بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College Of Graduate Studies

Simulation of Generators Protection System of Oil Field Using ETAP Software

نمذجة نظام حماية المولدات الكهربائية لحقل نفطي

باستخدام برنامج ETAP

A Thesis Submitted in Partial Fulfillment of the Requirements for
the Degree of M.SC
in Mechatronic Engineering

Prepared By : Bakry Hamad Elneel Abdallah Ahmed

Supervised By : Dr. Abdelfattah Bilal Abdelslam Alabbas

September 2019

بسم الله الرحمن الرحيم

الآية

(قَالوُا سبُحَانك لا عِلم لنَا إِلا مَا عَلمّتَنَا إِنك أنتَ الْعَليمُ الْحَكِيمُ)

صدق الله العلي العظيم

سورة البقرة

رقم الاية ٣٢

Dedication

To who give our life meaning

To my father and mother

To my sister and brother

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

To all of them I dedicate this work

ACKNOWLEDGEMENTS

I would like to give my appreciation to my advisor, Dr. Abdlfattah Belal, for his invaluable support in getting me started on this project, his constant generosity in providing the necessary advices to do the work

I would also like to appreciate all staff members of Department Mechatronic Engineering, I really enjoyed to be taught by them in different subjects of Mechatronic.

I’d also like to acknowledge all members of Elecon for Electrical Services Company especially Mr. Elshiekh Kamal for his constant support during preparation of this thesis.

Abstract

The main goal of this thesis is to simulate Petro-Energy Company 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 Petro-Energy Company oil field 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.

مستخلص

الهدف الرئيسي لهذه الاطروحه هو محاكاه الحمايه الكهربيه لمولدات الطاقه الكهربيه شركه بترو انرجي العامله في حقل بليله النفطي بولايه غرب كردفان لتسهيل دراسه وتحليل الاعطال التي تتعرض له محطه التوليد باستمرار خاصه عند خروج احمال كبيره من المحطات الفرعيه او خروج واحد من المولدات المرتبطه بالشبكه اومجموعه من المولدات العامله نجحت هذه الاطروحه في وضع افضل الاعدادات لمنظومه الحمايه الخاصه بالمولدات خاصه الاعطال الناتجه عن ارتفاع وانخفاض الجهد والتردد في شبكه التوليد تمت عمليه المحاكاه باستخدام برنامج(ETAP) باعتباره من احدث انظمه المحاكاه والتحليل لانظمه القدره الكهربائيه تم رسم شبكه الكهرباء للحقل النفطي المملوك لشركه بترو انرجي المرتبطه بثلاث انواع من المولدات الكهربائيه ، تم ادخال بيانات الحمايه الخاصه بالمولدات بنجاح وايضا تم تحسين اعدادات الحمايه في خمسه محطات فرعيه لتفادي وصول الاعطال للمولدات الكهربالئيه في الحقل .

تم تحسين عمليه تسلسل عزل وحمايه المولدات ووضع برنامج يسهل ويضمن تتطبيق التحديثات التي تتم على مدخلات الحمايه الكهربائيه على المولدات الكهربائيه الموجوده في الحقل النفطي.

.

TABLE OF CONTENTS

CHAPTER THREE: GENERATOR PROTECTION

List of figures

List of Tables

CHAPTER ONE

INTRODUCTION

1.1 Overview

Fula power plant which located in Baleela area in west Kurdofan State this power plant used gas generators to produce electrical power, total capacity around 30MW, using for oil extraction operations, so the stability of electrical power supply is very important and any interrupt will cost a lot due to oil production flow from oil wells will not resume quickly.

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 of block 6 oil field caused by big amount of load trip or one or group of generators within parallel generators trip and simulating protection system of generators using Fula 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 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 oil field 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 presents fault types and their effect, system transformers, circuit breaker, main concept of protection, ETAP software and previous studies. 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

Energy is vital for all living – being on earth, modern life style has further increase its importance so the purpose of an electrical power system is to generate and supply electrical energy to consumers. The system should be designed and managed to deliver this energy to the utilization points with both reliability and economy. Severe disruption to the normal routine of modern society is likely if power outages are frequent or prolonged, placing an increasing emphasis on reliability and security of supply. As the requirements of reliability and economy are largely opposed, power system design is inevitably a compromise.

2.2 Fault Types and their Effects

It is not practical to design and build electrical equipment or networks to eliminate the possibility of failure in service. It is therefore an everyday fact that different types of faults occur on electrical systems, however infrequently, and at random locations. Faults can be broadly classified into two main areas, which have been designated active and passive [2].

a) Active faults

The active fault is when actual current flows from one phase conductor to another (phase-to-phase), or alternatively from one phase conductor to earth (phase-to-earth). This type of fault can also be further classified into two areas, namely the solid fault and the incipient fault. The solid fault occurs as a result of an immediate complete breakdown of insulation as would happen if, say, a pick struck an underground cable, bridging conductors, etc. or the cable was dug up by a bulldozer. In mining, a rock fall could crush a cable, as would a shuttle car. In these circumstances the fault current would be very high resulting in an electrical explosion.

This type of fault must be cleared as quickly as possible, otherwise there will be:

- Increased damage at fault location.
- Danger to operating personnel (flashes due to high fault energy sustaining for a longtime).
- Danger of igniting combustible gas in hazardous areas, such as methane in coal mines which could cause horrendous disaster.
- Increased probability of earth faults spreading to healthy phases.
- Higher mechanical and thermal stressing of all items of plant carrying the fault current, particularly transformers whose windings suffer progressive and cumulative deterioration because of the enormous electromechanical forces caused by multi-phase faults proportional to the square of the fault current.
- Sustained voltage dips resulting in motor (and generator) instability leading to extensive shutdown at the plant concerned and possibly other nearby plants connected to the system.

The incipient fault, on the other hand, is a fault that starts as a small thing and gets developed into catastrophic failure. Like for example some partial discharge (excessive discharge activity often referred to as Corona) in a void in the insulation over an extended period can burn away adjacent insulation, eventually spreading further and developing into a solid fault. Other causes can typically be a high-resistance joint or contact, alternatively pollution of insulators causing tracking across their surface. Once tracking occurs, any surrounding air will ionize which then behaves like a solid conductor consequently creating a solid fault [2].

b) Passive faults

Passive faults are not real faults in the true sense of the word, but are rather conditions that are stressing the system beyond its design capacity, so that ultimately active faults will occur. Typical examples are:

- Overloading leading to overheating of insulation (deteriorating quality, reduced life and ultimate failure).
- Overvoltage: Stressing the insulation beyond its withstand capacities.
- Under frequency: Causing plant to behave incorrectly.
- Power swings: Generators going out-of-step or out-of-synchronism with each other. It is therefore very necessary to monitor these conditions to protect the system against [2].

2.3 Fault Classified

The faults are classified as:

1) Three phase fault
2) Three phase to ground fault
3) Single phase to ground fault
4) Phase to Phase fault
5) Double Phase to earth fault

Power systems have been in operation for over a hundred years now. Accumulated experience shows that all faults are not equally likely. Single Line to Ground (L-G) faults are the most likely whereas the fault due to simultaneous short circuit between all the three lines, known as the three-phase fault(L-L-L), is the least likely. This is depicted in Table 2.1 below [3].

Table 2.1Fault statistics with reference to type of fault

Fault	Probability of Occurrence **(%)**	Severity
Line-to-Ground	85	Least severe
Line-to-line	8	
Line-to-line-to-Ground	5	
Line-to-line-to-line	2	Most severe

The probabilities of faults on different elements of the power system are different. The transmission lines which are exposed to the vagaries of the atmosphere are the most likely to be subjected to faults. Indoor equipment is least likely to be subjected to faults. The fault statistics with reference power system element is shown in Table 2.1.

Table 2.2 Fault statistics with reference to power system elements

Power system element	Probability of faults (%)
Overhead Lines	50
Underground Cables	9
Transformers	10
Generators	7
Switchgear	12
CT, PT Relays, Control Equipment, etc	12

The severity of the fault can be expressed in terms of the magnitude of the fault current and hence its potential for causing damage. In the power system, the three-phase fault is the most severe whereas the single line-to-ground fault is the least severe [3].

2.4 System Transformers

Current transformers and voltage transformers form a very important link between the power system and the protective system. These transducers basically extract the information regarding current and voltage from the power system under protection and pass it on to the protective relays. While doing this, they insulate the low-voltage protective system (both personnel and protective apparatus) from the high-voltage power system [2].

2.4.1 Current Transformer

There are two types of Current Transformers (CTs) available: bushing and wound as shown in Figure 2.1. The core of a bushing transformer is annular, while the secondary winding is insulated from the core. The secondary winding is permanently assembled on the core. There is no primary winding. The primary winding of wound transformer consists of several turns that encircle the core. More than one core may be present. The primary windings and secondary windings are insulated from each other and from the core. They are assembled as an integral structure.

Bushing transformers have lower accuracy than the wound ones, but they are less expensive. Because of this favorable low-cost they are very often used with ideas to performing protection functions. Similarly, because of their great accuracy with low currents, wound transformers are usually applied in metering and similar applications. Another benefit of bushing transformers is their convenient placement in the bushings of power transformers and circuit breakers. This means that they take up no appreciable space in the substation.

The core of bushing transformers encompasses the conductor carrying the primary current. Because of such a design, the core presents relatively large path for the establishment of Electro Magnetic (EM) field, necessary for the conversion of current .This is the primary reason for their lower accuracy, when compared with wound transformers. However, bushing transformers are also built with increased cross-sectional area of iron in the core. The advantage of this is higher accuracy in scaling of fault currents that are of large multiples of nominal current, when compared to wound transformers. High accuracy for high fault currents is desirable in protective relaying.

Therefore, the bushing transformers are a good choice for protective applications[2].

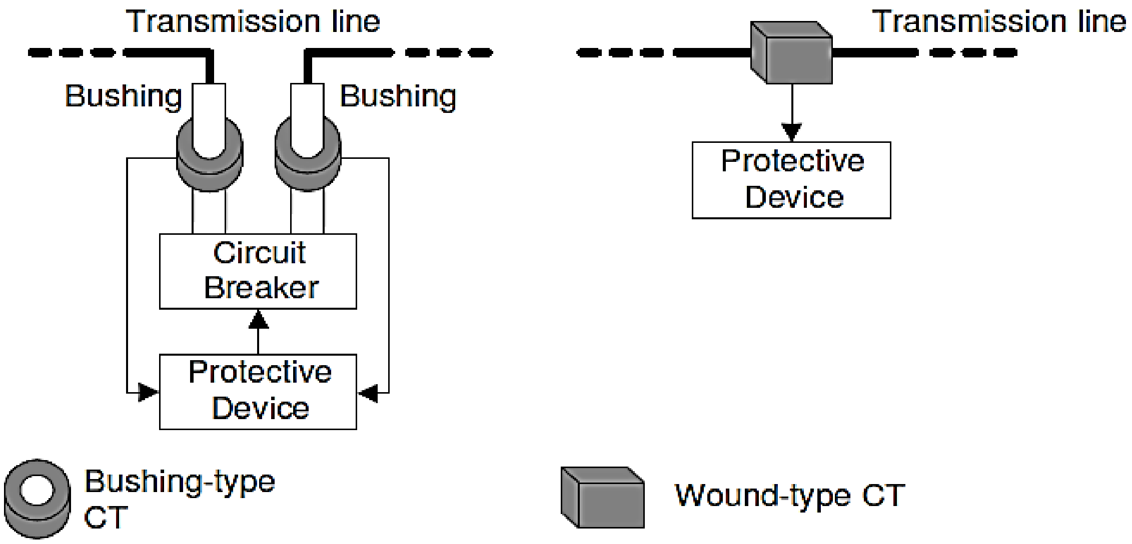


Figure 2.1: Two types of current transformers

2.4.2Voltage Transformer

There are basically, two types of Voltage Transformers used for protection equipment.

1) Electromagnetic type (commonly referred to as a Voltage Transformer (VT))
2) Capacitor type (referred to as a Capacitive Voltage Transformer (CVT)).

The electromagnetic type is a step down transformer whose primary (HV) and secondary (LV) windings are connected as shown in figure 2.2.

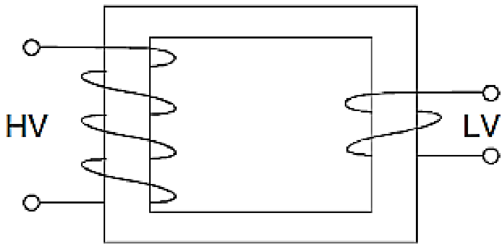


Figure 2.2 Electromagnetic type

The number of turns in a winding is directly proportional to the open-circuit voltage being measured or produced across it. The above diagram is a single-phase VT. In the three-phase system it is necessary to use three VTs at one per phase and they being connected in star or delta depending on the method of connection of the main power source being monitored. This type of electromagnetic transformers are used in voltage circuits up to 110/132 KV.

For still higher voltages, it is common to adopt the second type namely the capacitor voltage transformer (CVT). Figure 2.3 below gives the basic connection adopted in this type. Here the primary portion consists of capacitors connected in series to split the primary voltage to convenient values.

The magnetic voltage transformer is similar to a power transformer and differs only so far as a different emphasis is placed on cooling, insulating and mechanical aspects. The primary winding has larger number of turns and is connected across the line voltage; either phase-to-phase or phase-to-neutral. The secondary has lesser turns however, the volts per turn on both primary and secondary remains same. The capacitor VT is more commonly used on Extra High-Voltage (EHV) networks. The capacitors also allow the injection of a high-frequency signals onto the power line conductors to provide end-to-end communications between substations for distance relays, telemetry/supervisory and voice communications. Hence, in EHV national grid networks of utilities, the CVTs are commonly used for both protection and communication purposes [2].

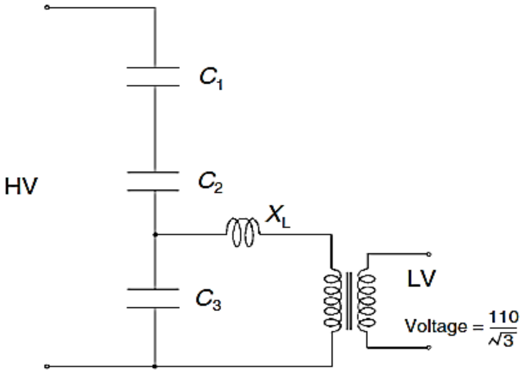


Figure 2.3: Capacitor-type VT

2.4.3 Circuit Breaker

Where fuses are unsuitable or inadequate, protective relays and circuit breakers are used in combination to detect and isolate faults. Circuit breakers are the main making and breaking devices in an electrical circuit to allow or disallow flow of power from source to the load. These carry the load currents continuously and are expected to be switched ON with loads (making capacity). These should also be capable of breaking a live circuit under normal switching OFF conditions as well as under fault conditions carrying the expected fault current until completely isolating the fault side (rupturing/breaking capacity).

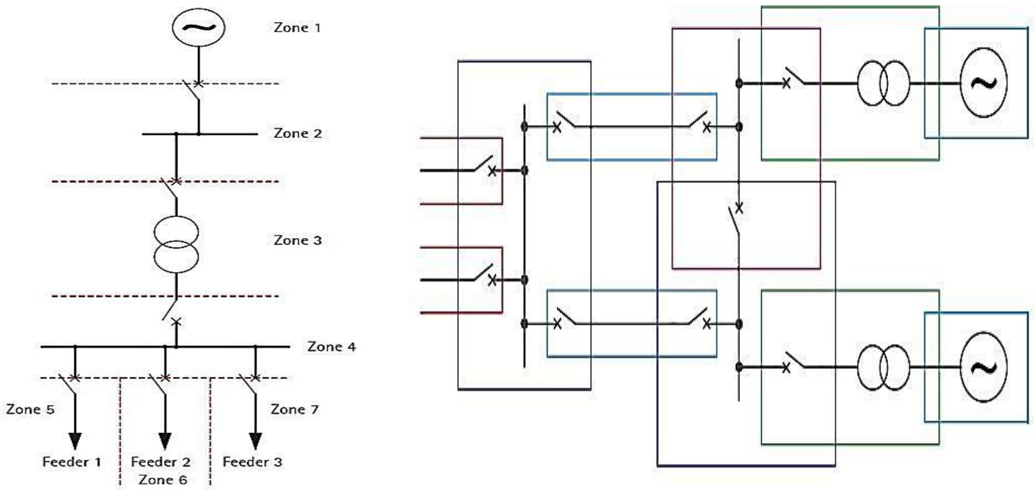
Under fault conditions, the breakers should be able to open by instructions from monitoring devices like relays. The relay contacts are used in the making and breaking control circuits of a circuit breaker, to prevent breakers getting closed or to trip breaker under fault conditions as well as for some other interlocks.The types of breakers basically refer to the medium in which the breaker opens and closes. The medium could be oil, air, vacuum or SF6. The further classification is single break and double break. In a single break type only the bus-bar end is isolated but in a double break type, both bus-bar (source) and cable (load) ends are broken. However, the double break is the most common and accepted type in modern installations.

2.5 Organization of Protection

The idea of what to provide a ring of security around each and every element of the power system. If there is any fault within this ring, the relays associated with it must trip all the allied circuit breakers so as to remove the faulty element from the rest of the power system. This 'ring of security' is called the zone of protection [3].

2.6 Zones of Protection

To limit the extent of the power system that is disconnected when a fault occurs, protection is arranged in zones as shown in Figure 2.4. Ideally, the zones of protection should overlap, so that no part of the power system is left unprotected [1].



(a) **(b)**

(a) Division of power system into protection zones, (b) Overlapping zones of protection systems.

Figure 2.4 Protection Zones

2.7 Over Current Protection

The term over current refers to abnormal current flow higher than the normal value of current flow in an electrical circuit. Uncorrected over current can cause serious safety hazards and costly damage to electrical equipment and property. There are three basic types of current flow in an electrical circuit:

1) Normal intended current flow to operate electrical equipment.
2) Abnormal over current flow with a value of up to 10 times normal current flow. This is known as an overload.
3) Abnormal over current flow with a value more than 10 times the normal current flow is known as short-circuit or fault current flow

2.7.1 Non-directional over-current protection

This type depends on only the magnitude of the current, without taking any cognizance of its phase angle [3].

2.7.2 Directional over-current protection

This type takes into account, not only the magnitude of the current but also its phase with respect to the voltage at the relay location. It discriminates between faults in front of the breaker and faults behind the breaker (better selectivity) [3].

2.7.3 Types of Over current Relay

These are the types of over current relay:

a) Instantaneous over current relay (define current)

Definite current relay operate instantaneously when the current reaches a predetermined value.

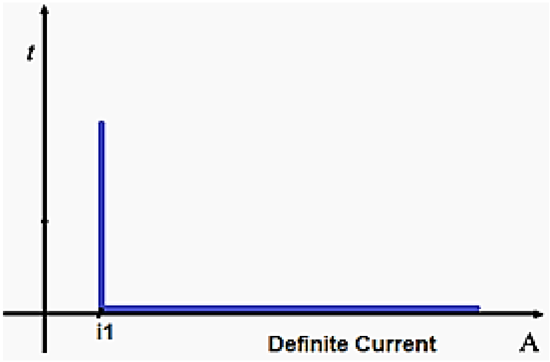


Figure 2.5 Instantaneous over current relay – definite current

- Operates in a definite time when current exceeds its Pick-up value.
- Its operation criterion is only current magnitude (without time delay).
- Operating time is constant.
- There is no intentional time delay.
- Coordination of definite-current relays is based on the fact that the fault current varies with the position of the fault because of the difference in the impedance between the fault and the source
- The relay located furthest from the source operate for a low current value
- The operating currents are progressively increased for the other relays when moving towards the source.
- It operates in 0.1s or less

This type is applied to the outgoing feeders

b) Definite Time Over current Relays

In this type, two conditions must be satisfied for operation (tripping), current must exceed the setting value and the fault must be continuous at least a time equal to time setting of the relay.

Figure 2.6: Definite time of over current relay

Modern relays may contain more than one stage of protection each stage includes each own current and time setting.

1. For operation of definite time over current relay operating time is constant
2. Its operation is independent of the magnitude of current above the pick-up value.
3. It has pick-up and time dial settings, desired time delay can be set with the help of an intentional time delay mechanism.
4. Easy to coordinate.
5. Constant tripping time independent of in feed variation and fault location.

- The main drawbacks of relay are:

1. The continuity in the supply cannot be maintained at the load end in the event of fault.
2. Time lag is provided which is not desirable in on short circuits.
3. It is difficult to co-ordinate and requires changes with the addition of load.
4. It is not suitable for long distance transmission lines where rapid fault clearance is necessary for stability.

5. Relay have difficulties in distinguishing between Fault currents at one point or another when fault impedances between these points are small, thus poor discrimination.

Definite time over current relay is used as:

1. Back up protection of distance relay of transmission line with time delay.
2. Back up protection to differential relay of power transformer with time delay.
3. Main protection to outgoing feeders and bus couplers with adjustable time delay setting.

c) Inverse time over current relays (*IDMT* relay)

In this type of relays, operating time is inversely changed with current.

So, high current will operate over current relay faster than lower ones. There is standard inverse, very inverse and extremely inverse types .Discrimination by both time and current. The relay operation time is inversely proportional to the fault current**.**

Inverse Time relays are also referred to as Inverse Definite Minimum Time (IDMT) relay. Figure2.7 show inverse types discrimination by both time and current

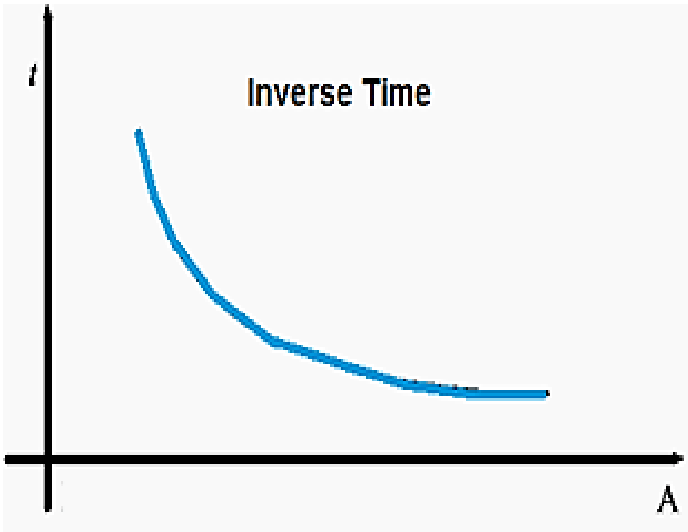


Figure 2.7Inverse definite minimum time (IDMT)

The operating time of an over current relay can be moved up (made slower) by adjusting the time dial setting. The lowest time dial setting (fastest operating time) is generally 0.5 and the slowest is 10.

- Operates when current exceeds its pick-up value.
- Operating time depends on the magnitude of current.
- It gives inverse time current characteristics at lower values of fault current and definite time characteristics at higher values
- An inverse characteristic is obtained if the value of plug setting multiplier is below 10, for values between 10 and 20 characteristics tend towards definite time characteristics.
- Widely used for the protection of distribution lines.

2.8 Protection Performance

Protection system performance is frequently assessed statistically. For this purpose each system fault is classed as an incident and only those that are cleared by the tripping of the correct circuit breakers are classed as 'correct'. The percentage of correct clearances can then be determined. This principle of assessment gives an accurate evaluation of the protection of the system as a whole, but it is severe in its judgment of relay performance. Many relays are called into operation for each system fault, and all must behave correctly for a correct clearance to be recorded.

Complete reliability is unlikely ever to be achieved by further improvements in construction. If the level of reliability achieved by a single device is not acceptable, improvement can be achieved through redundancy, e.g. duplication of equipment. Two complete, independent, main protection systems are provided, and arranged so that either by itself can carry out the required function. If the probability of each equipment failing is x/unit, the resultant probability of both equipments failing simultaneously, allowing for redundancy, is x2. Where x is small the resultant risk (x2) may be negligible. Where multiple protection systems are used, the tripping signal can be provided in a number of different ways. The two most common methods are:

a) All protection systems must operate for a tripping operation to occur (e.g. ‘two-out-of-two’ arrangement).
b) Only one protection system need operate to cause a trip (e.g. ‘one-out-of two’ arrangement).

The former method guards against mal-operation while the latter guards against failure to operate due to an unrevealed fault in a protection system Rarely, three main protection systems are provided, configured in a ‘two-out-of three’ tripping arrangement, to provide both reliability of tripping, and security against unwanted tripping.It has long been the practice to apply duplicate protection systems to bus-bars, both being required to operate to complete a tripping operation. Loss of a bus-bar may cause widespread loss of supply, which is clearly undesirable. In other cases, important circuits are provided with duplicate main protection systems, either being able to trip independently. On critical circuits, use may also be made of a digital fault simulator to model the relevant section of the power system and check the performance of the relays used [1].

2.8.1 Selectivity

When a fault occurs, the protection scheme is required to trip only those circuit breakers whose operation is required to isolate the fault. This property of selective tripping is also called 'discrimination' and is achieved by two general methods.

a) Time grading

Protection systems in successive zones are arranged to operate in times that are graded through the sequence of equipments so that upon the occurrence of a fault, although a number of protection equipments respond, only those relevant to the faulty zone complete the tripping function. The others make incomplete operations and then reset. The speed of response will often depend on the severity of the fault, and will generally be slower than for a unit system [1].

b) Unit systems

It is possible to design protection systems that respond only to fault conditions occurring within a clearly defined zone. This type of protection system is known as 'unit protection'. Certain types of unit protection are known by specific names, e.g. restricted earth fault and differential protection. Unit protection can be applied throughout a power system and, since it does not involve time grading, is relatively fast in operation. The speed of response is substantially independent of fault severity [1].

Unit protection usually involves comparison of quantities at the boundaries of the protected zone as defined by the locations of the current transformers. This comparison may be achieved by direct hard-wired connections or may be achieved via a communications link. However certain protection systems derive their 'restricted' property from the configuration of the power system and may be classed as unit protection, e.g. earth fault protection applied to the high voltage delta winding of a power transformer.

Whichever method is used, it must be kept in mind that selectivity is not merely a matter of relay design. It also depends on the correct coordination of current transformers and relays with a suitable choice of relay settings, taking into account the possible range of such variables as fault currents, maximum load current, system impedances and other related factors, where appropriate[1].

2.8.2 Stability

The term ‘stability’ is usually associated with unit protection schemes and refers to the ability of the protection system to remain unaffected by conditions external to the protected zone, for example through load current and external fault conditions[1].

2.8.3 Speed

The function of protection systems is to isolate faults on the power system as rapidly as possible. The main objective is to safeguard continuity of supply by removing each disturbance before it leads to widespread loss of synchronism and consequent collapse of the power system.

As the loading on a power system increases, 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 2.8 shows typical relations between system loading and fault clearance times for various types of fault. It will be noted that phase faults have a more marked effect on the stability of the system than a simple earth fault and therefore require faster clearance.[1]

System stability is not, however, the only consideration. Rapid operation of protection ensures that fault damage is minimized, as energy liberated during a fault is proportional to the square of the fault current times the duration of the fault. Protection must thus operate as quickly as possible but speed of operation must be weighed against economy. Distribution circuits, which do not normally require a fast fault clearance, are usually protected by time-graded systems. Generating plant and EHV systems require protection gear of the highest attainable speed; the only limiting factor will be the necessity for correct operation, and therefore unit systems are normal practice [1].

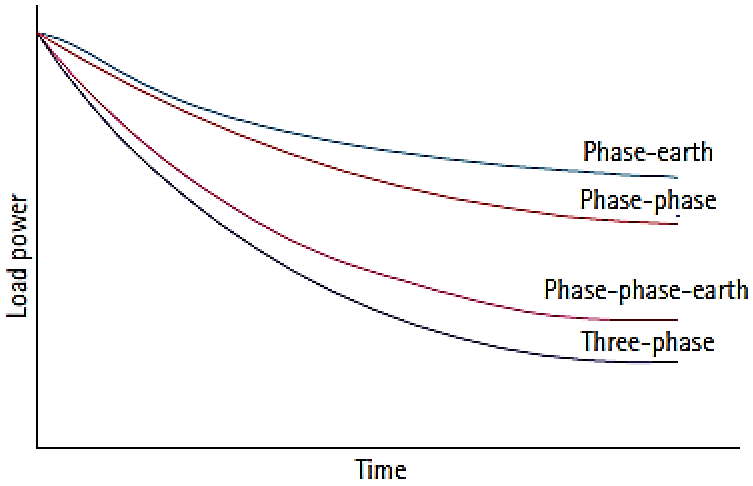


Figure 2.8: Typical power/time relationship for various fault types

2.8.4 Sensitivity

Sensitivity is a term frequently used when referring to the minimum operating level (current, voltage, power etc.) of relays or complete protection schemes. The relay or scheme is said to be sensitive if the primary operating parameter(s) is low. With older electromechanical relays, sensitivity was considered in terms of the sensitivity of the measuring movement and was measured in terms of its volt-ampere consumption to cause operation. With modern digital and numerical relays the achievable sensitivity is seldom limited by the device design but by its application and CT/VT parameters[1].

2.9 Differential Protection

Differential protection is based on the fact that any fault within an electrical equipment would cause the current entering it, to be different, from that leaving it. Thus, we can compare the two currents either in magnitude or in phase or both and issue a trip output if the difference exceeds a predetermined set value. This method of detecting faults is very attractive when both ends of the apparatus are physically located near each other. A typical situation, where this is true, is in the case of a transformer, a generator or a busbar. In the case of transmission lines, the ends are too far apart for conventional differential relaying to be directly applied. For the operating condition of normal load flow shown in Figure 2.7, the currents transformed by the two CTs, being equal in magnitude as well as in phase, just circulate on the secondary side. There is no tendency for the current to spill into the over-current relay. The over-current relay connected in the spill path is wired to trip the two circuit breakers on either side of the equipment being protected [3].

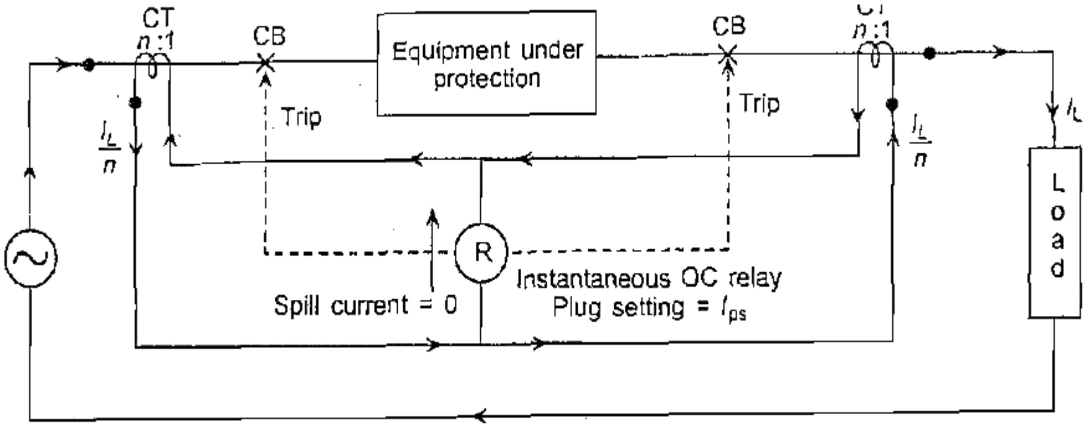


Figure 2.9 Simple differential protections

2.10 Protective Relay Evolution

The last thirty years have seen enormous changes in relay technology. The electromechanical relay in all of its different forms has been replaced successively by static, digital and numerical relays, each change bringing with it reductions and size and improvements in functionality.

At the same time, reliability levels have been maintained or even improved and availability significantly increased due to techniques not available with older relay types. This represents a tremendous achievement for all those involved in relay design and manufacture. This chapter charts the course of relay technology through the years. As the purpose of the book is to describe modern protection relay practice, it is natural therefore to concentrate on digital and numerical relay technology. The vast numbers of electromechanical and static relays are still giving dependable service, but descriptions on the technology used must necessarily be somewhat brief. For those interested in the technology of electromechanical and static technology

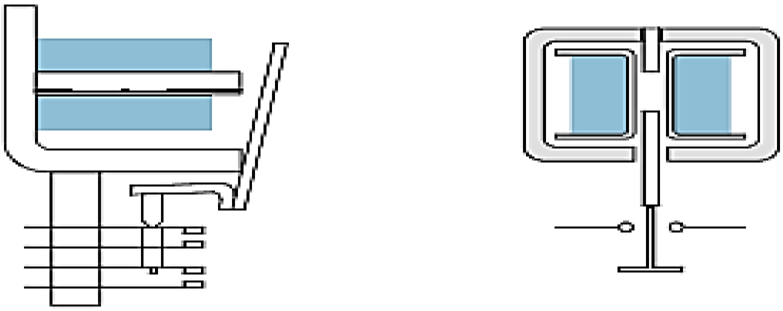
2.10.1 Electromechanical relays

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:

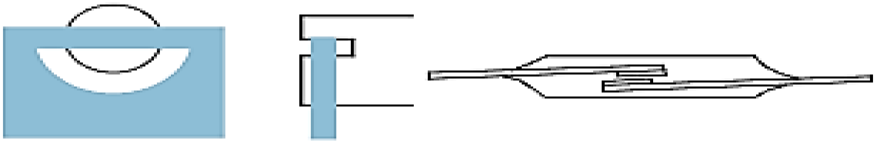
However, only attracted armature types have significant application at this time, all other types having been superseded by more modern equivalents [1].

a) Attracted armature relays

These generally consist of an iron-cored electromagnet that attracts a hinged armature when energized. A restoring force is provided by means of a spring or gravity so that the armature will return to its original position when the electromagnet is de-energized. Typical forms of an attracted armature relay are shown in Figure 2.10. Movement of the armature causes contact closure or opening, the armature either carrying a moving contact that engages with a fixed one, or causes a rod to move that brings two contacts together. It is very easy to mount multiple contacts in rows or stacks, and hence cause a single input to actuate a number of outputs. The contacts can be made quite robust and hence able to make, carry and break relatively large currents under quite onerous conditions (highly inductive circuits). This is still a significant advantage of this type of relay that ensures its continued use.[1]



(a) D.C. relay (c) Solenoid relay



(b) Shading loop modification to pole of relay (a) for a.c. operation (d) Reed relay

Figure 2.10: Typical attracted armature relays

The energizing quantity can be either an Alternating Current (AC) or a Direct Current (DC) current. If an AC current is used, means must be provided to prevent the chatter that would occur from the flux passing through zero every half cycle. A common solution to the problem is to split the magnetic pole and provide a copper loop round one half. The flux change is now phase-shifted in this pole, so that at no time is the total flux equal to zero. Conversely, for relays energized using a DC current, remnant flux may prevent the relay from releasing when the actuating current is removed. This can be avoided by preventing the armature from contacting the electromagnet by a non-magnetic stop or constructing the electromagnet using a material with very low remnant flux properties.Operating speed, power consumption and the number and type of contacts required are a function of the design. The typical attracted armature relay has an operating speed of between 100ms and 400ms, but reed relays (whose use spanned a relatively short period in the history of protection relays) with light current contacts can be designed to have an operating time of as little as 1msec. Operating power is typically 0.05-0.2 watts, but could be as large as 80 watts for a relay with several heavy-duty contacts and a high degree of resistance to mechanical shock.

b) Moving coil

The moving coil relay or polarized DC moving coil relay is most sensitive electromagnetic relay. Because of its high sensitive, this relay is used widely for sensitive and accurate measurement for distance and differential protection. This type of relays is inherently suitable for DC system. Although this type of relay can be used for AC system also but necessary rectifier circuit should be provided in current transformer.

In a moving coil relay the movement of the coil may be rotary or axial. Both of them have been perfected to a large extent by the various manufactures but the inherent limitation of a moving coil relay remains i.e. to lead the current in and out of the moving coil system which, for reasons of sensitivity has to be designed to be very delicate. Between these two types of moving coil relay a axial moving type has twice sensitivity than that of rotary type. With moving coil relay, sensitivities of the order of 0.2 MW to 0.5 MW are typical. Speed of operation depends upon damping provided in the relay.

c) Induction Disc

In order to operate, the induction disk relay torque is produced that acts on a metal disc to make contact, according to the following basic current/torque equation:

$$T = K \times \phi_1 \times \phi_2 \sin\theta \qquad (2.1)$$

Where K is a constant ϕ1 and ϕ2 are the two fluxes and θ is the phase angle between the fluxes.The relay's primary winding is supplied from the power systems current transformer via a plug bridge, which is called the plug setting multiplier (psm). Usually seven equally spaced tapping or operating bands determine the relays sensitivity. The primary winding is located on the upper electromagnet. The secondary winding has connections on the upper electromagnet that are energized from the primary winding and connected to the lower electromagnet. Once the upper and lower electromagnets are energized they produce eddy currents that are induced onto the metal disc and flow through the flux paths. This relationship of eddy currents and fluxes creates torque proportional to the input current of the primary winding, due to the two flux paths been out of phase by 90°.

A restraining spring forces the disk to rotate in the direction that opens the trip contacts while current creates operating torque to close the contacts. The net positive torque closes the contacts. The (IPU) relay setting fixes the value of the pickup current. When the current applied to the relay equals the pickup current, the contact closing torque just equals the restraining torque and the disk will not move regardless of its position. If the applied current increases above the pickup current, the disk will begin to rotate so that the trip contacts come closer together [4].

d) Induction cup

Can be considered as a different version of induction disc type relay. The working principle of both type of relays are more or less some. Induction cup type relay are used where, very high speed operation along with polarizing and/or differential winding is requested. Generally four pole and eight pole design are available. The number of poles depends upon the number of winding to be accommodated.

The inertia of cup type design is much lower than that of disc type design. Hence very high speed operation is possible in induction cup type relay. Further, the pole system is designed to give maximum torque per KVA input. In a four pole unit almost all the eddy currents induced in the cup by one pair of poles appear directly under the other pair of poles – so that torque / VA is about three times that of an induction disc with a c-shaped electromagnet. Induction cup type relay is practically suited as directional or phase comparison units. This is because, besides their sensitivity, induction cup relay have steady non vibrating torque and their parasitic torque due to current or voltage alone are small[4].

e) Thermal relay

Thermal relays, of the bimetallic type, work on the principle of strain generated due to unequal linear expansion of two different metals as a result of heat generated by the passage of the fault current[3]. Figure2.11 show the bimetallic type relay and its operation.

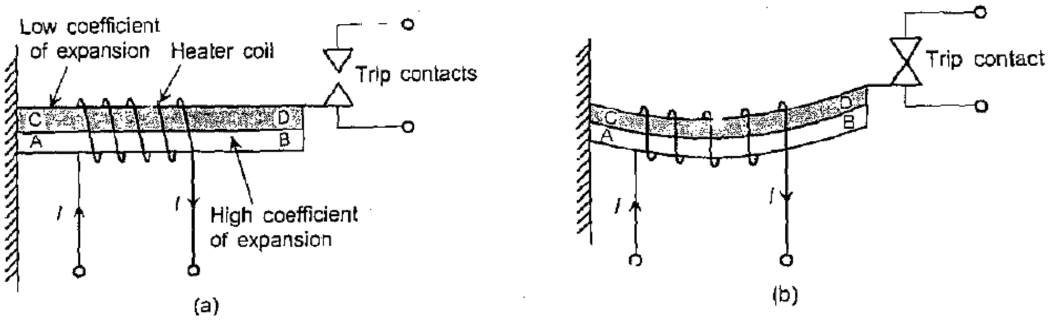


Figure 2.11 (a) bimetallic type relay (b) bimetallic type relay operation

Figure2.11 : Bimetallic type relay and its operation.

2.10.2 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 [1].

2.10.3 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 Analogue to Digital (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. The limited power of the microprocessors used in digital relays restricts the number of samples of the waveform that can be measured per cycle. This, in turn, limits the speed of operation of the relay in certain applications. Therefore, a digital relay for a particular protection function may have a longer operation time than the static relay equivalent. However, the extra time is not significant in terms of overall tripping time and possible effects of power system stability [1].

2.10.4 Numerical Relays

The distinction between digital and numerical relay rests on points of fine 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.

2.10.5 Relay Software

The software provided in the relay is commonly organized into a series of tasks, operating in real time. An essential component is the Real Time Operating System (RTOS), whose function is to ensure that the other tasks are executed as and when required, on a priority basis. Other task software provided will naturally vary according to the function of the specific relay, but can be generalized as follows:

a. System services software – this is akin to the Binary I/O Signal BIOS of an ordinary Personal Computer (PC), and controls the low-level

Input/Output (I/O) for the relay (i.e. drivers for the relay hardware, boot-up sequence, etc.)

b. HMI interface software – the high level software for communicating with a user, via the front panel controls or through a data link to another computer running suitable software, storage of setting data, etc.
c. Application software – this is the software that defines the protection function of the relay
d. Auxiliary functions – software to implement other features offered in the relay – often structured as a series of modules to reflect the options offered to a user by the manufacturer [1].

2.11 ETAP Software Package:

ETAP is an electrical system simulation software, it provides platform to draw single line diagram of the system which wanted to be designed or analyzed, and suitable the module to solve it, and generates the graph and reports with the parameters of consideration in the studies [6].

There are many the modules integrated of the software, among the most used are the following:

- Load Flow.
- Short-circuit.
- Protection device co-ordination.
- Motor acceleration.
- Ground grid systems.
- Star view – over current simulation

2.12 Previous Studies:

2.12.1 Design of electrical system based on load flow analysis using ETAP for IEC projects

Published in IEEE 6th International Conference on Power 2016

This paper explains about performing load flow analysis using ETAP for IEC projects and selection of electrical equipment parameters based on ETAP result. Load flow analysis is the basic analysis for electrical power system design, electrical power system planning, etc. This paper discusses about input required for modeling electrical system, standard/typical values of input, values to be assumed if input is not available, acceptable limit of load flow analysis result and methods to be followed to achieve correct result. All the power system equipments are designed to withstand worst case conditions. This paper also discusses about certain worst cases to be analyzed using load flow analysis.

2.12.2 Transient Stability Analysis and Enhancement of IEEE- 9 BUS system

Electrical & Computer Engineering: An International Journal (ECIJ) Volume 3, Number 2, June 2014

Renuka Kamdar1, Manoj Kumar2 and Ganga Agnihotri31,3Department of Electrical Engineering, MANIT, Bhopal, India

System stability study is the important parameter of economic, reliable and secure power system planning and operation. Power system studies are important during the planning and conceptual design stages of the project as well as during the operating life of the plant periodically. This paper presents the power system stability analysis for IEEE- 9 bus test system. The fault is created on different busses and transient stability is analyzed for different load and generation conditions. The critical clearing time (CCT) is calculated by using time domain classical extended equal area criterion method. The system frequency and voltage variation is observed for different fault locations and CCT. The IEEE-9 bus test system is simulated and stability is analyzed on ETAP software.

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

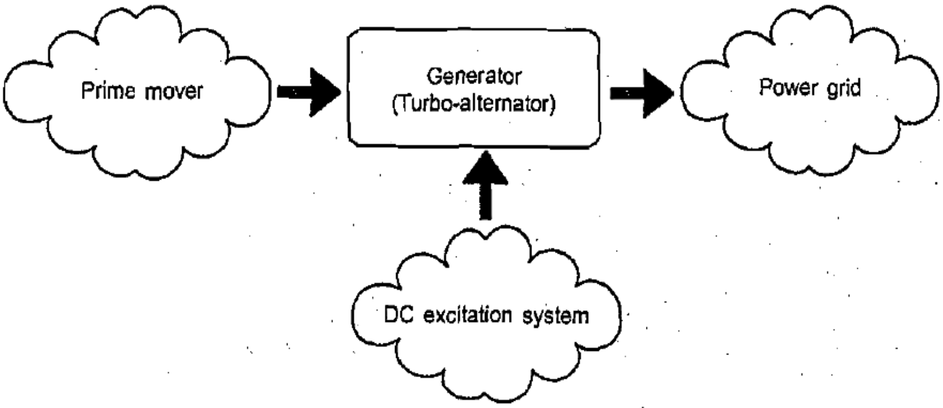


Figure 3.1 Generation system main connection.

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.

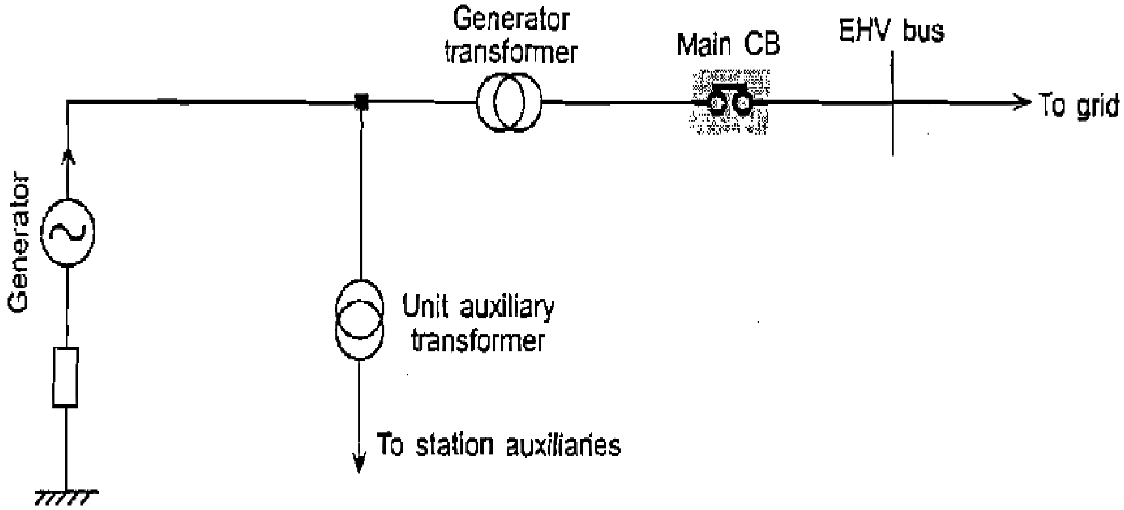


Figure 3.2 Alternator unit auxiliary transformer and main CB.

3.2.2 Generator grounding

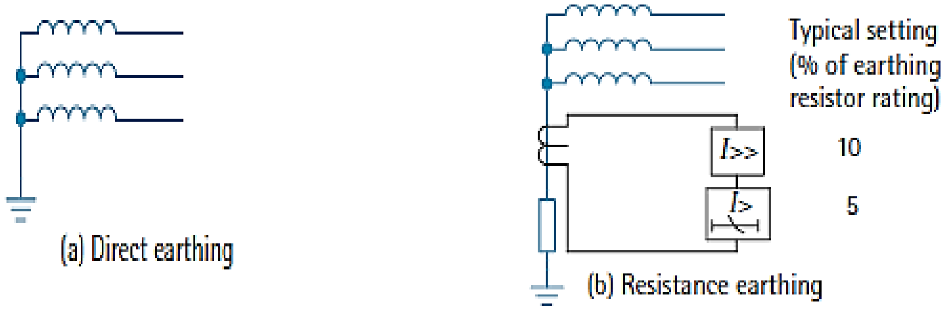
The neutral point of a generator is usually earthed to facilitate protection of the stator winding and associated system. Grounding also prevents damaging transient over-voltages in the event of an arcing earth fault or fero-resonance. For High Voltage (HV) generators, impedance is usually inserted in 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).

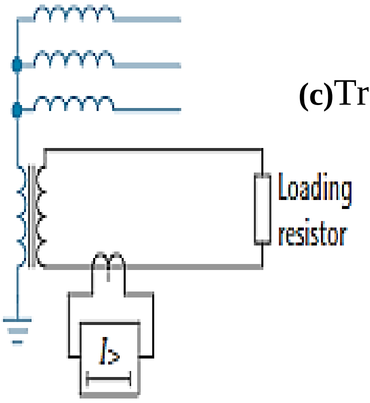
The main methods of impedance-grounding a generator are shown in Figure 3.3. Low values of earth fault current may limit the damage caused from a fault, but they simultaneously make detection of a fault towards the stator winding star point more difficult. Except for special applications, such as marine, 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].

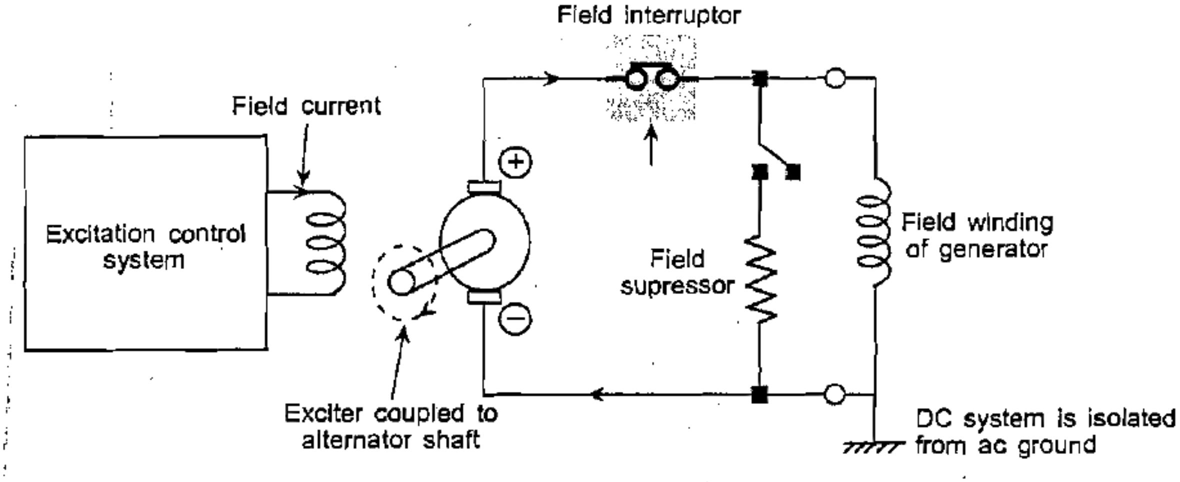


Figure 3.4: Electrical circuit of the exciter of the generator.

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].

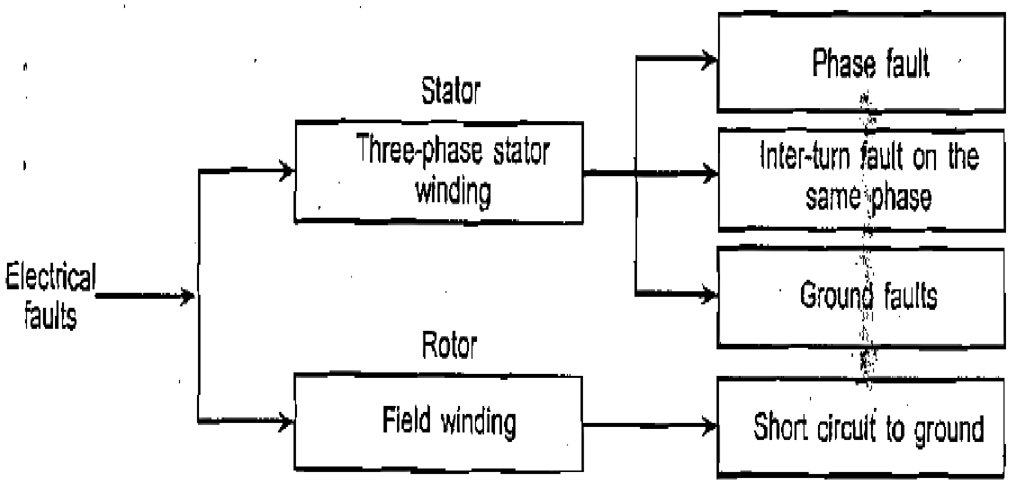


Figure 3.5:Various electrical faults on a turbo-alternator

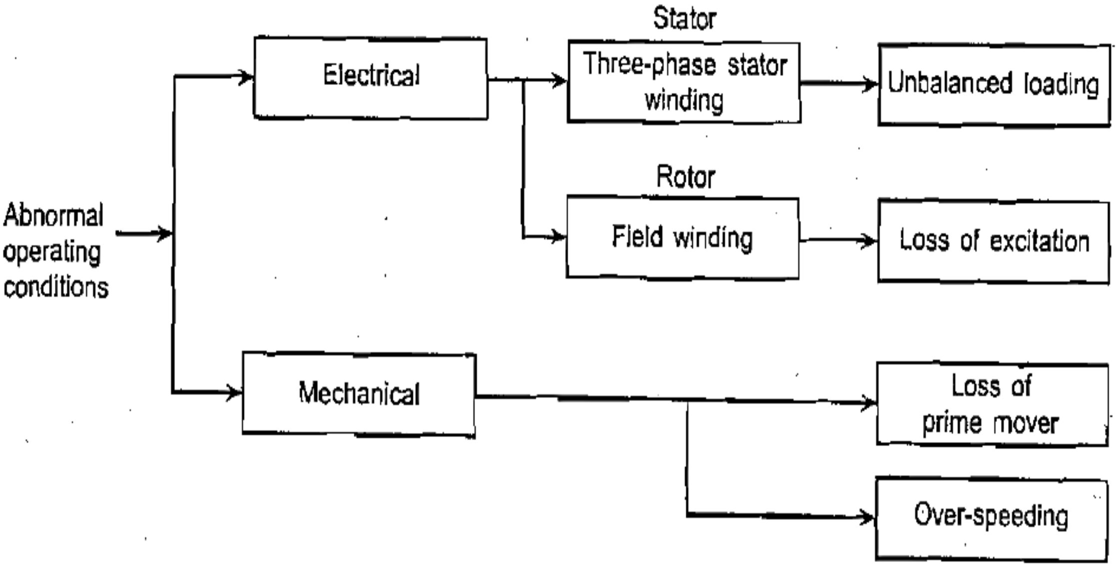


Figure 3.6: Various abnormal operating conditions of a turbo-alternator.

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).

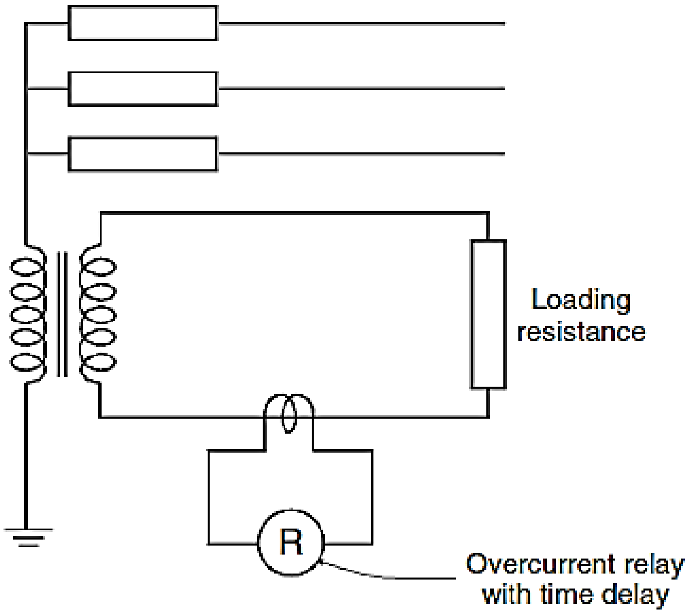


Figure 3.7: Earth fault protection using a relay to measure secondary current

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).

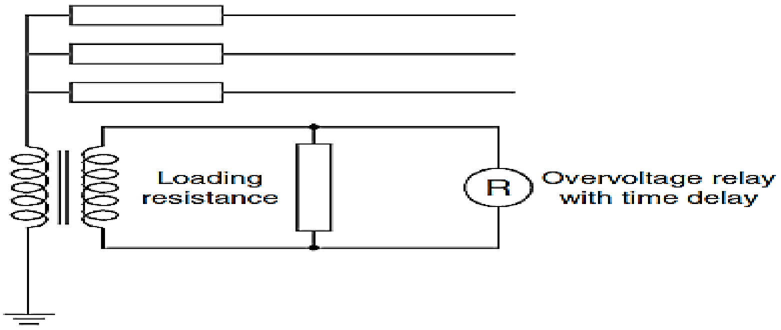


Figure 3.8 Earth fault protection using a relay in parallel with loading resistor

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 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].

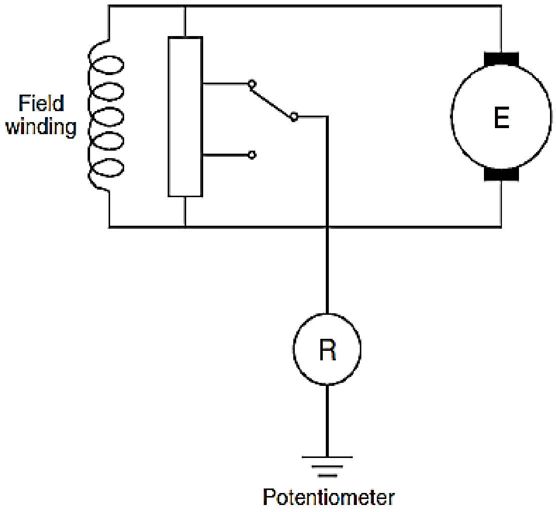


Figure 3.9 Potentiometer

(a) 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 4.10)[2].

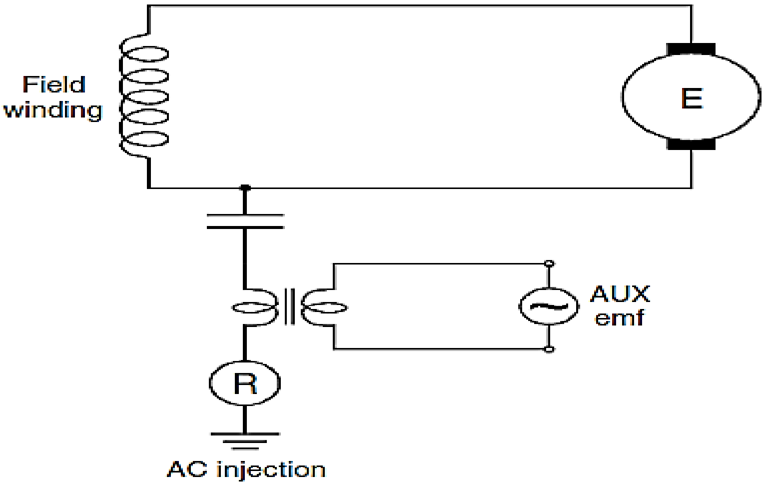


Figure 3.10 AC injection

(b) 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].

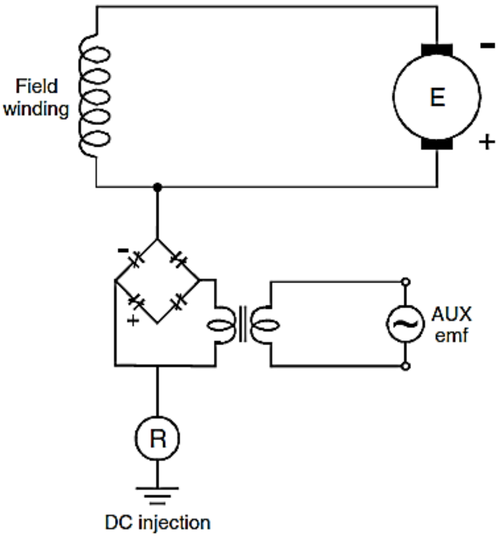


Figure 3.11 DC injection

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 equipments, 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].

3.6.2 Unbalanced Loading

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_2^2Rt, 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

$I_2^2Rt=k$ (4.1)

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

$I_2^2\,t=k$ (4.2)

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

Thus, the current-time characteristic can be written as

$T \leq K/I_2^2$ (4.3)

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

3.6.3 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].

3.6.4 Under voltage 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].

3.6.5 Losses of excitation

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

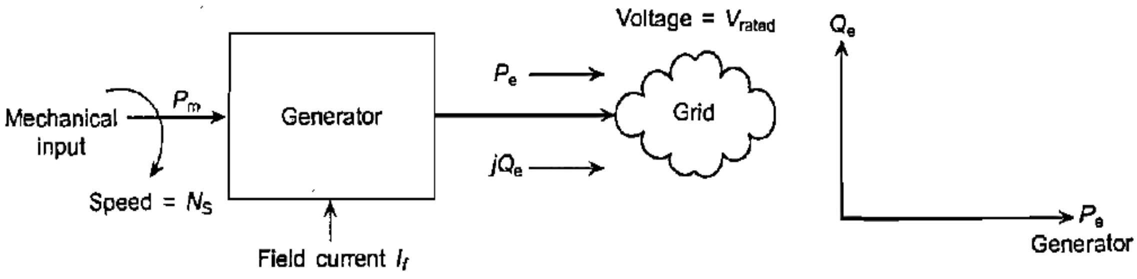
1- Loss of field to main exciter
2- Accidental tripping of the field breaker
3- Short circuit in the field winding
4- Poor brush contact in the exciter
5- Field circuit breaker latch failure
6- Loss of ac supply to excitation system

Effects

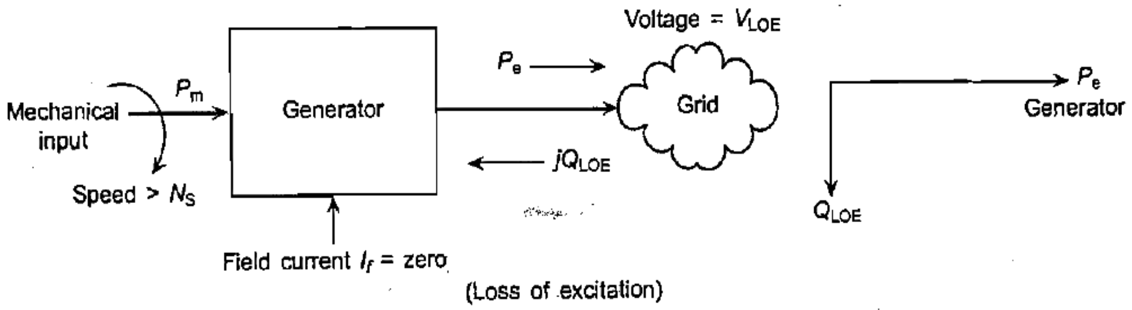
- ❖ Single generator:
    - Loses output volts and therefore load.
- ❖ Parallel generators:
    - Operate as induction generator (> synch speed).
    - Flux provided by reactive stator current drawn from system-leading PF.
    - Slip frequency current induced in rotor - abnormal heating.

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, $S = P + jQ$ 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 3.13 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].

3.6.6 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].

3.6.7 Over fluxing

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 1.05p.u. normally being indicative of this condition. Excessive flux can arise 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 (see Chapter 16 for transformer protection). 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

SIMULATION, RESULTS AND DISCUSSION

4.1 Introduction

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

4.2 ETAP Software

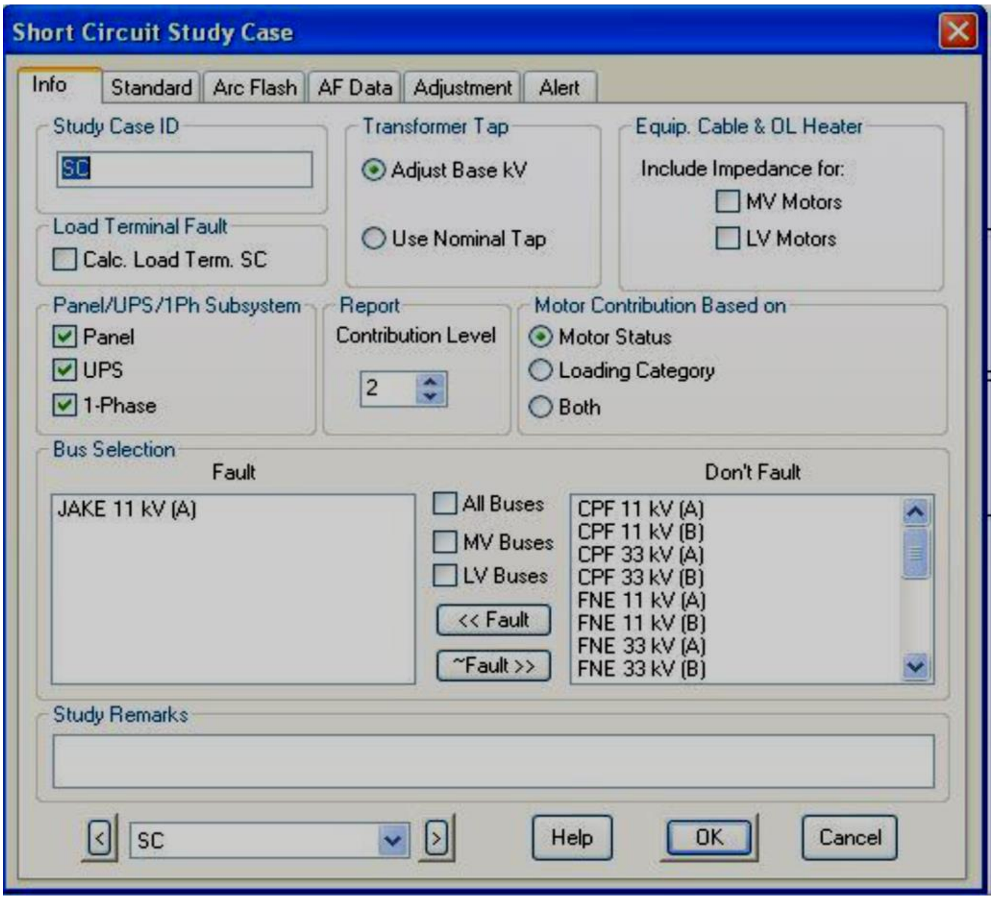
In a power system, one of the most critical aspects is the power system protection. Power system protection involves using protective devices to ensure that in the case of a short circuit or any electrical fault, system components are not damaged and as little of the system is such down as possible. 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

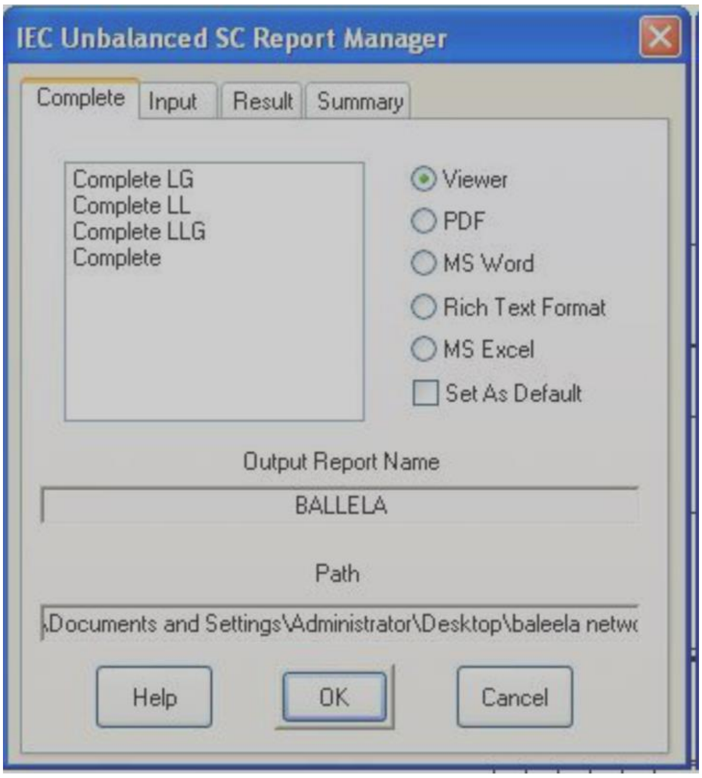
Bus Selection

Fault		Don't Fault
JAKE 11 kV (A)	☐ All Buses ☐ MV Buses ☐ LV Buses	CPF 11 kV (A) CPF 11 kV (B) CPF 33 kV (A) CPF 33 kV (B) FNE 11 kV (A) FNE 11 kV (B) FNE 33 kV (A) 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

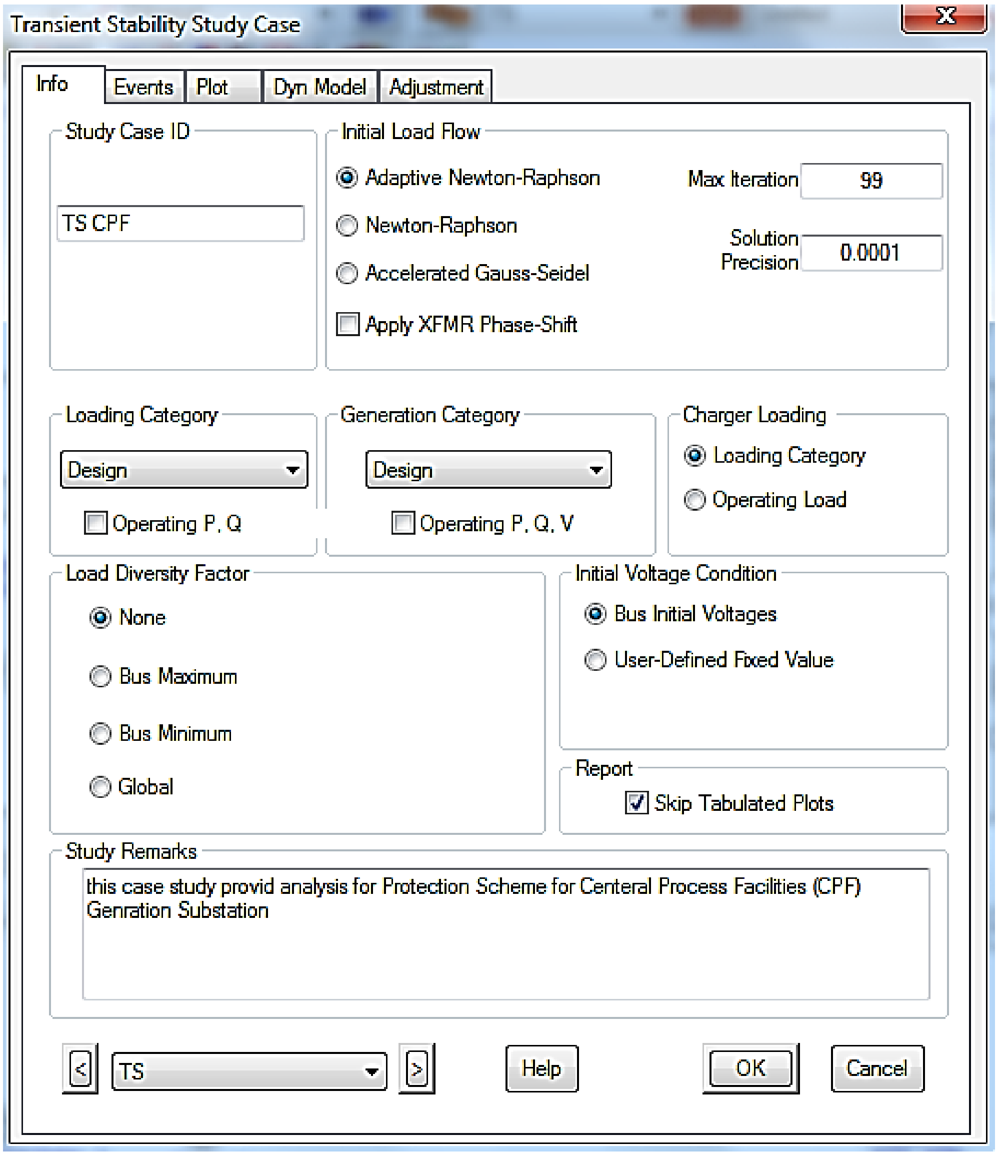
Output Report Name: BALLELA

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:



Transient Stability Study Case

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

Figure4.3: Transient stability case study editor

4.5 Fula Oil Field 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.
- FNE-1, FNE-2, Moga and Jake-1, Moga and Jake-2, KEYI-1 and KEYI-2 which are basically lump load on the oil field.
- Rolls-Royce generators (D, E, F, G) and Wartsila generator (1 and 2): Which are generators on Central Process Facilities (CPF) Power Plant of block 6 oil field in Sudan.
- OV: Voltage relay.
- Freq.: Frequency relay.
- Relay: Over-current relay.

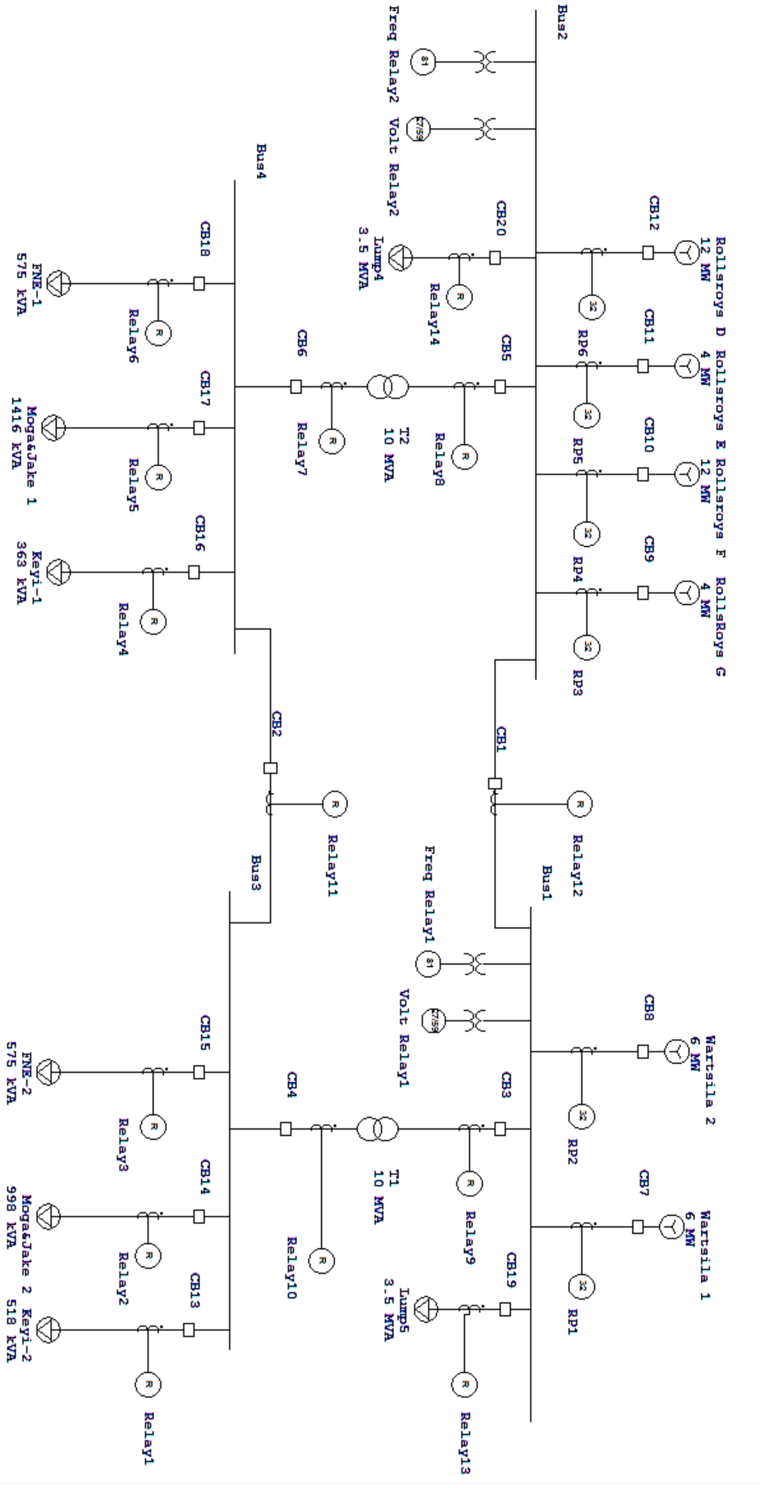
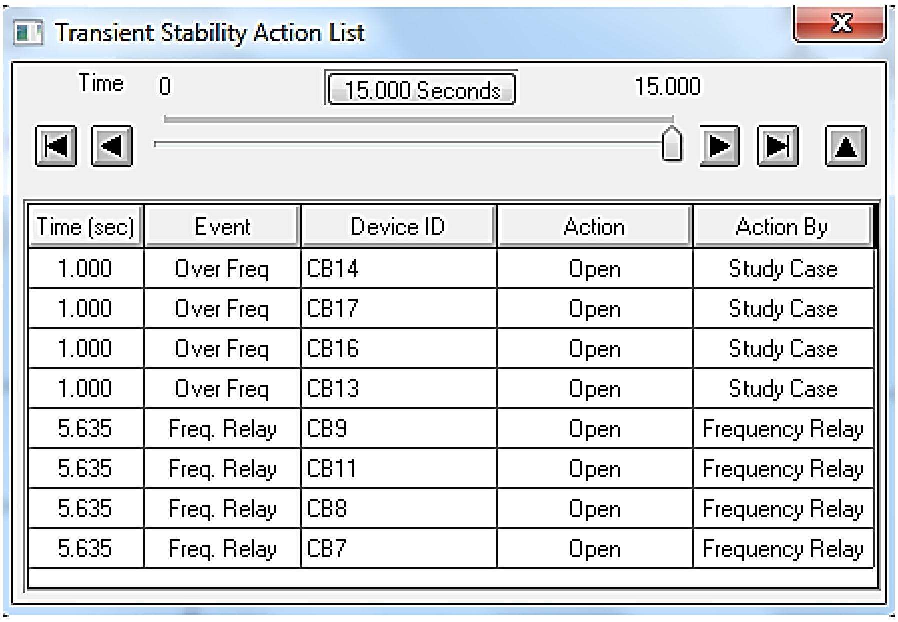


Figure 4.4 Single line diagram Fula CPF generation power plant

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 (i.e. by rejecting Moga, Jake and Keyi feeders) 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

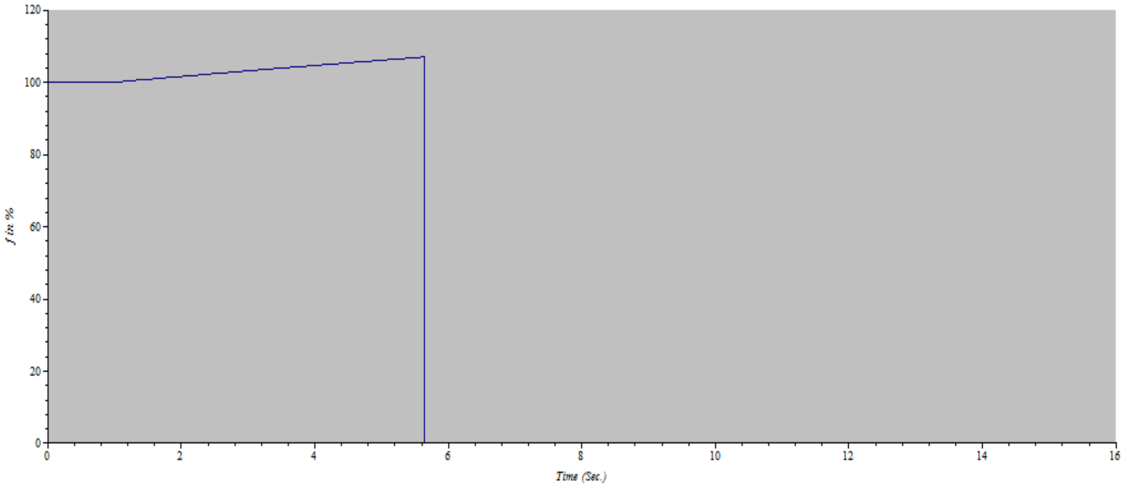


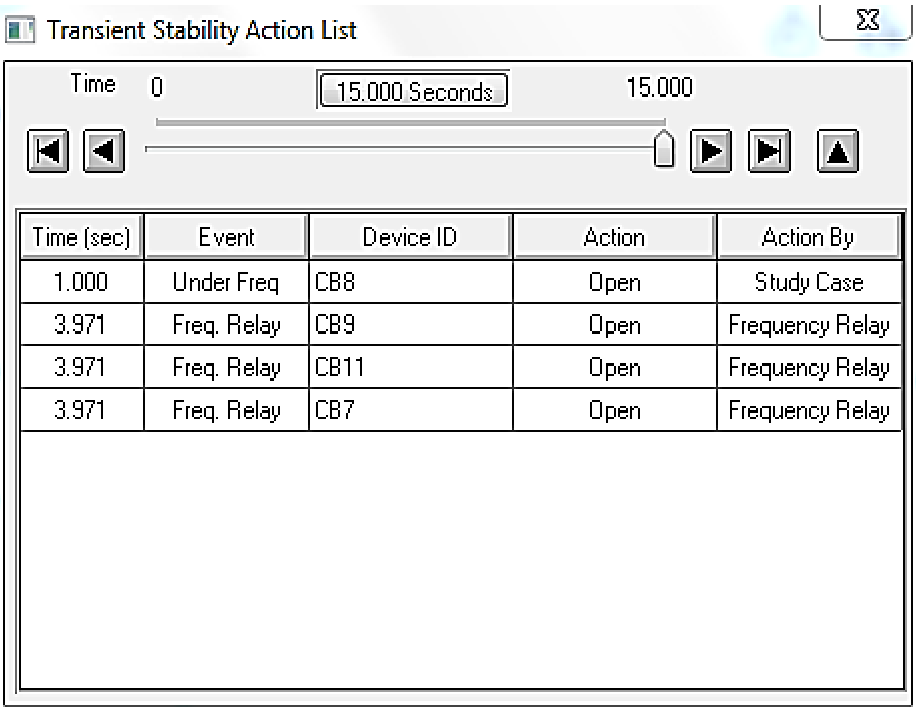
Figure 4.6: Over frequency condition frequency/time graph at Bus2

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

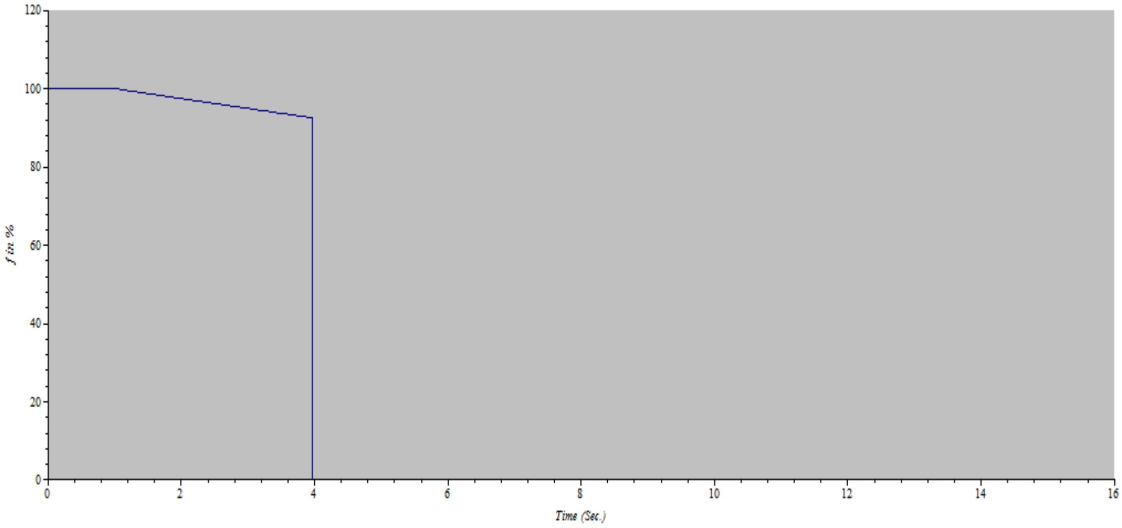
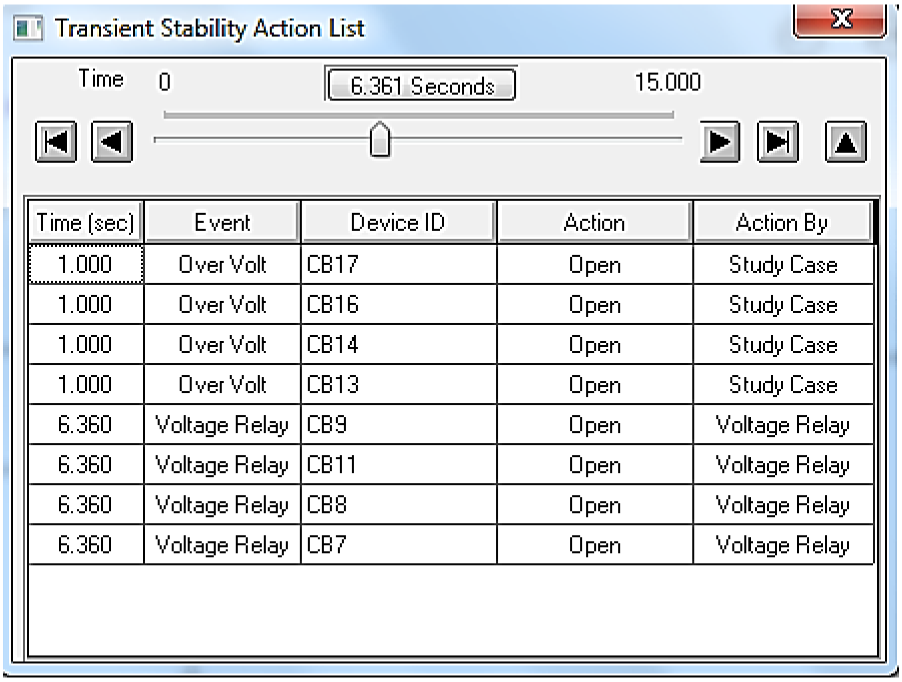


Figure 4.8: Under frequency condition frequency/time at Bus1 when the network is connected

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 (i.e. by rejecting Moga, Jake and Keyi feeders) 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

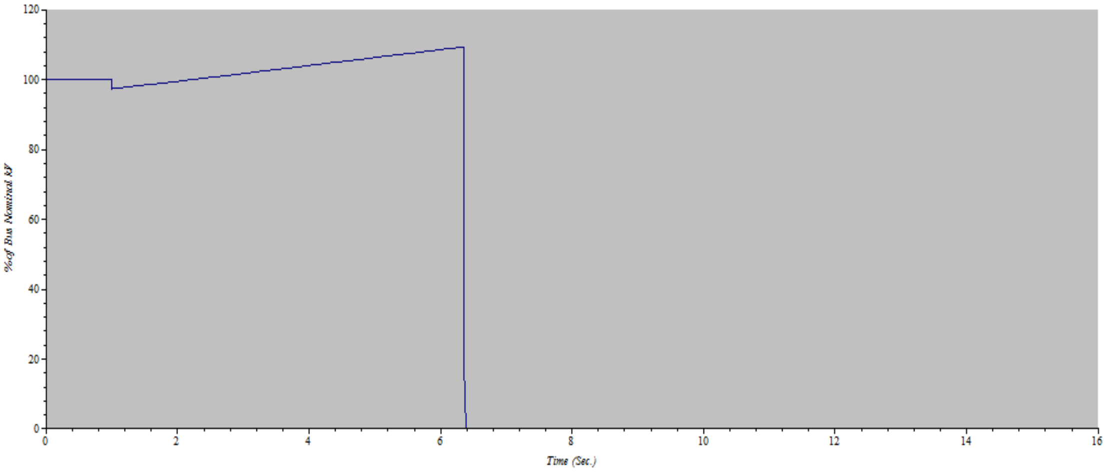


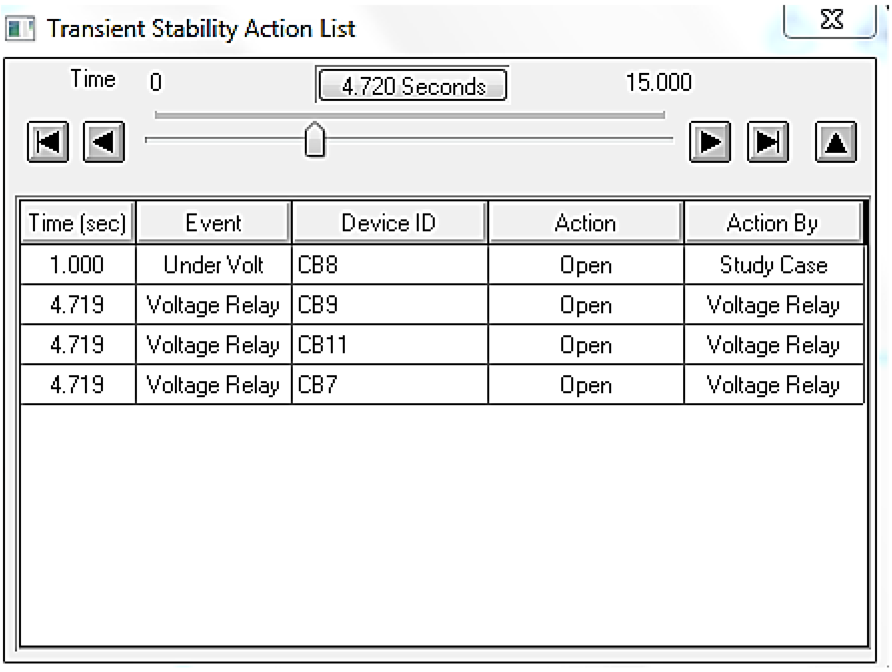
Figure 4.10Over voltage condition voltage/time graph at Bus2

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 Over voltage condition event and over voltage relay response

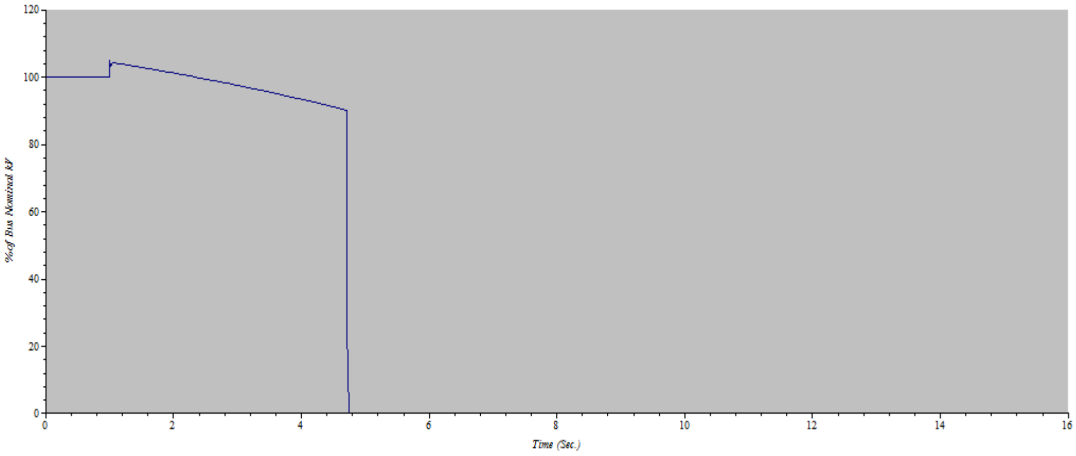
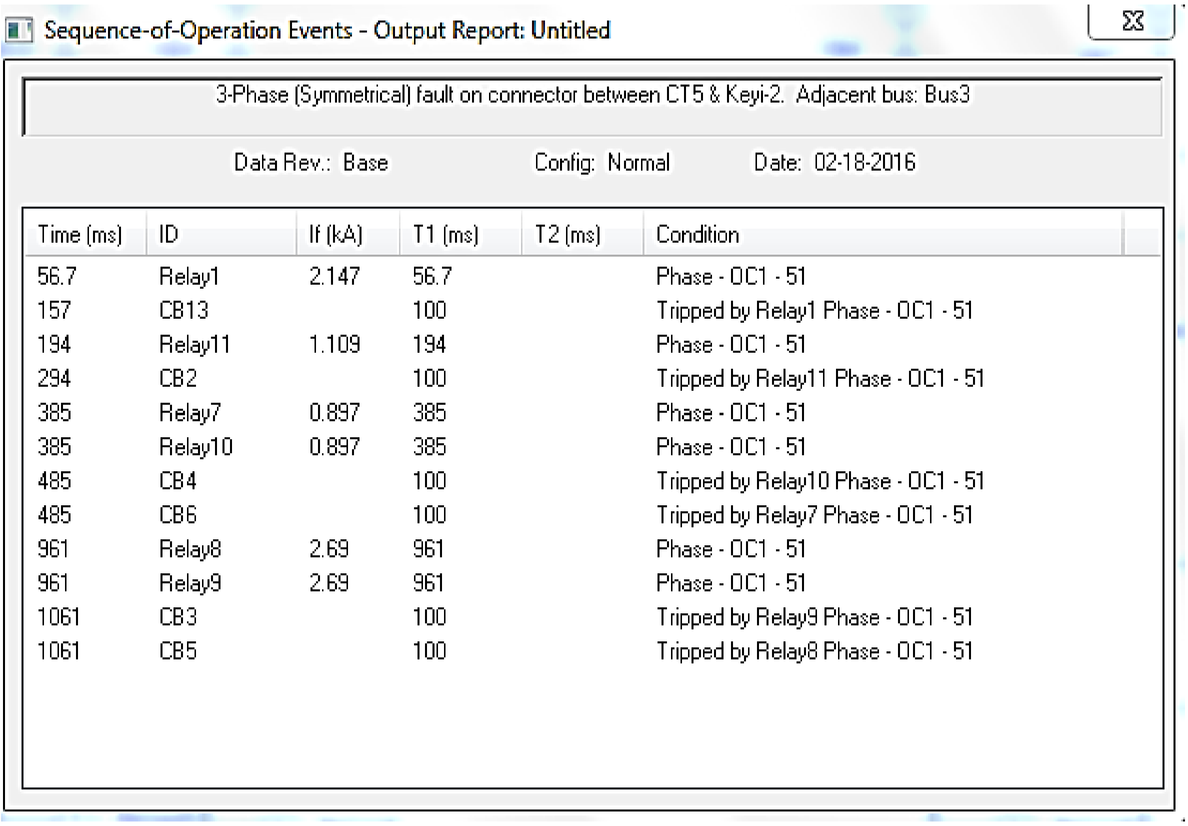


Figure 4.12 under voltage condition voltage/time graph at Bus2

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 KEYI-2 is initiated to examine the response of substation phase protection. Figure 4.13 show Relay responses to 3phase fault at Keyi2 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 KEYI-2 outgoing feeder.

- As a result of 3-phase (symmetrical) fault at KEYI-2 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 .

4.7 Results Discussion

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 KEYI-2 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

5.1 Conclusion

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 associated 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.

REFERENCES

[1] Napag,Protectine Relay Application Guide, Third Edition, (PRAG), (2006).

[2] Simens,Power Engineering guide E7,1 Edition.

[3] Block 6 Sudan oil field manuals (Rolls rosy &Wartsila generators), 2011.

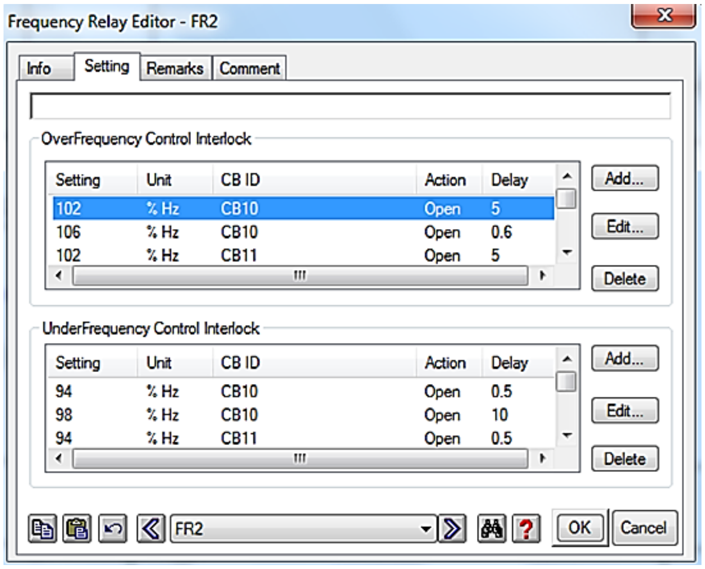
[4] Arun Phadke ,Protection Power System, Third Edition,2008.

[5] Leslie G, Practical Power System Protection, Hewitson, 2005.

[6] Prof.Mahmoud Gilany , Electrical Protection System, Cairo , 2006

APPENDIX

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



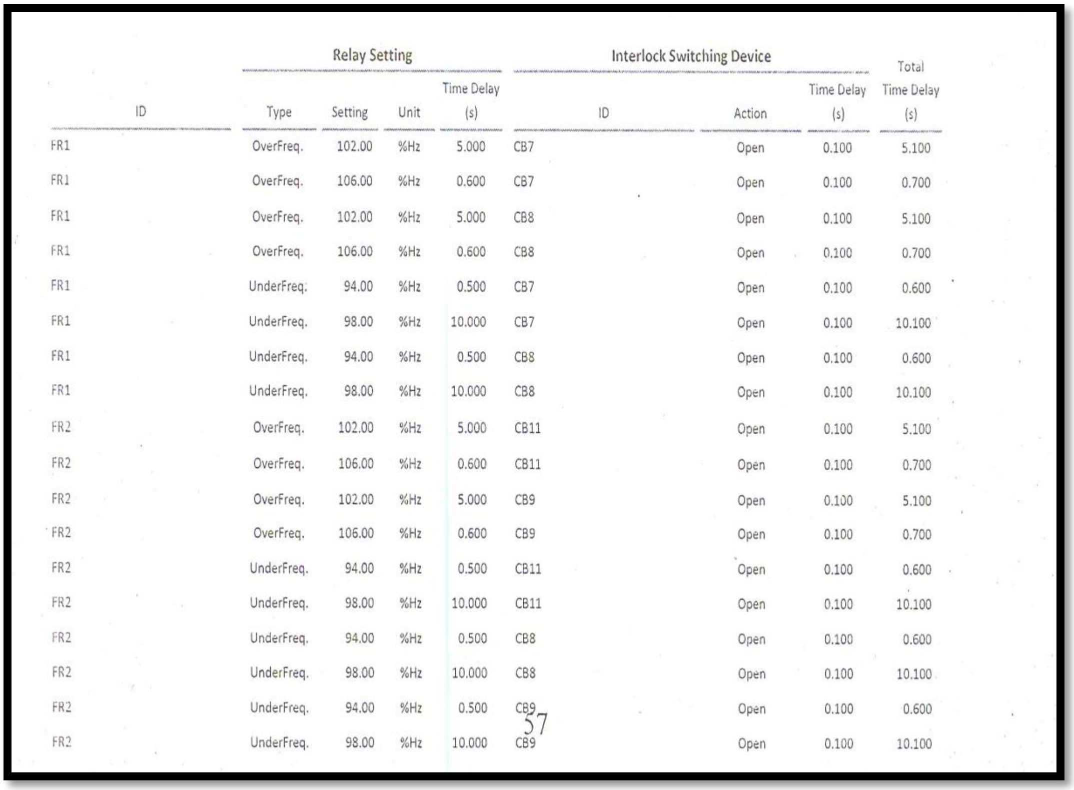
OverFrequency Control Interlock

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

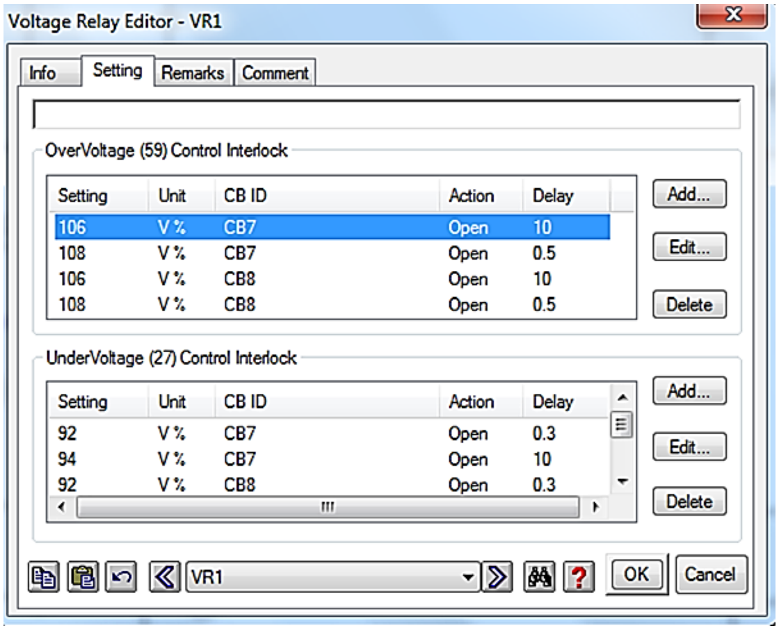
Figure A.1: Frequency relay setting



	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



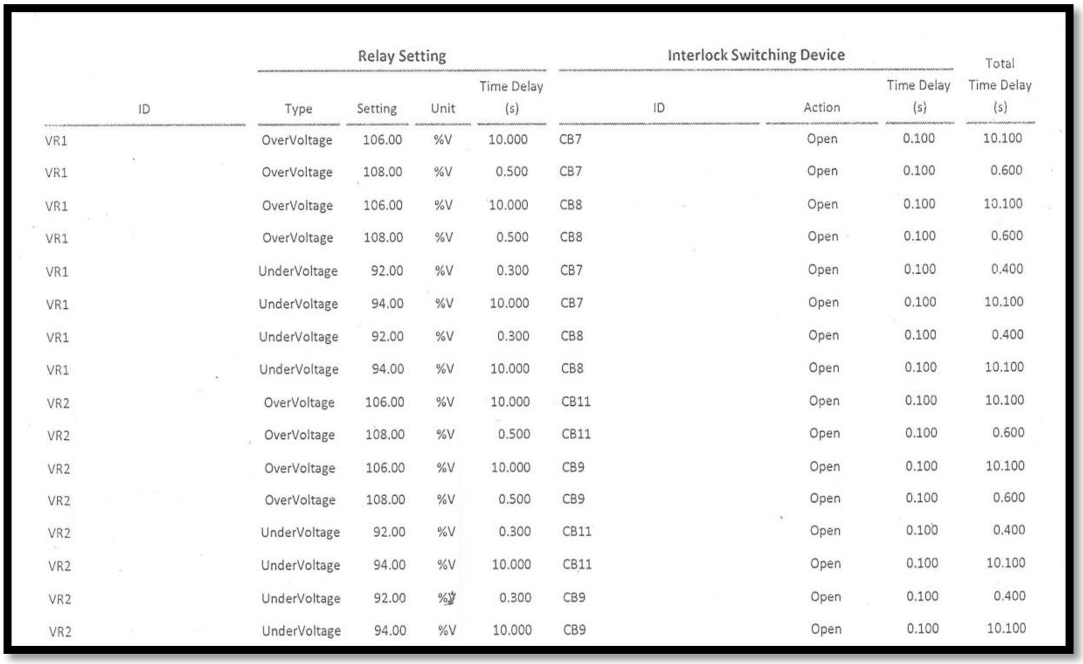
OverVoltage (59) Control Interlock

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



	Relay Setting				Interlock Switching Device			Total
ID	Type	Setting	Unit	Time Delay (s)	ID	Action	Time Delay (s)	Time Delay (s)
VR1	OverVoltage	106.00	%V	10.000	CB7	Open	0.100	10.100
VR1	OverVoltage	108.00	%V	0.500	CB7	Open	0.100	0.600
VR1	OverVoltage	106.00	%V	10.000	CB8	Open	0.100	10.100
VR1	OverVoltage	108.00	%V	0.500	CB8	Open	0.100	0.600
VR1	UnderVoltage	92.00	%V	0.300	CB7	Open	0.100	0.400
VR1	UnderVoltage	94.00	%V	10.000	CB7	Open	0.100	10.100
VR1	UnderVoltage	92.00	%V	0.300	CB8	Open	0.100	0.400
VR1	UnderVoltage	94.00	%V	10.000	CB8	Open	0.100	10.100
VR2	OverVoltage	106.00	%V	10.000	CB11	Open	0.100	10.100
VR2	OverVoltage	108.00	%V	0.500	CB11	Open	0.100	0.600
VR2	OverVoltage	106.00	%V	10.000	CB9	Open	0.100	10.100
VR2	OverVoltage	108.00	%V	0.500	CB9	Open	0.100	0.600
VR2	UnderVoltage	92.00	%V	0.300	CB11	Open	0.100	0.400
VR2	UnderVoltage	94.00	%V	10.000	CB11	Open	0.100	10.100
VR2	UnderVoltage	92.00	%V	0.300	CB9	Open	0.100	0.400
VR2	UnderVoltage	94.00	%V	10.000	CB9	Open	0.100	10.100

Table A.2: Voltage input data

Figure A.3 Show the over current relay setting.

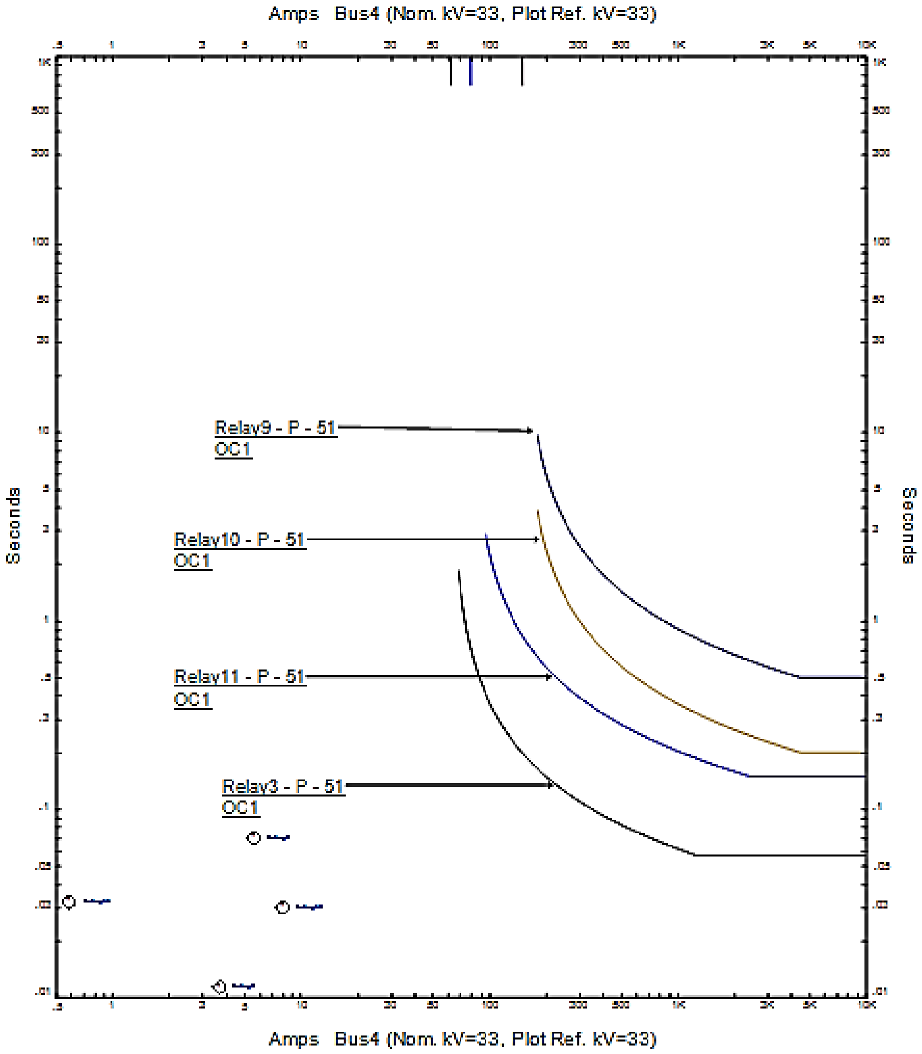


Figure A.3 0ver current relay setting