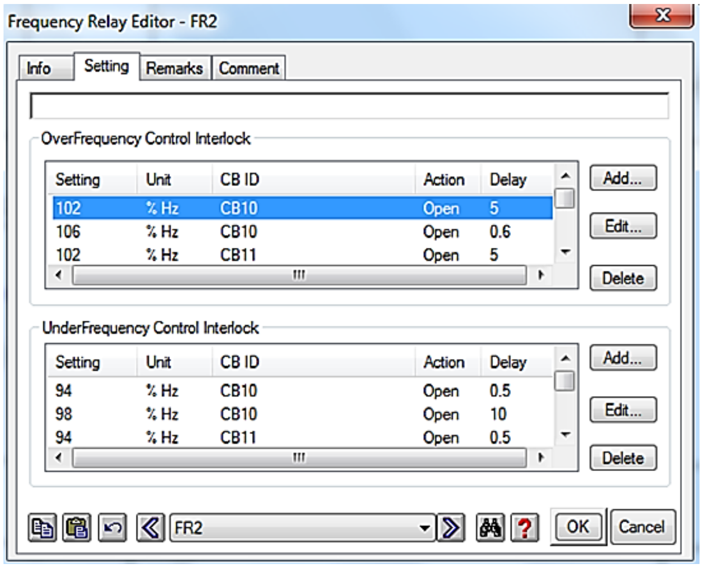
# APPENDIX

Frequency relay settings is shown in figure A.1 Table A1 show the frequency relay input data



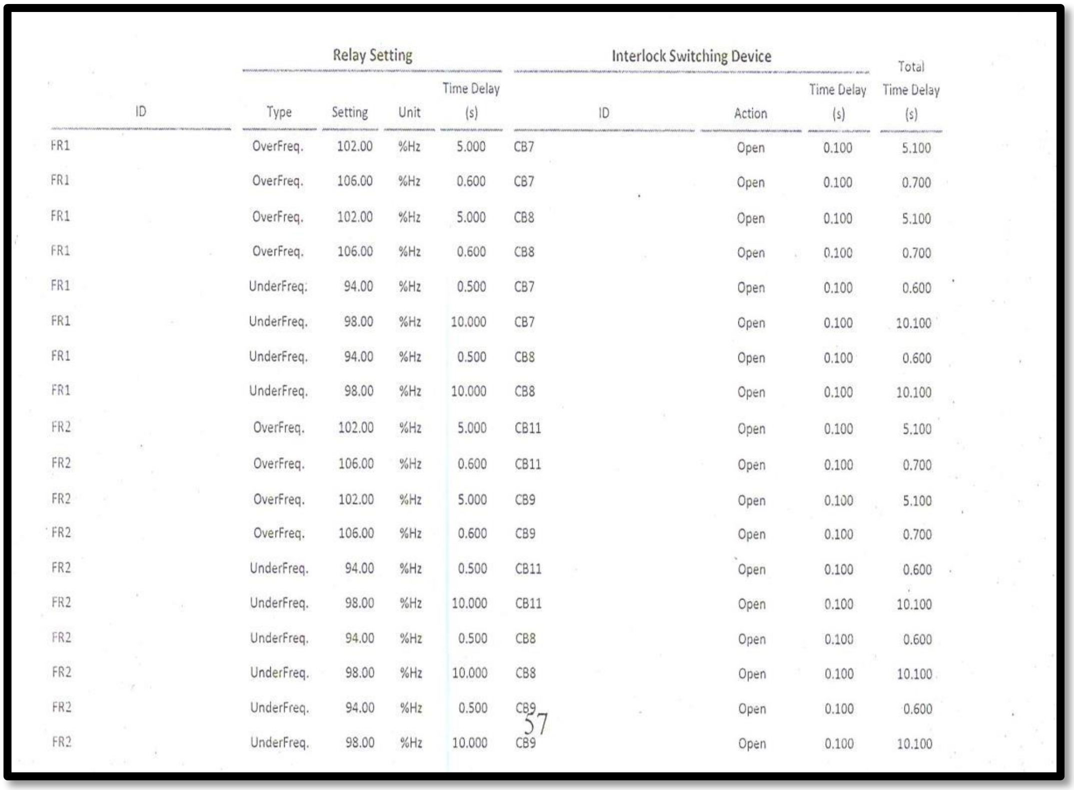
OverFrequency Control Interlock

| Setting | Unit | CB ID | Action | Delay |
|---|---|---|---|---|
| 102 | % Hz | CB10 | Open | 5 |
| 106 | % Hz | CB10 | Open | 0.6 |
| 102 | % Hz | CB11 | Open | 5 |

UnderFrequency Control Interlock

| Setting | Unit | CB ID | Action | Delay |
|---|---|---|---|---|
| 94 | % Hz | CB10 | Open | 0.5 |
| 98 | % Hz | CB10 | Open | 10 |
| 94 | % Hz | CB11 | Open | 0.5 |

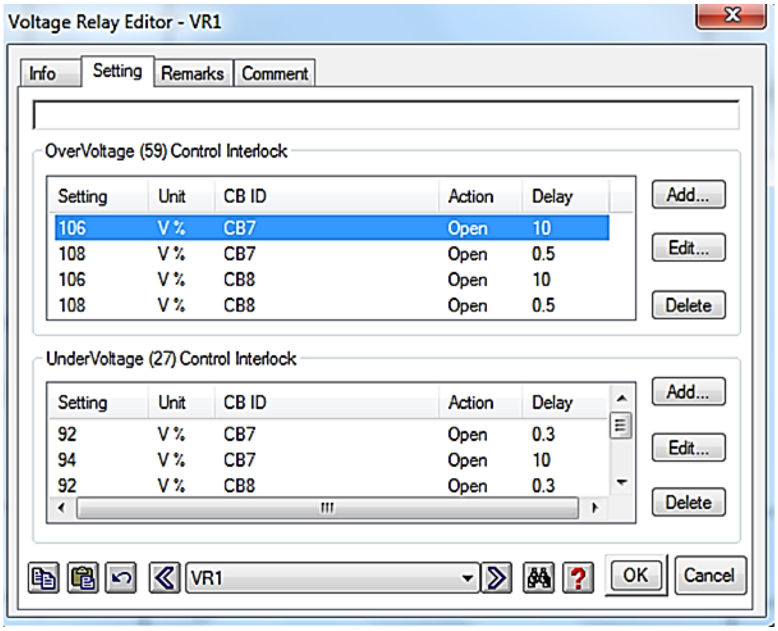
Figure A.1: Frequency relay setting



| | Relay Setting | | | | Interlock Switching Device | | | Total |
|---|---|---|---|---|---|---|---|---|
| ID | Type | Setting | Unit | Time Delay (s) | ID | Action | Time Delay (s) | Time Delay (s) |
| FR1 | OverFreq. | 102.00 | %Hz | 5.000 | CB7 | Open | 0.100 | 5.100 |
| FR1 | OverFreq. | 106.00 | %Hz | 0.600 | CB7 | Open | 0.100 | 0.700 |
| FR1 | OverFreq. | 102.00 | %Hz | 5.000 | CB8 | Open | 0.100 | 5.100 |
| FR1 | OverFreq. | 106.00 | %Hz | 0.600 | CB8 | Open | 0.100 | 0.700 |
| FR1 | UnderFreq. | 94.00 | %Hz | 0.500 | CB7 | Open | 0.100 | 0.600 |
| FR1 | UnderFreq. | 98.00 | %Hz | 10.000 | CB7 | Open | 0.100 | 10.100 |
| FR1 | UnderFreq. | 94.00 | %Hz | 0.500 | CB8 | Open | 0.100 | 0.600 |
| FR1 | UnderFreq. | 98.00 | %Hz | 10.000 | CB8 | Open | 0.100 | 10.100 |
| FR2 | OverFreq. | 102.00 | %Hz | 5.000 | CB11 | Open | 0.100 | 5.100 |
| FR2 | OverFreq. | 106.00 | %Hz | 0.600 | CB11 | Open | 0.100 | 0.700 |
| FR2 | OverFreq. | 102.00 | %Hz | 5.000 | CB9 | Open | 0.100 | 5.100 |
| FR2 | OverFreq. | 106.00 | %Hz | 0.600 | CB9 | Open | 0.100 | 0.700 |
| FR2 | UnderFreq. | 94.00 | %Hz | 0.500 | CB11 | Open | 0.100 | 0.600 |
| FR2 | UnderFreq. | 98.00 | %Hz | 10.000 | CB11 | Open | 0.100 | 10.100 |
| FR2 | UnderFreq. | 94.00 | %Hz | 0.500 | CB8 | Open | 0.100 | 0.600 |
| FR2 | UnderFreq. | 98.00 | %Hz | 10.000 | CB8 | Open | 0.100 | 10.100 |
| FR2 | UnderFreq. | 94.00 | %Hz | 0.500 | CB9 | Open | 0.100 | 0.600 |
| FR2 | UnderFreq. | 98.00 | %Hz | 10.000 | CB9 | Open | 0.100 | 10.100 |

Table A.1 : Frequency relay input data

Voltage relay settings is shown in Figure A2 Table A2 shows the voltage relay input data



OverVoltage (59) Control Interlock

| Setting | Unit | CB ID | Action | Delay |
|---|---|---|---|---|
| 106 | V % | CB7 | Open | 10 |
| 108 | V % | CB7 | Open | 0.5 |
| 106 | V % | CB8 | Open | 10 |
| 108 | V % | CB8 | Open | 0.5 |

UnderVoltage (27) Control Interlock

| Setting | Unit | CB ID | Action | Delay |
|---|---|---|---|---|
| 92 | V % | CB7 | Open | 0.3 |
| 94 | V % | CB7 | Open | 10 |
| 92 | V % | CB8 | Open | 0.3 |

Figure A.2 Voltage relay setting

V

Table A.2: Voltage input data

Figure A.3 Show the over current relay setting.

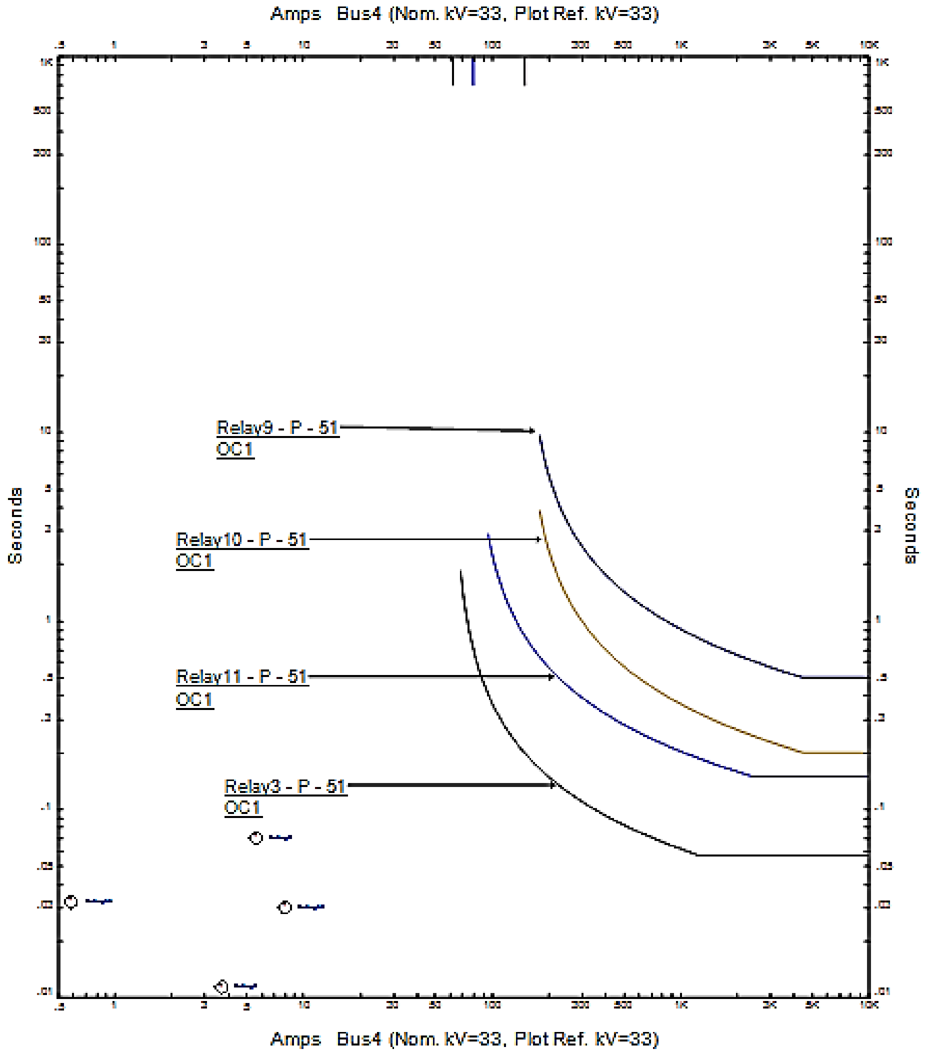


Figure A.3 0ver current relay setting