CHAPTER 1

INTRODUCTION TO DISTRIBUTION SYSTEM

1.1 INTRODUCTION

With the rising dependence on electricity necessities at local and commercial bodies, in both developed and developing countries, the need to attain an decent level of reliability, power quality and safety measures at an lowest possible price becomes more important to every type of customers. Preference of any electrical power supply system is that it should be properly designed and well maintained in order to meet a number of faults which might arise in a power system. Most important of this system is the protection system which isolates faulted system from healthy system and hence limit the damage to the equipments. Principal cause of fault is lightning discharge, tree fallen on transmission lines, overloading and deterioration of insulation. Using protective relays followed with current and voltage transformer we can measure electrical quantities and make decision for the operation of circuit breakers after crossing critical electrical quantities.

A power system is not simple as it looks like; there are several series and parallel branches followed by Bus bar, Transformer, Transmission line, Reactors and Compensators and many more. Protective system which is installed is HRC fuses, reclosers, overcurrent relay, over and under Voltage relay, under and over frequency relay, distance protection and backup protection and many more. Assembling these protective devices is not the only work of protection engineer. For a protection engineer each and every parameter is essential for the coordination purpose and engineer must assure that an electricity distribution network can act within present requirement for safety of individual items of equipments, public and overall. Automatic is necessary in the present world to reduce down the electricity wastage.

1.2 Based on feeder connection electric power distribution classification is given below-

1. Radial Distributed System.
2. Parallel Feeder System.

3. Ring main distribution system.
4. Interconnected distribution.

1.2.1 Radial Distribution System:

Electricity board radial distribution system when Customer is around the subsystem. In this electrical power distribution system, various feeders supply electrical power from a substation (Source or generating station) and feed this power to distributors located near around substation. It is different from other distribution system because in this system power flows unidirectional i.e. from source to the load. Electricity distribution board prefer this type of connection because of its simplicity and low cost but it is not highly reliable when compared with other system. It is not reliable because if fault occur at any section of feeder then supply may interrupt or tend to supply failure which is not desire from customer point of view. Figure 1 shows electrical radial distribution system in which power is infeed from one end (also known as Source Side) and sinks are present at various locations. One or more transformer may use in parallel to feed power at load end in this distribution system.

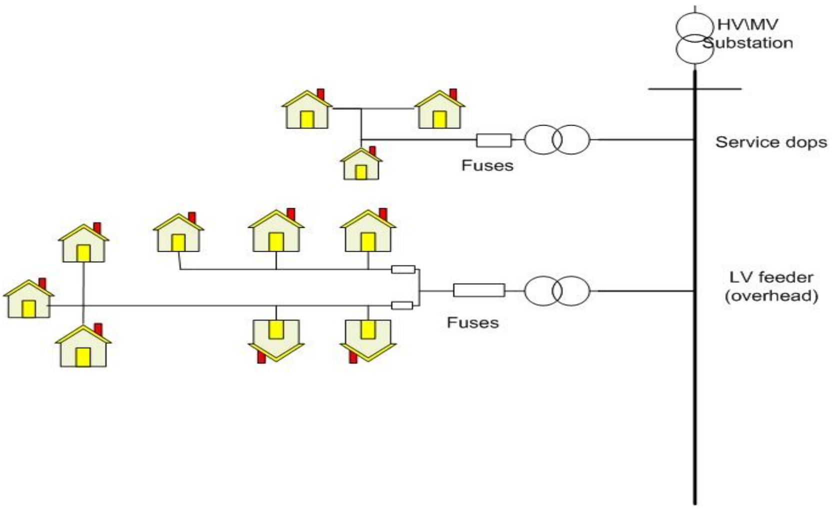

Figure 1: Radial Feeder System

1.2.2 Parallel Feeders Distribution System:

Disadvantage of radial distribution system can be minimised by using parallel feeder distribution system, here instead of using single feeder line distribution board multi-parallel distribution system. When comparing cost of parallel feeder with radial feeder system then its cost is high but it also improves system reliability by using multi feeder, as if one feeder become out of service then other feeder can supply power to load end. This system is preferred where load is high and reliability is an important factor.

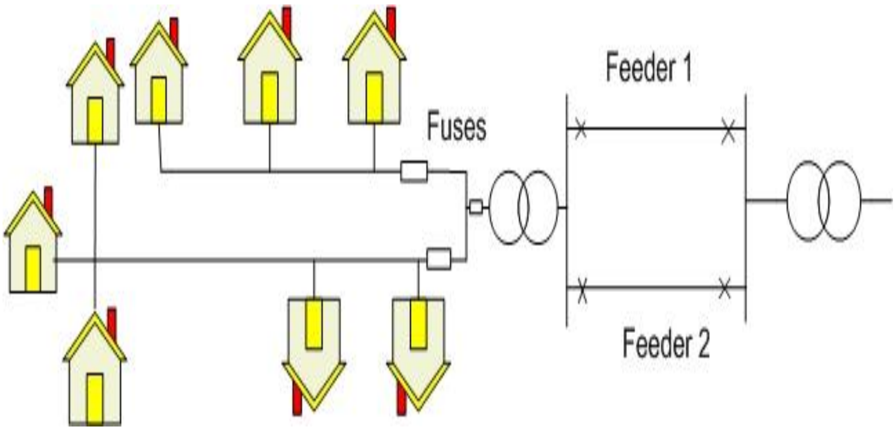

Figure 2: Parallel Feeder Distribution system.

1.2.3 Ring Main Distribution System

It is one of the highly reliable systems when compared with radial and parallel feeder system; it consists of one source and distributers or load centre as shown in the figure 3. Every distributer or load centre is connected from two ways power supply from both ends, which insures that if one feeder is out of service then power can be gathered from other feeder also or if line maintenance is performed the without interrupting any load electricity can be distributed. It looks like this system created a loop of power flow.

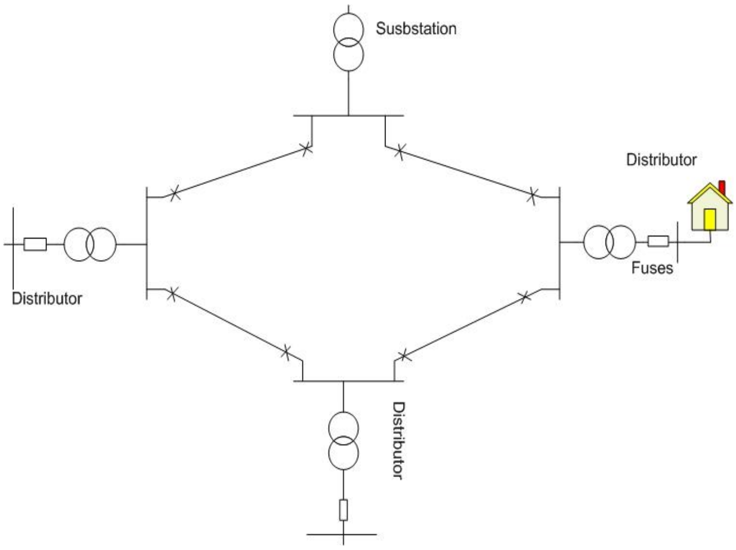

Figure 3: Ring Main Feeder system.

1.2.4 Interconnected Distribution System

This is a special case of ring main feeder system, i.e. when a ring main electric distribution feeder is energized from two or more local generating or utility grid then this makes an interconnected distribution system. Its reliability is good and needs more protection and accurate coordination for the protection of this system. One big most important advantage of selecting this distribution system is that is one generator fail to supply power then this power can be feed from the other generating station.

1.3 PROTECTING ELECTRICAL POWER SYSTEM

The basic and most important objective of protecting the electric power system is to provide fast isolation of electrical equipments in order to minimize the damage. It should be clear that protection devices work after intolerable sensing values. Following are some basic aspects of the relay application in whole power system.

- Reliability
- Selectivity
- Fast operation
- Simplicity and Clarity
- Economy

i. ELECTRICAL PROTECTION EQUIPMENTS

For the protection of power system some devices is needed which should have to sense the acting quantity (Relay), break the circuit if rules are violated (Circuit Breaker) and if system become healthy after some time make it in close position. These equipments are described below:

1.3.1.1 Circuit Breaker: it is an electrical switch which operates when a signal comes from the relay to operate. When relay signal reacted than breaker either open or close through some secondary means like motor or manual, in short it is a secondary mean controlled switch. This switch is usually operated when uncertainty comes in the selected line or portion. Its simple function is to break the connection in a line when signal received from the relay. These devices are largely used at houses, college's factories and even at distribution and generating plants but their shape and sizes are different. It is available in low voltage (1000V), medium voltage (72KV) and high voltages (above 72KV). With rise in voltage its shape becomes larger, use of insulation oil, use of insulating gas and eases mechanism. Its power deliver capability is very high then its use

Figure 4: ABB SACE E2 1250A Air Circuit Breaker of ABB.

Every circuit breaker has common operation i.e. NO or NC, it varies in characteristics like delay time, current capability, voltage, arc flash, open and close resistance and leakage current. Above figure 4 shows ABB air circuit breaker used at 11KV phase voltage.

1.3.1.2 Overcurrent Relays: It is an electrically managed switch which sense the relay input (Current and Voltage) and creates decision such as open or close according to the logic provided into it. There are many types of relay such as electromagnetic, solid state and microprocessor (Numerical/Digital) based relay. These relay are built to detect uncertainty into electrical lines and equipments i.e. these relay measure voltage, current, phase and frequency. Electromagnetic relay was invented at 1835 by Samuel Thomson for the electric telegraph (used in long distance telegraph circuits as amplifiers) and it is very famous till 1960 i.e. before the invention of static relay. In electromagnetic relays, manufacturer uses multiple coils in order to provide various relay applications. Solid state relay are introduces in 1960s and it is famous till 1969. This relay uses transistors, resistor, capacitors and inductors etc. Microprocessor based relays uses microprocessor and ICs. Using these relays user can edit curve, setting, and time dial and choose many relay functions within a single unit. These are highly recommended at high power applications and costly equipments due to its preciseness, accuracy, self medicate when error occurs and fast operation.

Using both relays and circuit breaker is not enough to control the circuitry but it needs some external equipment also such as CT's and PT's. Both of these gives input to relays to sense the current (5A) and voltage (110V). Figure 6 shows ABB digital multifunction relay. Relays are installed at each feeder, transformer (Both HT and LT side), transmission line (at both ends uses differential overcurrent and overcurrent) and generator. Two types of protection scheme are used for the protection of costly and highly valuable equipments i.e. backup and primary protection.

Figure 5: ABB REU615 Digital Relay for line protection.

1.3.1.3 Fuses

Fuses are the simplest interrupting device among all protective device from overload and short circuit. It can be used up to 33KV (Medium voltage). Modern High Rupturing Capacity Cartridge Fuses (HRC) provides reliable and accurate characteristics. It is also said as ADS (Automatic Disconnection of Supply) because it disconnects the circuit automatic whenever overcurrent flows through it.

Figure 6: Miniature time delay fuse having 100 sec for .3A and 15A for .1 sec.

Types of devices with fuses:

1. Rewireable Type: these types f fuses can be seen into the houses, these can be pulled out and rewired after it blown off.
2. Cartridge Type: these types of fuses element are totally enclosed in a container and provided end to end contact on both sides.
3. High Rupturing Capacity Cartridge Fuse: A cartridge fuse link has high breaking capacity, higher than specified values (i.e. above 16KA).
4. Striker Fuses: it is a device which incorporates fuses and a mechanical devices, its operation releases the striker with pressure and displacement. Striker is used for signaling purpose.

1.3.1.4 Recloser: this device is used to automatically reclose and energise the circuit breaker after fault, it has the ability to identify phase and line overcurrent condition. After recloser operation if still current is high then circuit breaker will again close for some duration, after then it will again check for the current. After some recloser interval this recloser will isolate the faulted section permanently till reset. About 80-95 percent fault is temporary in nature, only 5 percent of fault is permanent thus need special attention. It is designed in such a way it open-close circuit breaker for up to three times.

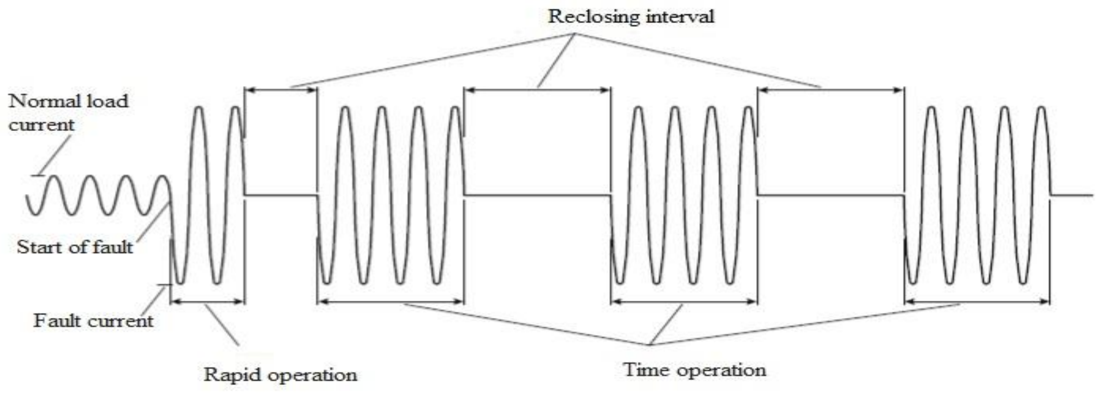

Figure 7: Reclosing operation

CHAPTER 2

LITERATURE REVIEW

In this research paper, a deep focus is made on current setting, current set point, curve characteristics, time dial and other relay features which are the important for relay selection. Also coordination is verified by IEEE and ANSI standards using ETAP, and sometimes curves are edited. Acting time could be varied by varying time dial (time grading), current setting (Current grading) and through curve characteristics. Proposed model is first verified by the load flow analysis and voltages at every node are maintained by selecting proper admittance of the power system elements. All these elements are verified by NEC & ANSI standards. Some values are auto-selected while other user has to. Voltage & current should not violate the rules defined by ETAP, if any value is violated then report will show red dark highlighted colour over it. Below are some literature review based on the overcurrent coordination and load flow analysis.

- After studying load flow analysis, Star view comes up for the power system protection. Relays are selected according to the application needed i.e. for each and every element ETAP created a library link; from there user can access these libraries. Values are calculated on the basis of acquitting quantity and with correspondence to that relay setting are chosen by users. For different applications different characteristics are chosen & are listed in the upcoming proposed model chapter. Any faults could be applied by the user on feeders, lines and equipments with own intensions and sequence of operation could be seen. Whenever this coordination techniques are revised coordination may get improved.
- Poonyapa Sookrod and Paramet Wirasanti[1] et al presented a research paper on relay coordination for radial system; DG may have a negative impact on the cooperation of overcurrent relays with respect to different rates of short circuits. Overcurrent relays are essential to guarantee power station efficiency by preventing system failure and unwanted failure of the good portion of the scheme. Based on the ability and place of the mounted DG, the relay configurations must be altered. Furthermore, to preserve protection cooperation, the impacts of DG existence on current relays must be explored. To solve the issue of relay cooperation, this article proposes an overcurrent relay communication instrument.
- Param Mehta[03] et al has presented a paper on modelling of overcurrent relay for radial feeders using MATLAB/simulink, this use IEEE and IEC relay curve characteristics. Correspondingly, the Simulink block output is verified and the inverse characteristic graph of the IDMT is acquired for varying time Multiplier Settings and Plug Setting Multipliers values. In fact, a developer-friendly Gui Software is intended to make it easy for users to run the radial feeder system by putting relays at different parameters and checking the network's efficiency and efficiency for distinct fault places.
- Ÿ GU Cailian and JI Jianwei[09] et al proposed a research paper on feeder protection in micro grid, there in which they have taken care of distributed generators connected system and its effect using software PSCAD. Conventional

power distributed system is turned from a single power power supply radial system into more than one power supply loop system, the trajectory of the power flow is altered, so the micro grid running in the grid-connecting mode and two types of operating mode of connectivity and isolated island switching cannot be finished. In article, impact on the micro-grid relay security is shown to fix the issue of micro-grid relay safety, according to the demand sensitivity of the buffer system, the present differential protection system and the inverse time overcurrent protection system are developed, the simultaneous action defense approach is intended, the simulation outcomes with the standard micro-grid.

- Hima A. patel and Vaibhov M. Sharma[08] et al has presented a paper on relay coordination where in which they used a large interconnected system using ETAP application. The whole research paper introduces short-circuit study and relay coordination of overcurrent relays of an industrial plant's radial power grid capability of 1218.5 MVAsc using stage modelling and hand computation and contrast of outcomes using techniques. The technique of short circuit study described here is the technique usually used in companies with regard to Schneider Electric's ect 158. The technique of relay cooperation used in this study is focused on manufacturing guides and IEEE journals.
- The concept of distribution system topologies is defined well and good by Venkatesh and Ranjan [38] using load flow method for radial distribution system. An effective distribution load flow technique performs a critical part in radial distribution system automation techniques that include fault detection, network reconfiguration and system recovery. Automation algorithms ' capacity to manage these complicated duties requiring periodic topology adjustments in the Radial distribution system requires a dynamic topology algorithm centered on a well-defined data structure. Generated data structure is used for the proposed load flow algorithm. This method is good over many other load flow methods.
- To analyse radial distribution system Gosh[55] and Das has presented a paper on load flow solutions, simple equations is used, effect of capacitance charging and magnitude-angle accuracy is also taken into care. While this system is efficient in terms of the speed, accuracy and preciseness.
- For the protection of radial distribution system by Amim Zamani, Amir Zamini[25] et al an easy method for the coordination of radial distribution system protective devices with multiple DG's is implemented, this paper addresses the problem of

protection flashing. The suggested approach advantages from numerical-based reclosers and directional components for radial feeder relays and tackles problems of security detection, fake tripping, recloser fuse and fuse-fuse mismatch and failure of self-reclosure. This case is studied in PSCAD/EMTDC application software that offers similar accuracy as ETAP.

- How much coordination is important for radial feeder and parallel feeder is discussed by the Acharya Sandesh[05] et al in his paper with different locations in radial feeder system and in order to guarantee continuous power supply to the load, its inspection must be worked out fast. Protection and integration of systems is an essential component of mitigating the failure. The study focuses on models and evaluation of the alignment of present relays for radial feeder systems. This study paper coordinates overcurrent relays for radial feeder systems to analyze time current features on ETAP application. Coordination between the relays and the corresponding protective devices is concentrated on efficient engagement of the relays. The main relay backup security is accomplished through the optimal time frame of coordination between both the relays. Essentially, suitable relay coordination removes the fault, rendering the security more secure.
- Paper presented on radial distribution system and effect on DG is disused by the J. A. Sa'ed and S. Favuzza[12] et al, they did simulation on MATLAB and POWER WORLD simulator. In addition to a variety of advantages, the introduction of DG systems into the distribution scheme presents some severe difficulties; privacy conditions are one of the most important problems in DG implementation. Adding DG to the project contributes to branch flows being redistributed, so standard security ideas need to be amended. DG's impact on the cooperation of protective devices is vulnerable to the setup of the delivery scheme, DG magnitude and place of the DG. In this study, the possibility for mismatch among radial power network systems is reviewed along with distributed generator capacity. The entry rate, amount, and place of interconnected DGs are used as variables to check DG's impacts on present fault status. DG capability limit status is provided while the local supply network security system can be retained.
- A very simple approach is made by Muhammad Yousaf[02] et al on their research paper on coordination for various system with multiple DG. The significant effects inflicted by DGs on a standard distribution scheme are increased error present size and modifications in energy supply instructions. This paper also

discuss with recloser-fuse coordination, relay-recloser coordination for both temporary and permanent fault. The strategy suggested introduces the recovery of recloser-fuse coordination for late-DG inclusion impacts to use a recloser's directional characteristics. This proposed paper used a highest voltage of 11KV and unidirectional power flow; they also introduced setting for relay for both upstream and downstream. Even though fuses do not have a specific function, they must be substituted by recloser if fuses were to be intended for directional security. The fault flow through the feeder relay is still one-way, so a specific ownership of this relay is not required.

- For the protection and coordination of power distribution system K Anupreyaa[06] et al, this paper discuss about the sequence of operation and relay characteristics needed for the protection using ETAP software. The goal of protective relay cooperation is to accomplish selectivity without loss of vulnerability and rapid removal of faults. Relay monitoring is a significant element in the layout of the safeguard scheme, as coordination systems must ensure rapid, targeted and safe contact procedure to prevent failed parts of the power system.
- Every New Year new sources are introduced in the power system, regardless of new characteristics these sources are used in power system. Yeonho OK and Jaewon Lee[07] et al has discussed relay coordination with sudden rise in input of renewable power system, this paper discuss about the current setting and its changes. This paper deals with Korean electric power corporation system for the relay coordination and number of operation required and if system fails then alternatives are used.
- For the complex power system, it is required to provide perfect coordination and best relay which is discussed by the Yawen Yi and Na Yi[26] et al in his research paper. This paper deals with difficult seen in power system when coordinating with largest sources in the power system.
- Divya S Nair[13] et al has presented a research paper based on relay coordination and discrimination based on the current setting with its solution. The choice of suitable configurations of these relays under different system circumstances performs a significant part in the timely abolition of the defective energy scheme segment. For a power system each relay is coordinated with the types of itself and other self also with various characteristics curves.

CHAPTER 3

MODELLING FOR SHORT-CIRCUIT CURRENT CALCULATIONS

3.1 R-L Transient Analysis

Sort circuit in a power system is very common in day today life and are characterised by its variation in magnitude of fault current, this change in fault current magnitude is because of thevenin equivalent of system impedance at the fault point. A short circuit produces two components when fault happen first is DC decaying component and second is AC decaying components this is because of the storing elements. When fault occur at any point, system impedance and current do not change instantaneously, if equivalent system's resistances and reactance are taken into account at the fault point of system, then it result in a decaying DC component.

Instantaneous system voltage, system equivalent resistance and inductance and power factor at the fault location will describe the rate of decaying of both AC and DC components of the system after fault. To show the comparable calculation faults measuring quantity should be a function of time "t". Let's suppose fault happened at t = 0, for finding constant values t = 0 should be used. Current just after the fault is equal to the current just before the fault, by using differential equations nonlinear equations can be created to understand AC and DC components in more deeply and also it will provide a clean image of it. This can be analysed by the simple series RL circuit as shown below in figure 9 having system voltage $V_{max}Sin(\omega t + \alpha)$

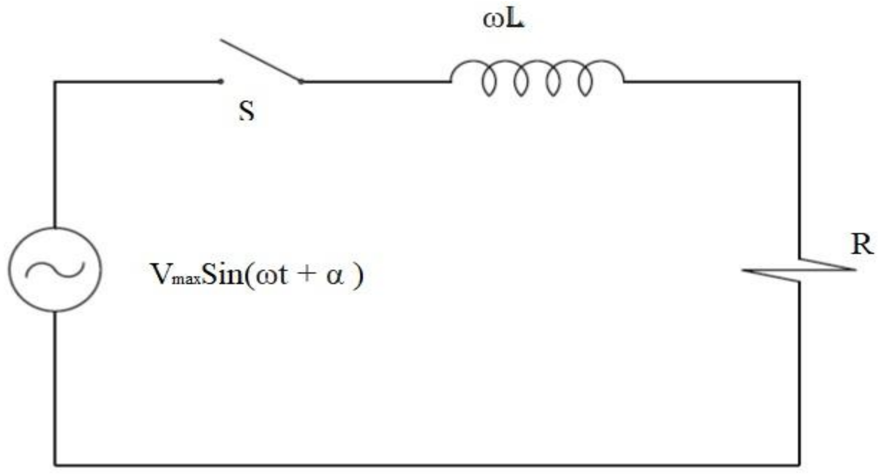

Figure 8: RL circuit for transient analysis

Above system equation can be written in differential equation as shown below

$$e(t) = L * \frac{di}{dt} + R * i(t) \quad (3.1)$$

$e(t)$ is the system voltage, L is the series inductance, *i (t)* is the series current and *R* is the series resistance.

I (t) can be broken into two parts as shown below

$$I(t) = Ih(t) + Ip(t) \quad (3.2)$$

Here,

$Ih(t)$ - Homogeneous equation corresponds to the transient period.

$Ip(t)$ - Particular equation corresponds to the steady state period.

Differential equation 3.1 can be solved as:

$$i(t) = Vmax * ZSin(\omega t + \alpha - \varphi) - Sin(\alpha - \varphi)e^{\frac{-Rt}{L}} \quad (2.3)$$

Where α - closing angle

$$Z = \sqrt{R^2 + \omega L^2}$$

$$\varphi = \tan^{-1}(\frac{\omega L}{R}) \quad (2.3)$$

From equation 2.3 it is clear that current consists of sinusoidal and exponential terms, second term decrease with the increase of time and first term will vary with time. At t= 0, second term is zero, if system is resistive than after disturbance current will be zero. Second term i.e. DC component will be maximum when $\alpha - \varphi = \pm \pi/2$, and zero value when $\alpha = \varphi$. AC component will be maximum at $\omega t + \alpha - \varphi = \pm \pi/2$, and minimum when $\omega t + \alpha - \varphi = 0$.

When fault happen in the RL circuit under that negative peak of sinusoidal component then exponential components of system reach its ideal maximum value after half sinusoidal cycle. To calculate the total system current (both AC and DC) can be expressed from the following formulae.

$$I_{rms.asym} = \sqrt{I_{rms}^2 + I_{DC}^2} \quad ()$$

3.2 Effect of rotating machinery

At machinery terminal decaying AC current is produced and it is very much similar to the above RL system. This decaying pattern is shown below in figure 11, as a fact that machinery magnetic flux does not change instantaneously and also the current before and after the fault is equal.

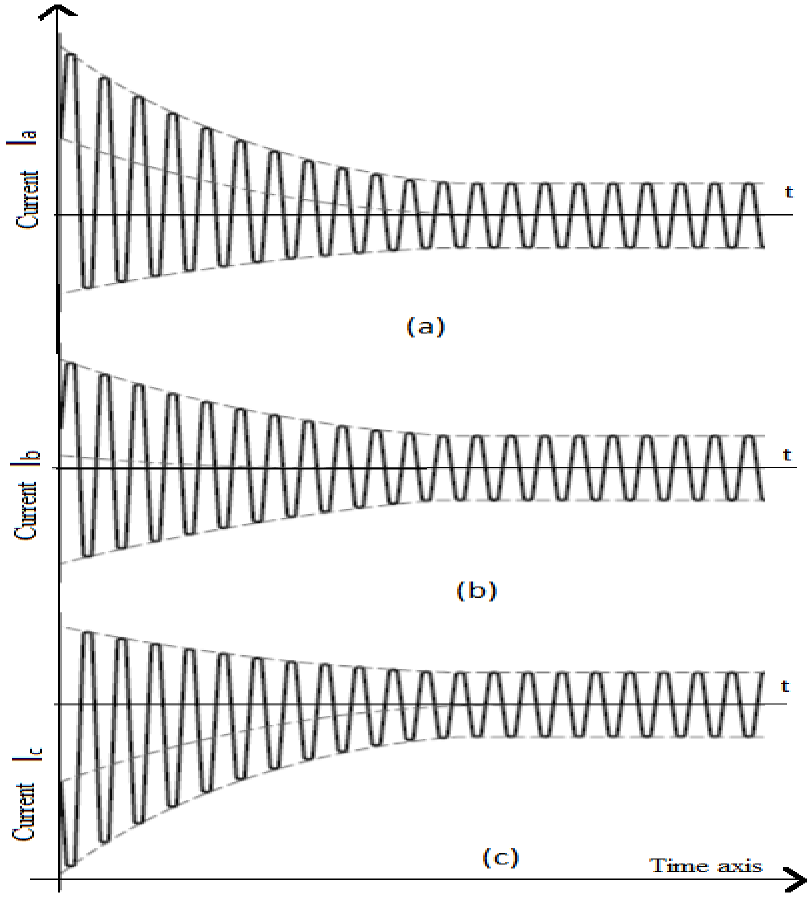

Figure 9: All phases Transient short-circuits currents of synchronous generator: (a) typical A phase short circuit current; (b) B phase short circuit current; (c) C phase short circuit current.

From above figure 11 it could be seen that current gradually decrease with time, it is because of the reduction of the magnetic flux caused by decrease in m.m.f. of machine field winding or RL circuit. This is also known as armature reaction. Reactance which varies with time is very difficult to describe in equation but it can be understood through differential equations, each and every storage element i.e. capacitor and inductor should be shown in differential equation. Variation of current is because of transient, sub transient and steady state current. This current is generated after the fault or after the switching performed. Transient current is the current just after the switching performance, sub-transient is the current after the transient cycle. When the variation becomes stable then this current is steady state.

Chapter 4

Radial Feeder Protection

4.1 Protection of Radial feeder with Overcurrent Relay

Overcurrent relays are very common in electrical power system to protect radial feeder and other feeder system also against over current in feeders. Protection of radial feeder is attain by installing circuit breaker and relays at various locations nearer to load and to the feeder & transmission line. These overcurrent relays are associated with current transformer (CT's) at the infeed, load and feeder. For simplicity, circuit breakers are installed at infeed of every feeder segment which can be seen in figure 16 .In this exercise most of the figures are simplified. The power transformer and fuses at substation buses A, B, C have been erased.

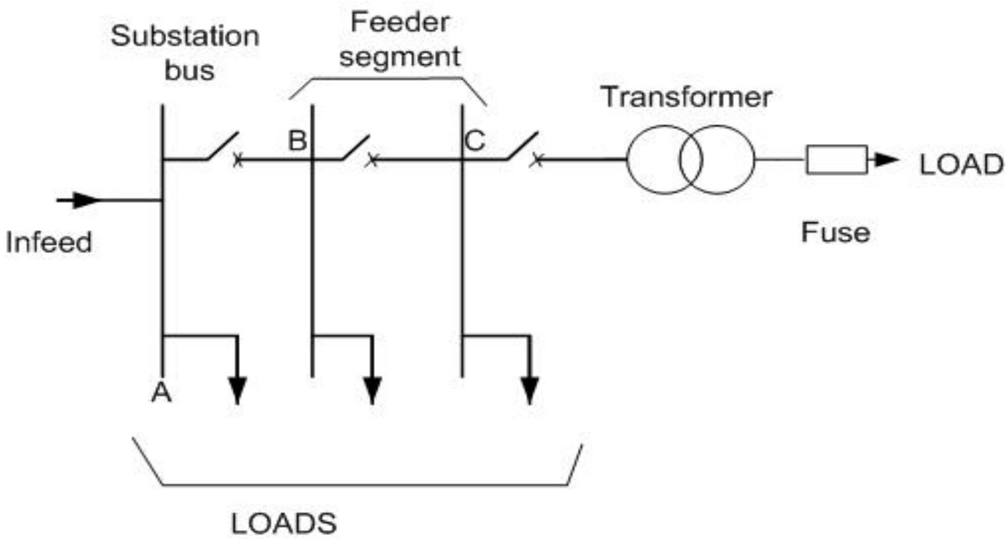

Figure 10: Single-line diagram of a radial feeder with overcurrent protection located at feeder A, B and C.

In a radial feeder protection system use of protective elements along feeder line is necessary to use proper and selective protection system in accordance to load. It should be so connected that under the abnormal conditions faulted part must be removed from healthy part and therefore limits the number of loss of loads. It is never accepted that for a big and heavy load feeder some protection devices are installed or single relay is installed in above figure 16 because if fault happen the whole feeder get out of operation; even fault is at fuse side.

To obtain proper selective operation of circuit breaker and relays, the operation of relays and circuit breaker delay timing must be acceptable and coordinated. This is termed as relay coordination and relay Grading. In brief, it is suggested that under fault condition circuit breaker nearer the fault must be tripped with suitable characteristics like IDMT, inverse, very inverse, definite, extremely inverse characteristics (some are given in appendix III). For the fault shown in the below figure 17 nearer to the transformer first circuit breaker C must be acted first than circuit breaker B and finally feeder A circuit breaker must be acted with some delay and characteristic. Delay to trip is chose such that it must be in sequence to lower down the minimum loss of load and must not be un-coordinated in any case and fault at any location.

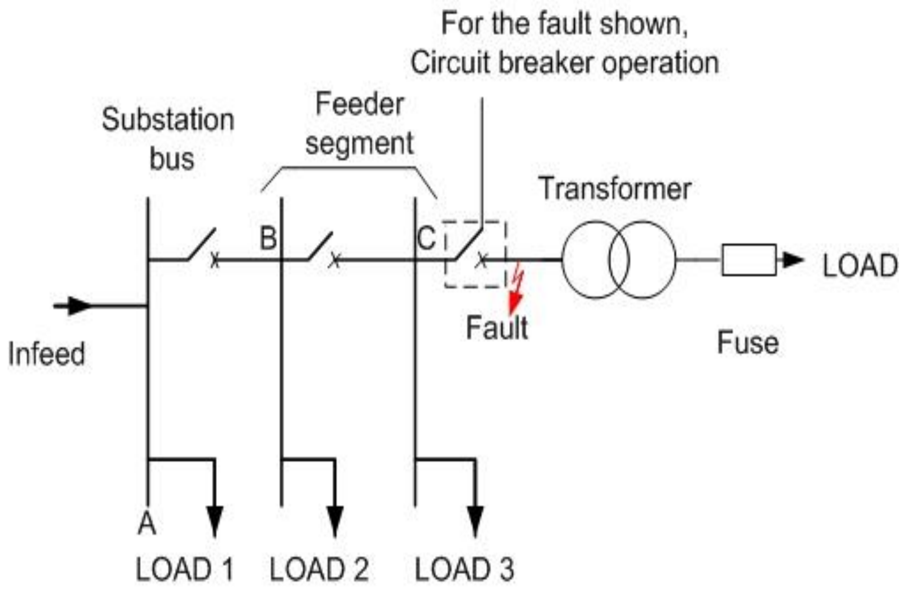

Figure 11: Sequences of operation under fault nearer to the feeder relay C.

4.2 Coordination Discrimination in Current

As name suggests overcurrent relay prime sensing quantity is line current and compare it with predefined saved value with suitable characteristic. Coordination I current can also be said as current coordination and current grading. Current grading is always based on the fact that amount of fault current decreases with increase in relay to fault distance or it could be said that impedance increase. Current coordination is always possible when different feeder segment have sufficient impedance to cause current fault value vary along the radial feeder, otherwise it does not make any sense or irreverent.

Revy setting is such chosen that the value of current at the farthest end of the feeder or the transmission line. This is because to sense the possible current flow within the area of protection. Relay having inverse characteristics trips within short period of time when fault is nearer to it and trip late when fault is very far away from it. In case of instantaneous relay trip at the same time, no matter how far fault is. Now considering about current setting of the above fig current setting close to the fault should be low as compared to the current setting at the infeed. With decreasing way current setting should be lower as moving towards end of the radial line.

Current setting of feeder relay A > Current setting of feeder relay B > Current setting of feeder relay C

Some Drawbacks of discrimination in radial feeder system based on the current coordination is listed below:

- Fault at the end of the feeder section i.e. starting of new section need to be properly discriminated even though there may or may not be more than one relay is installed. These two discussing locations may be separated by very less distance which can be compared as no more than the distance going through a substation bus and circuit breaker, this could be seen from figure 18. Discriminated could be finding through same as percentage rule. It is required to accurate the relay setting in the instantaneous relay.

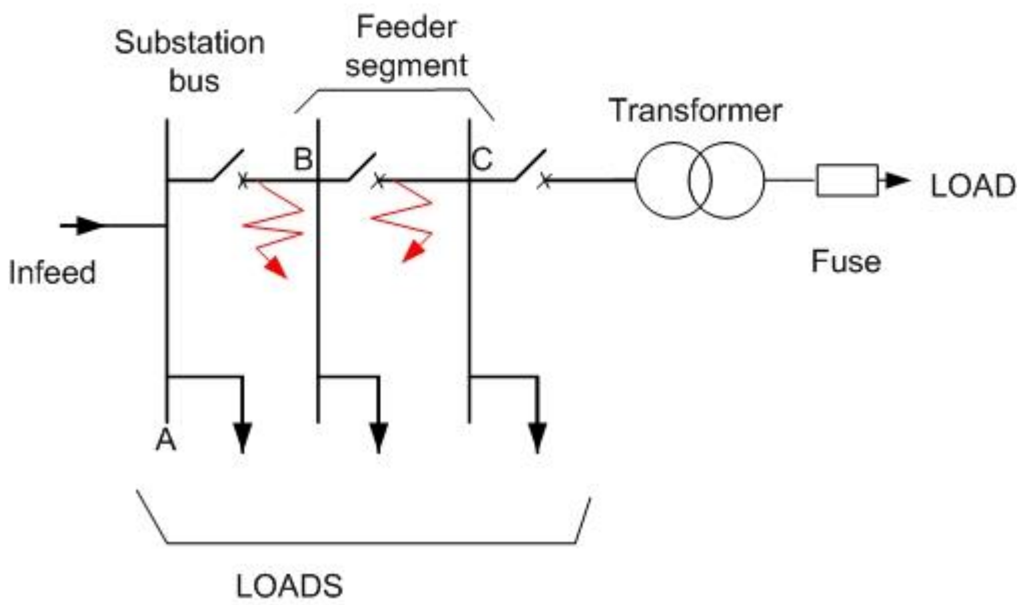

Figure 12: Discrimination of too close fault.

- When infeed of radial feeder protection system consists of more than one transformer and if one of these transformers is disconnected due to uncertainty/fault/service than the amount of the short circuit value will decrease. For instance if out of two, one transformer of same rating is disconnected than the short circuit rating infeed will decrease down to half.

4.3 Coordination discrimination on Time

In relay coordination based on time is also referred as time coordination or time grading. It can be achieved by making radial feeder relays farthest from the infeed feeder which must be operated in shortest time possible and moving towards the infeed feeder time should be increase. Relay close to the fault should trip faster than other relay. Whereas moving away from the fault, relay should trip with time delay when compared with closest relay. These timing characteristics depend upon the time-current characteristics of relay. Difference between two adjacent relays is referred as grading margin.

Current Setting: The current setting of every overcurrent relay is defined by the Current Transformer primary winding current or secondary winding current multiplied by turn’s ratio. Current setting is set above the maximum load current of the line that relay will protect above the minimum fault level current no matter the location is on the line. This is to be ensuring that relay should not act under normal conditions or high load conditions (within limits).

Time Setting: Relay timer setting is set in descending with the farthest from infeed first to nearer. Grading margin is used to determine setting of every other relay in radial feeder protection system. Grading margin can be seen from the compression of two curves in vertical axis positions as shown in figure 19 below.

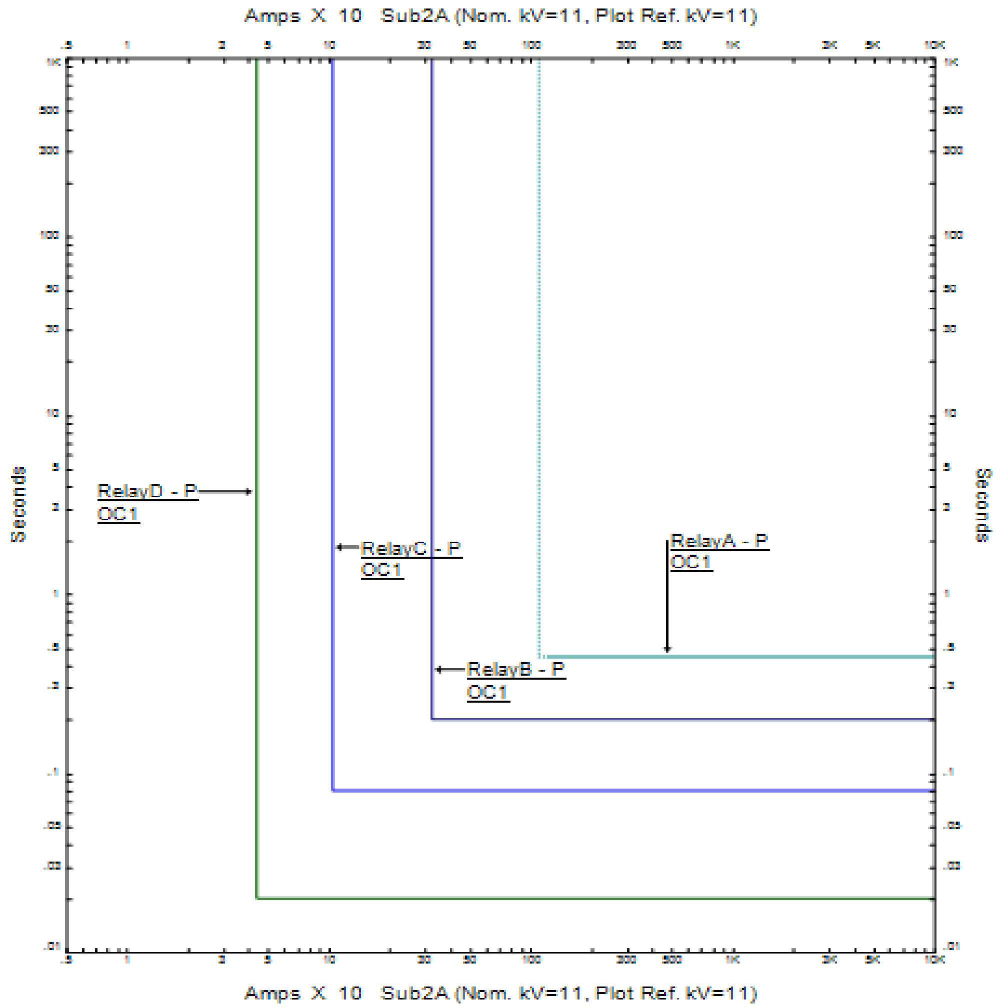

Figure 13: Time current characteristic of definite time overcurrent relay.

Above figure 19 shown different times and current setting of the four relay A, B, C, D. Time dial can be seen at the extreme right of figure 19 and current setting from the horizontal axis. The main drawback of this system is when fault occur at the nearer to the relay it will work at the same time as fault at the far end of other feeder. Every relay manufacturing industry uses different equations with different curve characteristics and there curve is also different when compare with others, where as mostly in parallel. Now a day's relays are available with customisable curve characteristics and time dial.

4.4 Setting of overcurrent relays using software techniques

It is very simple to disuses the relay setting for the electromechanical relay type but considering numerical/microcontroller based relay setting is fractionally different; using software technique user can edit the curve current setting, dial time and various more settings/function. Electromechanical relay provides good coordination but for the complex system it is not good, to make it good user may need many coils (torque) to get proper coordination. This become bulky so, using software technique system may become easy to use and installed, these relay have many relay within it so, this is also an advantage over electrometrical system. Don’t matters which topologies are used software can be adjusted using its burner that means single relay may be sufficient. Using this type of relay Current and voltage can be monitored and stored.

Setting up of Numerical relay take three steps:

1. Locate the fault, calculate fault/over current and obtain the current for setting up relays.
2. Look for numerical relays to be coordinated, decide which one should act first and which at last or for backup protection. Setting should be in accordance of standards.
3. Cross check setting with standards or verify using simulator that system is coordinated or not, if not then redo the procedure with greater margin or new relay should be tried

During execution of software downloading not only current setting is to be taken into account but time dial should be taken into account, user may edit the curve to get proper coordination.

Chapter 5

Protection schemes

Introduction

In an electrical power system it is tough to decide accurate protection schemes that should be accepted to safeguard a distribution system, there are tremendous amount of protection scheme is available to safeguard probably every section and every device. While selecting the protection scheme some points to be taken into account which is scheme should be economic, should give large protection, response time should be taken into account and most importantly it should be smart. Using costly equipments is not a good idea and as well as it is not an economic system. In an electrical power system 15-20 percent of cost is for its protection only.

5.1 Generator protection

5.1.1 For Small Generator up to 5MVA

The main source “Generator”, its protection must be given importance because it is the main source of entire power system. For reliability of system, customer and machines protection, technical attribute such as power, voltage, power factor and earthing arrangements plays vital role. As generator is an important and costliest unit of a power system, so its protection becomes important. Complex protection scheme is installed which ensure that for the worst condition generator and load both are safe. About two to 4 percent of the cost is used for the protection of the generator itself, such a huge cost should be justified for every small generator. From the figure 22 below it could be seen that more than 15 protective devices is installed to protect the generator only. It is necessary to install best and economic protection scheme. Small generators typically up to 5MVA less protection such as 87, 86, 51G, 46, 51V, 32, 40, 49 etc. is needed, scheme is necessary to have:

- Protection against internal faults- sometimes winding get short circuited, due to this sparking may cause or overheating of system.
- Small generators too needs Back-up protection for external faults like at its terminal so, need of overcurrent relays with voltage restraint
- When fault happen at the input of the generator then power flow in reverse direction so it need reverse-power protection
- Earth-fault protection, using an overcurrent relay
- Protection against overloads by means of thermal relays.

5.1.2 Large generators

For large generators, say over 5MVA, the protection, which is shown in Figure 22, should normally comprise of internal faults, reverse power, under/over voltage, over current, frequencies, phase sequence, out of step and many more. Some of this protection is listed below in table 2.

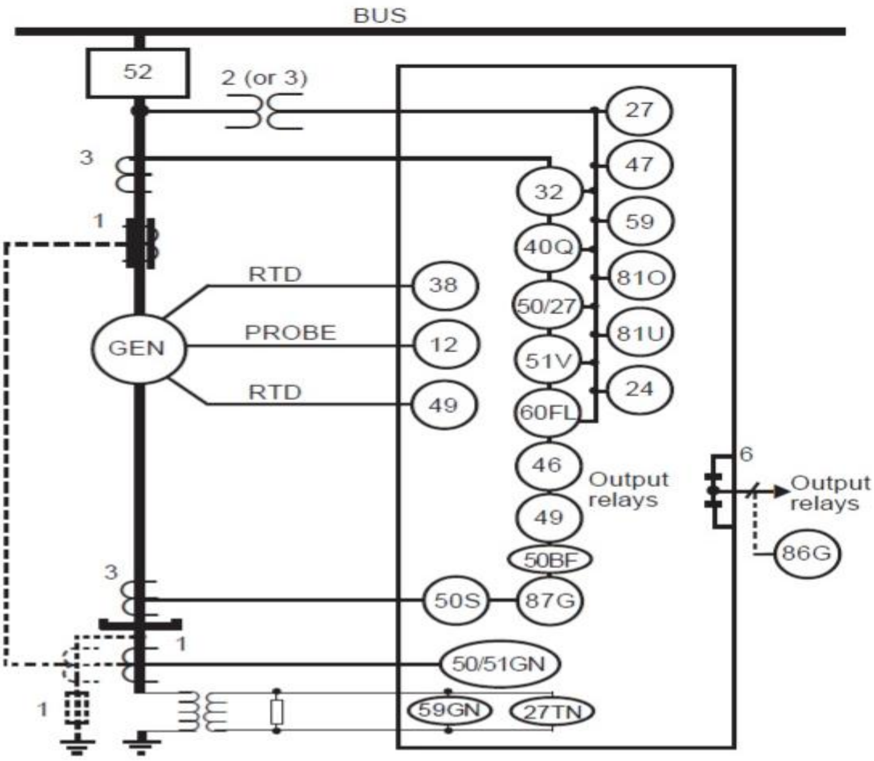

Figure 14: Generator protection

Table 1: List of Generator device Name

Protection device Number	Device Name
12	Over speed relay
24	Over excitation relay Volt/Hz
27	Under Voltage relay
50/27	Inadvertent generator energization relay
32	Reverse power for anti-motoring relay
38	Bearing over temperature relay

39	Bearing vibration relay
40Q	Loss of field relay
46	Negative sequence overcurrent relay
47	Voltage phase reversal relay
49	Stator thermal relay
50BF	Breaker failure detection relay
50S	Instantaneous overcurrent relay
50/51GN	Instantaneous or definite time overcurrent relay
51V	Voltage restrained phase overcurrent relay
59	Over voltage relay
59GN	Stator ground relay
60FL	VT fuse failure detection relay
81	Over and under frequency relay
87G	Phase differential relay
86G	Lock out auxiliary relay

Chapter 6

PROPOSED MODEL DICUSSION

6.1 Input and Model:

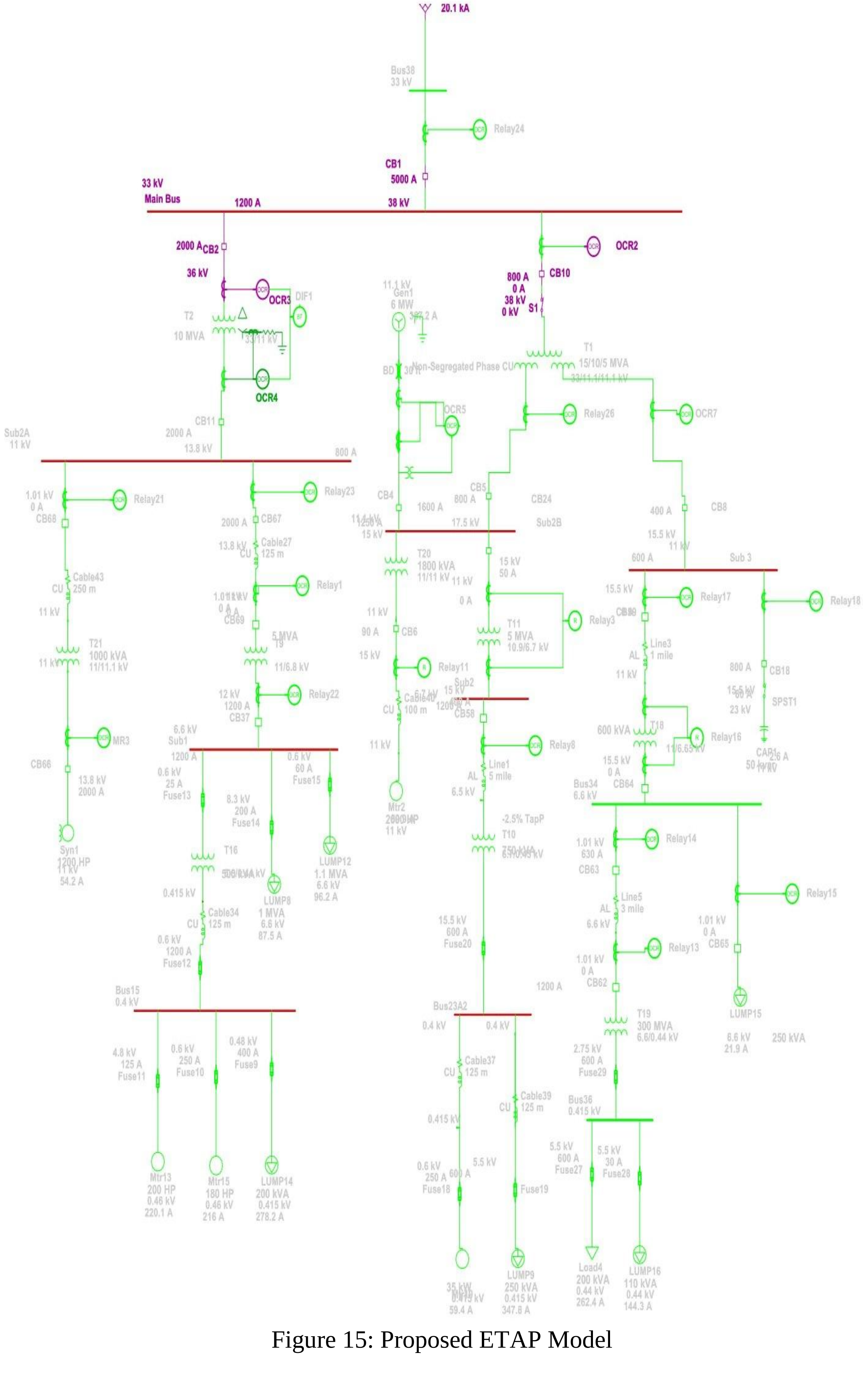

Figure 15: Proposed ETAP Model

Below diagram is the model on which coordination is performed. There are 25 buses and each is connected with some impedance offered by cable, transformer and transmission line. Practically current transformer do offers some impedance to transmission lines between two buses. At the end of the radial feeder each buses is connected with loads having different duty cycle, induction motors, Lump load, synchronous motors and a capacitor to improve power factor of system.

There are two power sources one at the top i.e. Utility Grid and other is generator, both of these is supplying power to different sections of proposed model. Given table 3 shows the number of power system element used in proposed model and its data is discussed in next chapter. This Proposed model is having voltage rating of same value as in power system i.e. .440, 6.6, 11, 33 KV. At extreme load end, loads are protected by fuses, where as middle branches are protected by digital library relays. All these data are extracted from ETAP library and are chosen according to ANSI/IEC standards.

Table 2: Elements used in proposed model.

Number of Buses	Swing =1	Voltage Control= 1	Load = 25			Total = 27
Number of branches	XFMR2 =9	XFMR3= 1	Reactor= 0	Line/Cable = 12	Tie PD=3	25
Number of Machine	Synchronous Generator=1	Power Grid = 1	Synchronous Motor =1	Induction Machine =4	Lumped load= 6	13

Following are the input data which is set to the various power system elements in proposed model. Each and every power system element is discussed with their IDs, type of connection and its offered impedance. These data includes all elements which is discussed in table 3.

Table 3: Proposed model element Impedance

Power Grid Input Data					
		% Positive Seq. Impedance		% Zero Seq. Impedance	
Power Grid	Connected Bus	Rating	100 MVA Base	Grounding	100 MVA Base

ID	ID	MVASC	kV	X/R	R	X	Type	X/R	R0	X0
Utility	Bus38	1200.000	33.000	45	0.18514	8.33128	Wye - Solid	45	0.110181	4.95812

Table 4: Synchronous Generator Input Data

				Positive Seq. Impedance					
Synchronous Generator	Rating				% Xd"		Grounding	Zero Seq. Impedance	
ID	Type MVA	kV	RPM	X"/R	% R	Tol.	Type	Amp	X/R, % R0
Gen1	Turbo 7.059	11.10	1800	48.0	0.250	12.0	Wye	Solid	48.0, 0.250

				Positive Seq. Imp.						
Rating (Base)				Xd"		Grounding		Zero Seq. Imp.		
ID	kVA	kV	RPM	X"/R	% R	% X'	Conn.	Type	Amp	X/R, % R0
Syn 1	1033.4	11	1800	25.84	0.595	23.077	Wye	Open	25.84	0.595, 15.38

Table 5: Induction Machine and LUMP Data

Induction Machine		Rating (Base)	Positive Seq. Imp.			Grounding			Zero Seq. Imp.		
ID	kVA	kV	RPM	X"/R	% R	% X"	% X'	Conn.	Type, Amp	% R0	% X0
Mtr 2	1713.37	11.00	1800	30.80	0.500	15.38	23.08	Wye	Open, 30.80	15.38	
Mtr 13	175.33	0.46	1800	11.01	1.816	20.00	50.00	Wye	Resistor, 20.00	1.816	20.00
Mtr 15	172.10	0.46	1800	10.45	1.914	20.00	50.00	Wye	Resistor, 20.00	1.914	20.00
Mtr 10	42.72	0.415	1800	5.34	5.217	27.83	9999.00	Wye	Open, 5.34	5.217	27.83

LUMP LOAD												
ID	kVA	kV	MTR	STAT	kW	KVAr	X"/R	X'/R	%R	%X"	%X'	Conn.
LUMP8	1000.0	6.600	60	40	558.0	220.5	6.67	6.67	2.307	15.38	23.08	Wye Open
LUMP9	250.0	0.415	76	24	180.5	59.3	2.38	2.38	10.049	23.92	9999.00	Wye Open
LUMP12	1100.0	6.600	60	40	613.8	242.6	6.67	6.67	2.307	15.38	23.08	Wye Open
LUMP14	200.0	0.415	80	20	147.2	62.7	2.38	2.38	7.757	18.46	46.15	Wye Solid
LUMP15	250.0	6.600	60	40	133.5	68.4	6.67	6.67	2.307	15.38	23.08	Wye Reactor
LUMP16	110.0	0.440	60	40	59.4	28.8	2.38	2.38	7.757	18.46	46.15	Wye Open

Table 6: Line /Cable Data

Line Cable		Adj. (ft)				
ID	Size		T (°C)	R1	X1	
Cable27	350	410.1	75	0.038151	0.045	0.3662496
Cable34	350	49.2	75	0.038151	0.045	0.3662496
Cable37	350	410.1	75	0.038151	0.036	0.3662496
Cable39	350	410.1	75	0.038151	0.036	0.3662496
Cable40	250	984.3	75	0.0524576	0.05	0.38151
Cable43	70	820.2	75	0.0997137	.0490119	0.0000183
Line1		26400	75	0.6081555	.1772735	0.0000009
Line3		12144	75	0.6333585	.1734234	0.000001
Line5		15840	75	0.60981063	.1561188	0.000001
Line7		26400	75	0.555114	.1600268	0.0000009
Line8		13200	75	0.3191291	.1550903	0.000001

Line9		2640	75	0.4704548	.145594	0.000001

Ω and Ω^{-1} per 1000 feet per Conductor or per Line.

Table 7: System 2-Winding Transformer Input Data

	Transformer Rating					Adjusted	Phase Shift
ID	MVA	Prim. kV	Sec. kV	% Z	X/R	% Z	Type
T2	8.000	33.000	11.000	6.90	23.50	7.1000	Dyn
T9	4.000	11.000	6.800	6.30	12.14	6.5000	Dyn
T10	0.750	6.700	0.450	5.78	3.70	5.7750	Dyn
T11	0.500	10.900	6.700	4.80	12.14	7.0000	Dyn
T16	0.500	6.600	0.440	4.80	4.70	4.8000	Dyn
T18	0.600	11.000	6.650	11.00	3.96	11.0000	Dyn
T19	0.350	6.600	0.440	6.75	50.00	6.7500	Dyn
T20	1.800	11.000	11.000	5.50	7.10	5.5000	Dyn
T21	1.000	11.000	11.100	5.50	5.79	5.5000	YNd

Table 8: 3-Winding Transformer Input Data

	Rating			Impedance			Z Variation		Phase Shift
ID	Winding	MVA	kV	% Z	X/R	MVAb	% Tol.	+ 5%	Type
T1	Primary:	15.000	33.000	50.2	7.10				
					Zps	397.20	15.000	+ 5%	0
	Secondary	10.000	11.100	14.10	Zpt = 40		15	+ 5%	30.000
	Tertiary:	5.000	11.100	14.10	Zst = 38		15.000	+ 5%	0

Table 9: Bus Input Data

Bus				Initial Voltage	
ID	Type	Nom. kV	Base kV	%Mag.	Ang.

Bus8	Load	11.000	11.000	100.00	-30.00
Bus10	Load	11.000	11.100	100.00	-30.00
Bus13	Load	0.415	0.453	100.00	-30.00
Bus15	Load	0.400	0.453	100.00	-30.00
Bus21	Load	0.415	0.470	100.00	-90.00
Bus22	Load	6.500	6.823	107.69	-60.00
Bus23	Load	0.400	0.470	120.48	-90.00
Bus23A2	Load	0.400	0.470	105.00	-90.00
Bus25	Load	11.000	11.100	100.00	0.00
Bus33	Load	11.000	11.100	100.00	0.00
Bus34	Load	6.600	6.710	104.55	30.00
Bus35	Load	6.600	6.710	103.03	30.00
Bus36	Load	0.415	0.447	106.02	60.00
Bus37	Load	11.000	11.100	100.00	0.00
Bus38	SWNG	33.000	33.000	100.00	0.00
Bus39	Load	11.000	11.100	100.00	-60.00
Bus42	Load	11.000	11.000	100.00	-30.00
Bus44	Gen.	11.100	11.100	100.00	-30.00
Bus46	Load	11.100	11.100	100.00	-30.00
Bus47	Load	11.100	11.100	100.00	0.00
Bus48	Load	11.000	11.000	100.00	-30.00
Main Bus	Load	33.000	33.000	100.00	0.00
Sub1	Load	6.600	6.800	100.00	-60.00
Sub2	Load	6.700	6.823	100.00	-60.00
Sub2A	Load	11.000	11.000	101.52	-30.00
Sub2B	Load	11.100	11.100	100.00	-30.00
Sub 3	Load	11.000	11.100	99.81	-0.50
27 Buses Total					

6.2 Sequence of operation:

Sequence of operation of events is a block of ETAP that deal with the operational time of each and every element of a system. Time operation includes relay delay timing by its internal characteristics, time dial of relay, circuit breaker delay. From the below figure 27 it could be seen that total operational timing in milli-seconds of each element (Relay, CB), with relay ID, fault current (KA) and what are the conditions of tripping of relay is also described in this topic sequence of operation in figure 27. Below given figure, it states the fault between load-4 and fuse 27 happened. Sequence of operation follows the path of first fuse 27 act, then fuse 29 act and at end relay 13 acted. These three indicators (crossed over CB & fuses) are the representation of the action of relays, not only to this several other relays acted but they were not under 3 sequence tripping.

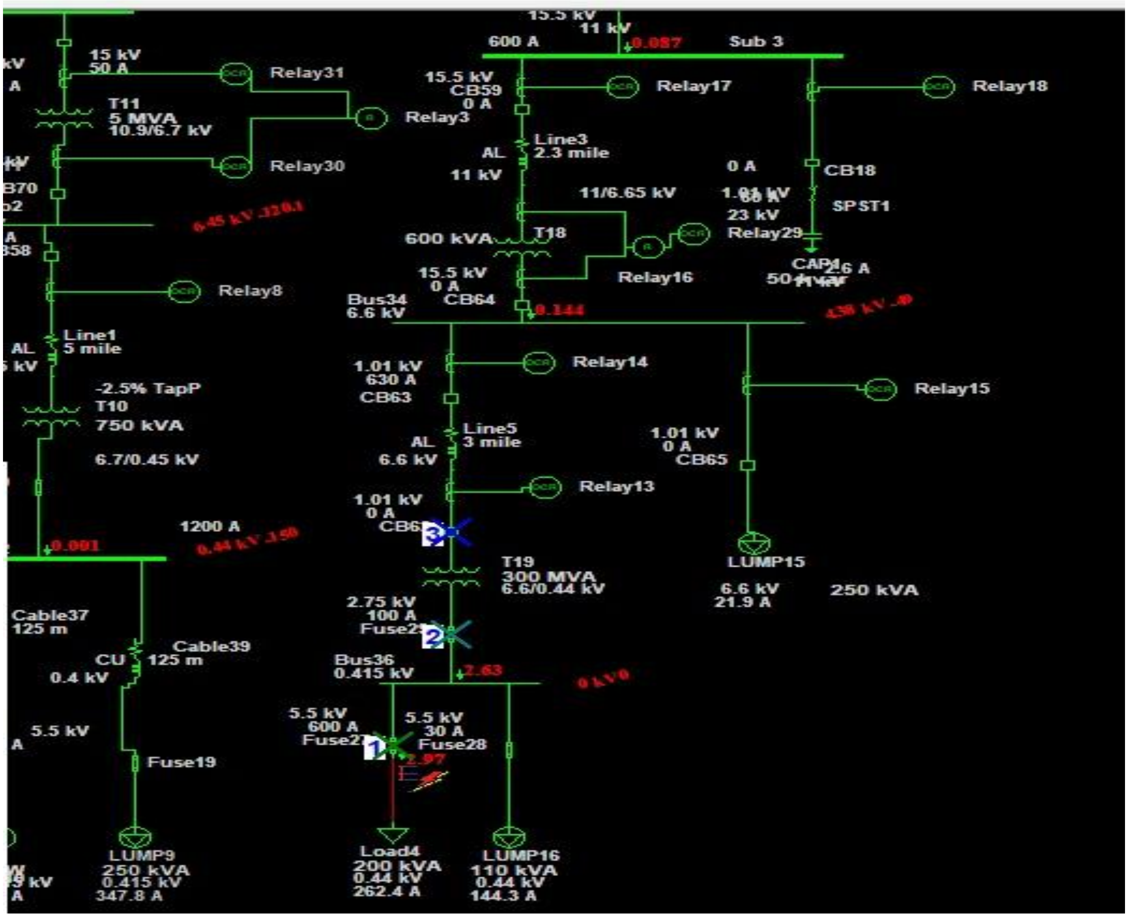

Figure 16: Sequence of operation of relay-circuit breaker and fuses

Other such as Relay 14, relay16, relay29 and relay17 also acted but they were quite slow to respond under fault current so fast tripping did not happen. For better sequence of operation first impedance should be calculated between relay to the fault location and hence decide relay setting, whereas up to the load total line impedance plus load impedance will tell us about the least overload current. So by increasing some delay a relay can be adjusted for the protection, it is true that no relay could do perfect operation in a power system and hence every time operation could be improved.

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between Fuse27 & Load4. Adjacent bus: Bus36

Data Rev.: Base Config: Normal Date: 05-27-2019

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
6.7	Relay13	0.175	6.7		Phase - OC1 - 51
8.1	Relay14	0.175	8.1		Phase - OC1 - 51
10.0	Fuse27	2.965	< 10.1	< 10.0	
10.0	Fuse29	2.627	< 10.0		
14.7	CB62		8.0		Tripped by Relay13 Phase - OC1 - 51
18.1	CB63		10.0		Tripped by Relay14 Phase - OC1 - 51
26.6	Relay16	0.087	26.6		Phase - OC1 - 51
29.4	Relay29	0.087	29.4		Phase - OC1 - 51
36.6	CB64		10.0		Tripped by Relay16 Phase - OC1 - 51
39.4	CB64		10.0		Tripped by Relay29 Phase - OC1 - 51
54.9	Fuse28	0.416	37.5	54.9	

Figure 17: sequence of operation events tool output of above case.

By analysing from here relay/fuse timing curve can be changed or from the curve customization tool. By observing above figure 28 it could be said that relay 13, relay 14 acted first and then fuses acted. Because when circuit breaker time delay is added into total operating time then its timing becomes increased by 14.7 and 18.1 where as fuses do not use any circuit breaker so, its timing is 10ms. Here both have 10ms of time but fuse 27 acted within less time as compared to the fuse 29 so fuse 27 act first then fuses 29. Let’s say current setting is in under pre-defined current value then response time is very low from relay.

Chapter 7

RESULT AND DISCUSSION

Radial feeder protection and its coordination are studied and following are the results which include relay used and its setting for the proposed model and sequence of operation up to three relay/fuse. Driescher, Doman smith, Bussman, Allischalmess, ABB, GE Multilinn, ALSTOM, VAMP LTD, Copper and Westinhhouse relays/ fuses library is used in proposed model. Every Relay/Fuse curve is having manufacturing default value that is installed in library. This curve can also be edited as per user defined. Characteristics such as long time inverse, extremely inverse, very inverse, IEC curve, ANSI curve are used which is defined as per manufacturer.

7.1: Relay Library Setting:

Table 10: Relay Types and its setting

RELAY/Fuse ID-Name	Location	Curve type	Pickup and its range & fuse rating	Time Dial	Relay Type	Action
Fuse 11, Driescher-DRS04	bus 15 to motor 13	M.D	4.8kv,250A-continious,40KA	Nil	OCR Fuse	Nil

Fuse 10, Driescher-DRS04	bus 15 to motor 15	M.D	4.8kv,200A-continious,63KA	Nil	OCR Fuse	Nil
Fuse 9, Driescher-DRS04	bus 15 to lump 14	M.D	4.8kv,250A-continious,40KA	Nil	OCR Fuse	Nil
Fuse 12, Driescher-DRS04	cable 34 to bus 15	M.D	4.8kv,315A-continious,40KA	Nil	OCR Fuse	Nil
fuse 13 doman smith class C	sub1 to T16	M.D	4.3KV, 50A, 200KA	Nil	OCR Fuse	Nil
fuse 14 Bussmann-JCR	sub 1 to lump 8	M.D	8.3kv, 3R, 50KA	Nil	OCR Fuse	Nil
fuse 15, dorman smit-class c	sub1 to lump 12	M.D	4.76KV, 100A, 200KA	Nil	OCR Fuse	Nil
fuse18, bussmann-DLS-R	bus 21 to motor 10	M.D	.6KV, 60A,200KA	Nil	OCR Fuse	Nil
fuse 19, bussman ECL 055	bus23 to lump 9	M.D	.6kv, 80E, 600Amp, 63KA	Nil	OCR Fuse	Nil
fuse 20, ITE-CL 13	T10 to Bus23A2	M.D	15.5KV,40E,600Amp, 50KA	Nil	OCR Fuse	Nil
fuse 27, Bussmann ECL 055	bus 36 to load 4	M.D	5.5KV, 40E, 600A, 63KA	Nil	OCR Fuse	Nil
Fuse 28, Bussmann ECL 055	Bus 36 to Lump 16	M.D	5.5KV, 30E, 36A, 63KA	Nil	OCR Fuse	Nil
Fuse 29 Allischalmess FM	T19 to Bus 36	M.D	2.75KV, 3X, 100A, 50KA	Nil	OCR Fuse	Nil
MR3,ABB REB 500	T21 to Syn1	Very inverse	1.433, .04-2.5*CT sec	0.013	OCMR	CB66
Relay21, ABB, REB 500	sub 2A to T21	Very inverse	1.63, .04-2.5*CT sec	0.03	OCR	CB68

Relay 22, ABB Red 500	t9 to Sub 1	Very inverse	1.26, .04-2.5*CT sec	0.01	OCR	CB37
Relay 1, ABB REB 500	cable27 to T9	Extremely Inverse	1.16, .04-2.5 CT sec	0.56	OCR	CB 69
Relay 23, REB 500	Sub2A to cable 27	Extremely inverse	1.236, .04-2.5Ctsec	0.67	OCR	CB67
OCR 4 GE Multilin 750/760	line 9 to sub2A	ANSI-extremely inverse	1.17, .05-20CT sec	0.1	OCR	CB11
Dif1, ABB 50B	T2 transformer	ANSI-extremely inverse	percentage,	0.02	DR	CB2 CB11
OCR 3, GE Multilin 750/760	Main bus to T2	ANSI-extremely inverse	1.32, .05-20CT sec	0.1	OCR	CB2
Relay 8, Weistinghouse	Sub2 to line1	IEC-C(EI)	.5-1.2CT sec, 1	1	OCR	CB 58
Relay 30, ALSTOM P139	T11- Sub2	ANSI-extremely inverse	1.112, .1-4*CT sec	0.02	OCR	CB 70
Relay 3, Seimens 7UT51	At T11	Extremely Inverse	.25, .1-20*CT sec	0.5	OCR	CB 24
Relay 31, ALSTOM P139	Sub 2B to T11	ANSI-Normally inverse	1.456, .1-4*CT sec	0.022	OCR	CB 24
Relay 11, VAMP LTD. VAMP-130	T20 to Cable 40	Extremely Inverse	.3, .1-5*CT sec	0.05	OCR	CB6
		instantaneous Relay	.1-40CT Sec, 37.91	0.05	OCR	CB6
OCR5, GE Multilin 750/760	Gen 1 to Sub 2B	ANSI Normally Inverse	1.25, .05-20*CT sec	0.01	OCR	CB4
Relay 26, ABB REB500	T1 to Sub2B	Long time inverse	.8, .04-2.5 CT sec	0.01	OCR	CB5
		instantaneous Relay	.1-20*CT sec, 20	- - -	OCR	CB5

Relay 13, ALSTOM P139	line 5- T19	ANSI Normally Inverse	.4-4*CT sec, 1.145	0.02	OCR	CB 62
Relay 14, ALSTOM P139	Bus 34 to line 5	ANSI Normally Inverse	.1-4*CT sec, 1.466	0.02	OCR	CB 63
Relay15 ABB REB 500	bus 34 to LUMP 15	Long time inverse	.04-2.5*CT sec, 2.5	0.04	OCR	CB65
Relay 16, Copper IXP 420	T18	Extremely Inverse	.05-9*CT sec 5A, 1.15	0.1	DR	CB 64
		Instantaneous	.05-90*CT sec,88.25	0.015	OCR	CB 64
Relay 29, ALSTOM P13	T18	ANSI Normally Inverse	.1-4*CT sec, 1.2	0.02	OCR	CB 64
Relay 17 ALSTOM P139	Sub 3 to line3	ANSI Normally Inverse	.1-4*CT sec, 1.449	0.019	OCR	CB 59
Relay 18, Westinghouse MMCO	sub 3 to cap1	IEC-A(i)	.5-12*CT sec5A, 5	1	OCR	CB 18
		instantaneous	.2-25.4CTsec1A,5	- -	OCR	CB 18
OCR7, ALSTOM P139	T1 to line8	ANSI Normally Inverse	.1-4*Ctsec,1.722	0.02	OCR	CB 8
OCR 2, ALSTOM P139	main bus to T1	ANSI Normally Inverse	.1-4*CT sec, 1.325	0.01	OCR	CB 10
Relay 24, ABB REB500	UG to MB	Very inverse	.04-2.5*CT sec, 1.465	0.061	OCR	CB 1
		Instantaneous	.1-20*Ctsec,15	0.005	OCR	CB 1

7.2 Coordination Outcome:

Below table 12 shows result of radial feeder protection. Using ETAP fault icon, at different-different location fault is applied and analysed using sequence of operation block. This research paper has lists sequence of operation up to three, but other may use more. Sequence of operation with faults like line to line (L-L), line to ground (L-G), line to line to ground (LL-G) and triple line to ground (LLL-G) can be analysed which will give same result as this paper. Fault is created at loads, transmission line, nearer to transformer and on bus (both main bus and load bus). Given sequence of operation includes time to respond, type of fuse/relay acted and current sensed by the relay. Whichever the circuit breaker ID is defied in relay editor box that relay will act, this can be known from the table 11 by short listing relay from table 12.

Table 11: sequence of operation (Time (ms), fuse/relay acted, fault current (kA))

Fault location	tripping Cause	sequence of operation with time (Time(ms), fuse/relay acted, fault current(kA))		
		Sequence 1	Sequence 2	Sequence 3
Nearer to Mtr13	Short circuit	10, Fuse-11, 8.632	12.1, Fuse -12, 8.632	21.2, Fuse -13, .575
Nearer mtr15	Short circuit	10, Fuse- 10, 8.632	12.1, Fuse -12, 8.632	21.2, Fuse -13, .575
Nearer lump14	Short circuit	10, Fuse -9, 8.632	12.1, Fuse -12, 8.632	21.1, Fuse -13, .575
Bus15	Short circuit	12.1, Fuse - 12, 8.632	21.2, Fuse -13, 0.575	49.5, Relay-22, .575
T16 to Cable 34	Short circuit	12.4, Fuse - 13, .662	36.1, Relay -22, .662	491, Relay -1, .409
Nearer to T16	Short circuit	10, Fuse -13, 2.1	12.1, Relay -22, 27	25.5, Relay -1, 1.696
Sub1	Short circuit	12.1 Relay - 22, 2.74	25.5, Relay -1, 1.696	33, Relay -23, 1.696
Cab 27- T9	Short circuit	16.1, Relay - 1, 2.6	19, Relay -23, 2.6	23.3, ocr-4, 2.6
sub 2a -Cab 27	Short circuit	18.9, Relay - 23, 2.7	22, OCR-4, 2.7	24.6, ocr-3, .902
sub 2A	Short circuit	23.2, OCR -4, 2.705	24.6, OCR -3, .902	24.6, Relay -24, .9
synchronous 1	Short circuit	13.2, MR-3, .731	14.1, Relay -21, .738	163, OCR -4, .738
cab43- t21	Short circuit	11.1, Relay - 21, 2.609	23.8, OCR - 4, 2.609	25.3, OCR -3, .89
sub2a- cab43	Short circuit	11, Relay -21, 2.705	23.2, OCR -4, 2.705	24.6, OCR -3, .902

Nearer to t2	Short circuit	15, Relay -24, 1.85	17.2, Diff-1	35, OCR -3, 1.838
Nearer motor 10	Short circuit	12.8, Fuse -18, 1.599	20.6, Fuse -20, 1.599	22.8, Relay -8, .11
lump 9	Short circuit	11.8, Fuse -19, 1.547	13.8, Fuse -20, 1.547	23.8, Relay -8, .106
bus 23A2	Short circuit	18.4, Fuse -20, 1.791	20.2, Relay -8, .123	40.5, Relay -30, .123
b/w line 1 & t10	Short circuit	16.8, Relay -8, .151	30.3, Relay -30, .151	32.2, Relay -31, .093
line 1 & sub 2	Short circuit	13.2, Relay -8, .512	14.8, Relay -30, .512	16.7, Relay -31, .315
at bus sub2	Short circuit	14.8, Relay -30, .512	16.7, Relay -31, .315	20.0, Relay -3, .315
At t11	Short circuit	14.3, Relay -31, 1.719	14.7, OCR -5, 1.613	15.3, Relay -26, .315
Nearer to motor 2	Short circuit	12, Relay -11, .861	24.6, OCR-5, .808	………
sub2B	Short circuit	14.7, OCR -5, 1.628	15.1, Relay -26, .318	341 OCR -2, .107
Load 4	Short circuit	10, Fuse -27, 1.845	20.5, Fuse -29, 1.845	20.6, Relay -13, .123
Lump 6	Short circuit	9.9, Fuse -28, 1.845	20.5, Fuse -29, 1.845	20.6, Relay -13, .123
Bus 36	Short circuit	20.5, Fuse -29, 1.845	20.5, Relay -13, .123	29, Relay -14, .123
between CB 62 - T19	Short circuit	16.8, Relay -13, .158	22.4, Relay -14, .158	32.2, Relay -16, .095
Between CB63- Lin 5	Short circuit	15.5 Relay -14. .323	17.9, Relay -29, .195	19.6, Relay -17, .195
Lump 15	Short circuit	17.8, Relay -15, .323	17.9, Relay -29, .195	19.5, Relay -17, .195
Bus 34	Short circuit	17.9, Relay -29, .195	19.5, Relay -17, .195	20.8, OCR- 7, .195
T18 internal fault	Short circuit	14.4, Relay -29, .428	14.6, Relay -17, .428	14.9, OCR -7, .428

Nearer to capacitor	Short circuit	10, Relay -18, 1.235	1.9, OCR -7, 1.285	15.8, OCR-2, .431
Sub 3	Short circuit	13.9, OCR- 7, 1.285	15.8, OCR-2, .431	52, Relay -24, .431
Main line	Short circuit	11.6, Relay -24, 21.414	16.5, Relay -26, .299	416, OCR- 2, .101

As above table 12 is for sequence of actions using star protection tab icon that means string of actions will be performed without interrupting or separating any section of proposed model. First sequence 1 acted then sequence 2 acts if current value exceeds the predefined value and at last sequence 3 will act. Higher the time setting of relay higher time it will take to respond, so at the nodes having more than 2 branches, the main branch of source should have high current setting. Coordination not only depends on current setting, time dial and curve but also depends on circuit breaker response.

Chapter 8

CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

Radial feeder protection and its coordination is studied, from above chapter result has been seen. For coordination tripping timing should be high, by justifying my view let's suppose fault is temporary then this high time may cause system in operation and recloser can utilise its application. On other hand if fault is for long duration then sequence operation will occur and also backup protection will also play its role along with recloser.

By observing above results it could be observe that with calculated impedance from fault location to the relay, if it is high then time will be high and if it is low then time to act will below.

1) Heavy motor/loads nearer to generator or utility grid require high relay setting and dial time.
2) Generator backup protection Relay i.e. 51 device uses definite time or short inverse or inverse delay characteristics.
3) A protection scheme that enables high tripping speed at every terminal along with high security and dependability inherently provides selectivity.
4) For the protection of generator using backup protection scheme needs time margin of .5 second.
5) All generators are never solidly grounded because if generator is solidly grounded then single line to ground current is very large. So a single unity is grounded with high resistance and other are kept open.
6) The great attribute of a protection device is that its ability to resolve flow of power i.e. direction by using this property to open the associated switch under fault.
7) For low voltage CB IEEE standard C37.13-1990 and 242-1986 is used for reactance X value.

8) Selection of fuses, circuit breaker, current transformer, potential transformer and relay is based on the voltage, current, burden, saturation and space occupied.
9) Each and every element of protection should follow IEC/IS/ANSI standards.
10) Main protection should eliminate permanent and temporary fault as soon as possible and thus do not give any chance to operate backup protection.
11) Transmission line which are hang in open area, could be affected by many abnormal conditions either fault or lightning strike. Here a highly reliable numerical distance protection relay is needed in order to minimize the black out.
12) Current and potential transformer should be chosen in order that it should not be affected by over voltage and overcurrent either in fault condition or overload condition.
13) Let's suppose failure of electricity happen at some place for more than some minutes, then whenever board reenergise the feeder then because of high inrush current by inductive load may cause cold load pickup to relays, so relay should be smart enough to recognize this condition.
14) There should be well and proper coordination between primary and backup protection along with relay which are sequence to source.

8.2 Coordination of Very Inverse Overcurrent Relay with Different types of Time-Current Characteristics

When using IDMT relay or any other relay with same time-current characteristic in radial feeder protection system than the action timing of relay must be high for the farthest relay and minimum for the nearer relay. Fault at any feeder or anywhere on lower line where coordination has already performed then the difference between operation time may increase due to the increase in thevenin impedance at fault point, this ensure that proper relay coordination is maintained and performed. IDMT or any other overcurrent relay can be used with different types of time-current characteristic in radial feeder protection system. In electric power system it is very easy to use IDMT overcurrent relay with IEC- inverse characteristics to protect radial feeder or other feeder system.

If it is required to coordinate relay having normal inverse characteristic with extremely inverse characteristics then it is required to keep in mind that extremely inverse characteristic curve is widely used when coordinating with inverse characteristics or fuse. When coordination between an inverse relay with other inverse minimum time relay having different curve characteristic or with a fuse could be considered, it is necessary to readjust the curve or setting after the generic relay coordination procedure has been performed. This must be ensured that give two or more curve characteristic must not be intersecting in any feeder or system protection system. If miss-coordination happens then try to increase relay time setting of that relay which needs more time to respond still did not work then try to increase time dial of relay. If still it did not work then redo the procedure as long as this curve did not separate fully.

Table 12: Relay coordination process.

Settings	S1	S2	S3	S4
Relay Function	Increase the time setting of Relay 1	Increase current setting of relay 1	Redo procedure S2	Redo procedure with higher current setting
Relay Current setting)	.780	1.00	1.10	1.20
Time Dial	.40	.45	.50	.56
Coordinatio n Satisfactory YES/NO	NO	NO	Exact Time	Good Coordination

Table 1 shows the procedure to get proper coordination between extremely inverse and normal inverse with satisfactory conditions. The time coordination time between relays should be big and countable. There may be a big probability for the failure of sequence with two or different types of time-current characteristics.

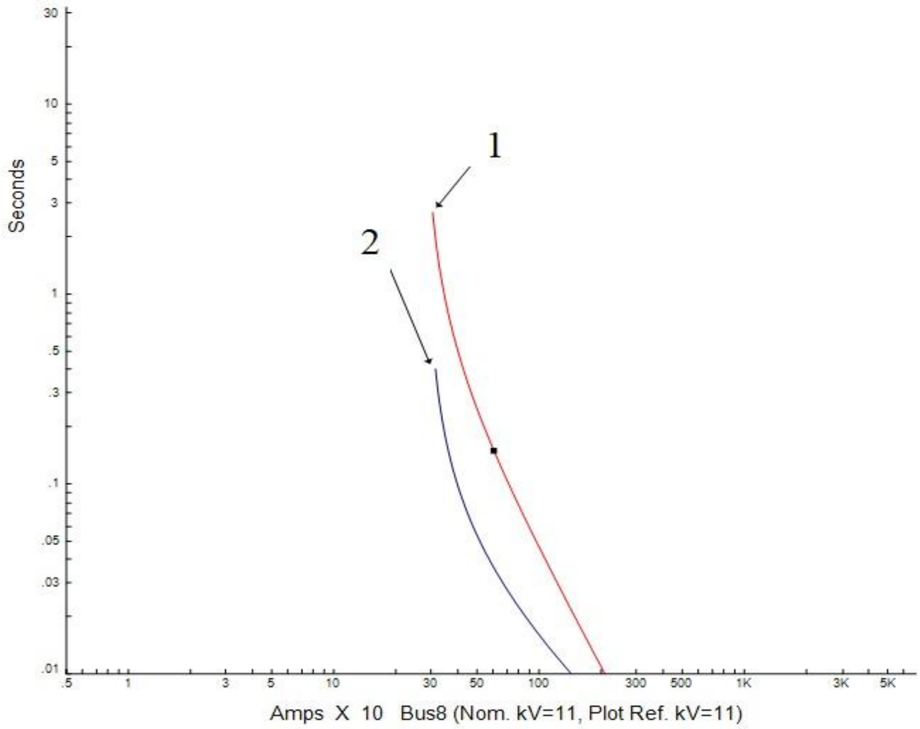

Figure 18: Miss-coordination of Normal Inverse and Extremely Inverse.

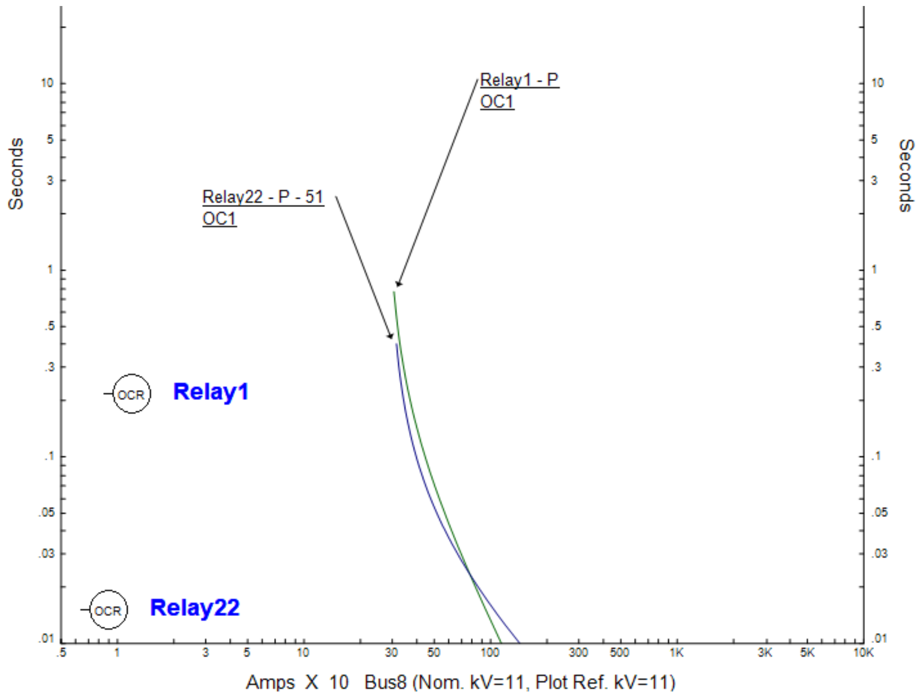

Figure 19: Miss-coordination of Normal Inverse and Extremely Inverse

8.3 Future Scope

Coordination is studied but this does not mean that this coordination is perfect and no coordination is perfect, it can be improved more and more. This thesis main scope is how coordination among fuse to fuse and relay of various types is performed in a radial feeder distribution system. Time plays important roles in coordination processes which is derived from circuit breaker, time dial and relay itself. With the improvement of technologies time to respond may reduce and fast operation could be performed and relay curve could be can also be congested more with improved coordination.

- Public and equipment Safety- both public and equipment protection is very important, even if power lines hang due to any reason there are much more time that whole line is in electrified, which is not good specially at raining season, so using proper relay these faults can also be eliminated.
- Power quality- relay are manufactured in accordance to the application i.e. it will sense voltage, current or its phases for the protection reasons only, but it can also programmed to check power quality also.
- More precise and accurate coordination- with increase in updating library more accurate and precise coordination can be achieved, at where time dial, delay communication and current setting are the main function.

At buses having lighter load and heavy load is very hard to coordinate if fault happen at that bus or at other nearby bus. So this coordination could become simple with upgraded ETAP library or using other specific relay.

Appendix I

Introduction to ETAP

It is an application which is used to design, simulate and automate various power system designs such as transmission line, generating station, grid, distribution system, protection, solar system and etc. There are many libraries present within it of various manufacturer followed by the ANSI, IEC and IEEE standards. Each and every power system elements used in ETAP follows international as well as national standards, by using editing tool user can design specific electrical system. This provides a single linked device with embedded apps. It works as an exe file application model under construction. This application is used worldwide by industries due to its advantages such as monitoring, intelligent solutions, optimization and result generating capability in MS-Excel, Word, PDF and many more. Following are the test/analysis along with key features which can be used on ETAP:-

AC/ DC Short Circuit and Arc flash Analysis – this tool analyse both AC and DC short circuit of various types (phase and line faults) ANSI/IEEE C37 Standards, integrated with protective device coordination. ETAP Arc Flash tool enables user to locate and evaluate strong-risk flash arc regions in an electrical scheme, as well as simulating various techniques used by technicians to minimize high-incidence energy. This module also involves extensive one-phase and three-phase arc flash evaluation computations and an essential arc flash monitoring system instrument to read and understand arc flash research outcomes.

Load flow analysis- this tool analyse power flow, Demand, power factor correction, multi report result analyser. Load flow analysis defines the entire system working status for a particular load. It is essential to have quick, effective and precise mathematical solutions to fix non-linear algebraic expressions. The output of this tool deals with node voltage, line losses, angle and power in a given system.

Star protection Coordination and Selectivity- Using this tool user can analyse coordination and protection strategy for the new power system design or to renew old system. This tool works on both AC and DC system with various manufacturer libraries given; curves can be edited, analysed and tracing abilities. System can be introduced with various types of faults, monitor relay timing, checks its condition and view sequence of operation. Reports could be generated in many formats as discussed in this appendix chapter.

Panel Designing and one line diagram planning- it is easy to plan and built panel, and one line diagram to study by giving some time over it, its GUI shows every icons on the board and analyse 3-phase (3W & 4W), 1-phase (2W & 3W), 1 phase (A, B, C, AB, AC & BC) board. It automates and show result on screen and also give warning when system breaks rule.

Harmonics analysis – With this tool user can analysis and measure system harmonic current and voltage sources. These measured quantities will help user to re-design the circuit and can also gives nuisance trips design and test filters. These tests can be compiled through IEEE 519, ANSI/IEEE 399, IEEE 141, IEEE 519-2014-MV/HV/EHV, IEC 61000-3-6, IEC 61000-3-14-LV. Key features of this module is to find THD & IHD, Telephone influence factor, harmonic current injection method.

Motor starting analysis – this tool used for the motor analysis, engineer can calculate acceleration time, speed, torque and impact produced by the initial voltage to motor. This application is fully capable of using individual motor operation (given in library) or the transit of a whole electrical structure to another state. This module also offers compressive alert & warning, motor operated value, motor starter, multi sequence starting, voltage flicker, dynamic motor acceleration.

Reliability Assessment – it deals with availability and quality of electrical power system at each services end. Customer failure statistics shows result compared to other portion of electrical power system. System reliability, customer oriented indices, energy indices, sensitivity analysis, single & double contingency are the silent features of this module.

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Appendix-II

Time Setting of IEC, IEEE, Texas Instrument

Curve derived equation from British Standard 142, Texas Instruments and ANSI standards are listed below in tables 13, 14 and 15. Using different values of TMS, A, B, C various kinds of curve can be obtained.

$$T = TMS * \frac{A}{I_r^B - C} \qquad ()$$

Table 13: Curve derived from BS 142

Relay Characteristics	**IEC equation**
Standard Inverse	T = TMS*.14/($I_r^{.02}$ - 1)
Very Inverse	T = TMS*13.5/($I_r^{.}$ - 1)
Extremely Inverse(EI)	T = TMS*80/($I_r^{.2}$ - 1)
Lon time standard earth fault	T = TMS*120/(I_r - 1)

Table 14: Curve derived from ANSI standards

Relay Characteristics	**IEEE Equation**
IEEE Moderately Inverse	T = TD/7[{.0155/($I_r^{.02}$ -1) + .114}]
IEEE Very Inverse	T = TD/7[{19.61/($I_r^{.2}$ -1) + .491}]
Extremely Inverse	T = TD/7[{28.2/($I_r^{.2}$ -1) + .1217}]
US CO_8 Inverse	T = TD/7[{5.95/($I_r^{.2}$ -1) + .18}]
US CO_2 Sort time Inverse	T = TD/7[{.02394/($I_r^{.02}$ -1) + .01694}]

Where, TD – time delay

I_r = Ratio of fault current.

TMS=Time multiplier setting

These various types of curves are used at different locations in respect with knowing load behaviour. In some of the relays these curves can be adjusted and edited. So, there could be a great chance of getting accuracy in coordination.

Texas Instruments timing

There are multiple norms such as ANSI C37.90, IEC255-4, IEC60255-3, IAC, etc. that regulate the protective relay's reaction time to the fault circumstances that may happen at any place in the radial feeder scheme. Texas Instruments use its own formula for relay delay timing graph. The output graphs called Inverse Definite Minimum Time Lag (IDMTL) curves usually represent these reaction features. IDMTL is an NPR reaction period metric

$$T_{res} = DMF * \frac{A}{\frac{I_R}{I_{set}}^B - C}$$

Where, T_{res} = Response time

DMF = Delay Multiplier Factor

I_r = Read Current

I_{set} = set current value

Table 15: Texas Instruments timing

Delay Type	A	B	C
LTI Long-time inverse	.086	.185	.02
LTVI Long-time very inverse	28.55	.712	2
LTEI Long-time extremely inverse	64.07	.250	2
MI Moderately inverse	.0515	.1140	.02
VI Very inverse	19.61	.491	2
EI Extremely inverse	28.2	.1217	2
STI Short-time inverse	.16758	.11858	.02

Appendix III

Relay Overview

A non-directional overcurrent relay may include instantaneous, thermal overload inverse, definite time overcurrent relay and many more. These relays can also be further classified by its operating quantities like individual phase, residual and line negative sequence current. Depending on relay time-current characteristic shape, these relays can be used for motor, feeder, and breaker failure protections. There is only one actuating quantity i.e. current (current coil) no voltage coil.

In an overcurrent relay there must a current operated coil. When there is not any fault in the line i.e. healthy line then the magnetic field produced by the relay coil is not sufficient to cause trip if set point is above normal point. This operation could also be defined by saying restoring torque is more than deflecting torque. If short circuit fault occur then of cause current become large enough to harm the system, as this current become more than current setting then a high magnetic field will be produced that cause relay operation i.e. deflecting torque is greater than restoring torque. In this case moving element starts moving as current cross its limits and by tracing the curve it respond and disconnect the curve.

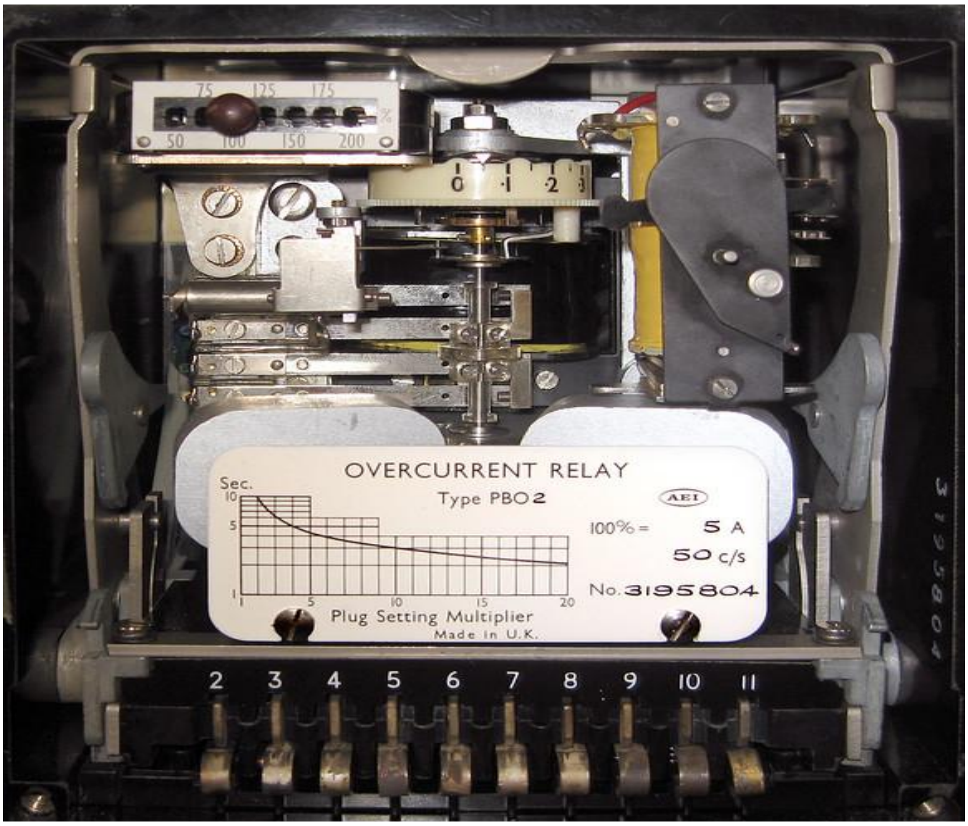

Figure 20: Electromagnetic Relay.

From the above figure 14 a relay is connected in series of the power line and load. A circuit is sensing the current regularly, as it gets high then movable contacts gets disconnect with stationary contact. This process is processed by electromagnetic coil, excited by secondary circuit or circuit connected to it. Restoring torque is applied by the spring connected at the other end of the relay system.

Relay Characteristics Curve

Any curve can be constructed and edited as per user demand by using microprocessor based types relay. For the action of the circuit breaker there is a requirement of some intentional delay which can be acquired based on the curve, there are various types of curve characteristic which are listed below:

a. Extremely Inverse Overcurrent Relay
b. Definite Time Overcurrent Relay
c. Long Time Inverse Overcurrent Relay
d. Normal Inverse Overcurrent Relay
e. Instantaneous Over Current Relay
f. Inverse Definite Minimum Time Overcurrent Relay

5.2.1 Extremely Inverse Relay: it gives more inverse characteristics than inverse definite minimum time overcurrent (IDMT) relay. It is used where reduction in fault current occur fault distance from relay is could be high. This relay is very effective when ground fault occur as its characteristics are very steep. This relay is suitable for the protection of motors, heaters feeders, transformers and small alternators.

5.2.2 Definite Time Overcurrent Relay: This relay uses an intestinal delay relay when relay current setting is violated or line current exceed the predefined current (fault current at least same as relay current setting). Acting time constant, operating time does not depend on current (after set point) and this feature makes this relay east to coordinate. This relay could not be used ay every point, not good for power transmission line and if fault occur nearer to relay then a large amount of current will flow that is not desirable. It is mainly used for backup protection due to its advantage of time delay characteristics.

5.2.3 Long Time Inverse Overcurrent Relay: As it offers long time delay the main application of this relay is for backup earth fault protection in power system. This curve is more linear when compared with extreme inverse relay. It is used at generator earth protection and power transformer earth protection.

5.2.4 Normal Inverse Time Overcurrent Relay: For each and every induction rotating device inverse time is a natural characteristic. This relay is more inverse than long time inverse relay. It is mostly used at industries and area where fault is more frequent.

5.2.5 Instantaneous Overcurrent Relay: Its construction is very simple as compared with other relays especially definite time overcurrent relay. These relays have minimum amount of time to respond, a amount time current is measured (10 to 20 times normal current) if current exceeds for that time limit than circuit is made to open. It must be used farthest from the source; it has wide application at put going feeder and backup protection.

5.2.6 Inverse Definite Minimum Time Overcurrent Relay: It has similar construction as wattmeter or reverse power relay and it is operated with time having inversely proportional equation of fault current. At high current rel**a**y operation time is very low and at low current its operation time is very high. It is widely used for the protection of distribution lines.

Relays always compare input current from the CT's with curve detailed below, as current exceeds the predefined value then trip signal starts its role. These relay curve characteristics have various applications at different locations I terms of nature of load and type of protection either backup or primary.

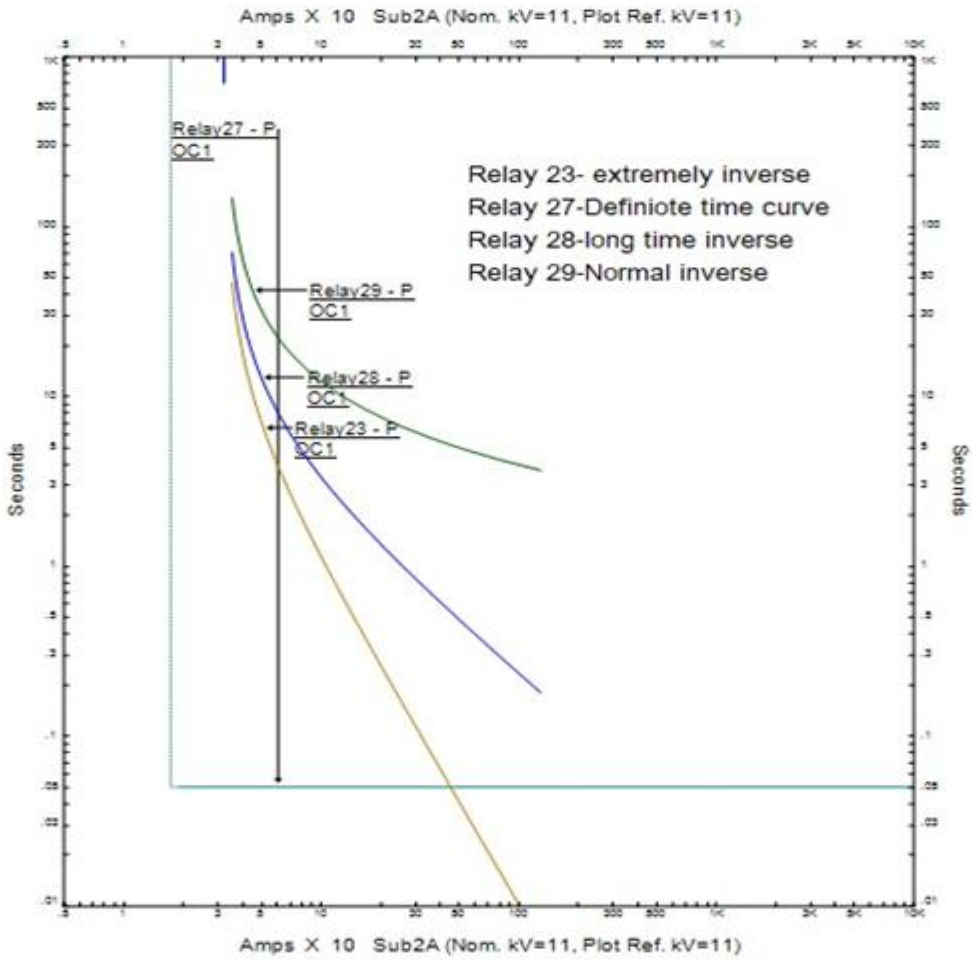

Figure 21: Various Time-Current characteristics.

Based on end application various standards is followed by these relays such as ANSI C37.90, IEC 255-4, IS 3231-0, IEC60255-3 and IAC govern response time of relay to fault condition, some of curve data is discussed in appendix III. It is not necessary that for a specific curve it is purely similar with other standard or manufacturer, there may be some changes.