Study of the Protective Equipments of a Substation And Power Factor Improvement

B.Sc. Engineering Thesis Paper

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This Thesis submitted to the Department of Electrical and Electronic Engineering to fulfill the requirements of the degree of Bachelor of Science in Electrical and Electronic Engineering.

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DECLARATION

It is hereby, declared that the work presented in this thesis is the outcomes of the investigation performed by us under the supervision of Prof. Dr. Mirza Golam Rabbani, Chairperson of the Department of Electrical and Electronic Engineering, Eastern University, Bangladesh. We also declared that no part of this thesis has been submitted elsewhere for the award of our degree.

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Dedicated

To

OUR HONOURABLE TEACHER

Prof. Dr. Mirza Golam Rabbani

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Abstract

In the power distribution industry today, utility companies are trying to come up with a solution to increase the efficiency of distributed power. One way of achieving this task is by improving the power factor of a system by adding power factor correction capacitors. Power factor improvement is a very important aspect of power distribution. Without a good power factor, there cannot be an efficient means of transporting energy over long distances due to the losses associated with moving power through a wire. This action has led to multiple studies on power factor correction. In order to achieve maximum efficiency, we had to increase our power factor as close to unity as possible. Power factor correction (PFC) is usually achieved by adding capacitive load to balance the inductive load present in the power system. The power factor of the power system is constantly changing due to variations in the size and number of the motors being used at one time. This makes it difficult to balance the inductive and capacitive loads continuously. Wasted energy capacity, also known as poor power factor, is often overlooked. It can result in poor reliability, safety problems and higher energy costs. The lower your power factor, the less economically your system operates.

There are many benefits to having power factor correction. As a customer the cost doesn’t get passed on for having a low power factor. As a utility company, equipment has a much longer life span and maintenance costs remain low.

Chapter -1
Introduction to electrical substation

1.1 Introduction

An Electrical Power Substation receives electric power from generating station via transmission lines and delivers power via the outgoing transmission lines. Substations are integral parts of a power system and form important links between the generating stations, transmission systems, distribution systems and the load points. Various power substations located in generating stations, transmission and distribution systems have similar layout and similar electrical components. Electrical power substation basically consists of number of incoming circuit connections and number of outgoing circuit connections connected to the busbars. Busbars are conducting bars to which number of circuit connections is connected. Each circuit has certain number of electrical components such as circuit breakers, Isolators, earth switches, current transformers, voltage transformers etc.

In a Power Substation there are various indoor and outdoor switchgear and equipment. Transformers are necessary in a substation for stepping up and stepping down of a.c voltage. Besides the transformers, the several other equipment include busbars, circuit breakers, isolators, surge arresters, Substation Earthing System, Shunt reactors, Shunt Capacitors etc . Each equipment has certain functional requirement. The equipment are either indoor or outdoor depending upon the voltage rating and local conditions.

In a large power System large number of Generating stations, Electrical Power Substations and load centers are interconnected. This large internetwork is controlled from load dispatch center. Digital and voice signals are transmitted over the transmission lines via the Power substations. The substations are interlinked with the load control centers via Power Line Carrier Systems (PLCC). Modern Power System is controlled with the help of several automatic, semiautomatic equipment. Digital Computers and microprocessors are installed in the control rooms of large substations, generating stations and load control centers for data collection, data monitoring, automatic protection and control.

1.2 Functions of Electrical Power Substations are

- Supply electric power to the consumers continuously
- Supply of electric power within specified voltage limits and frequency limits
- Shortest possible fault duration.
- Optimum efficiency of plants and the network
- Supply of electrical energy to the consumers at lowest cost.

1.3 Types of Electrical Power Substations

Based on Nature of Duties:

1.3.1 Step up or primary Electrical Power substation

Primary substations are associated with the power generating plants where the voltage is stepped up from low voltage (3.3, 6.6, 11, 33kV) to 220kV or 400kV for transmitting the power so that huge amount of power can be transmitted over a large distance to load centers.

1.3.2 Primary Grid Electrical Power Substation

Such substations are located at suitable load centers along with the primary transmission lines. At primary Grid Power Substations the primary transmission voltage (220kV or 400kV) is stepped down to secondary transmission voltages (110kV) . This Secondary transmission lines are carried over to Secondary Power Substations situated at the load centers where the voltage is further stepped down to Sub transmission Voltage or Primary Distribution Voltages (11kV or 33kV).

1.3.3 Step Down or Distribution Electrical Power Substations

Such Power Substations are located at the load centers. Here the Sub transmission Voltages of Distribution Voltages (11kV or 33kV) are stepped down to Secondary Distribution Voltages (400kV or 230kV). From these Substations power will be fed to the consumers to their terminals

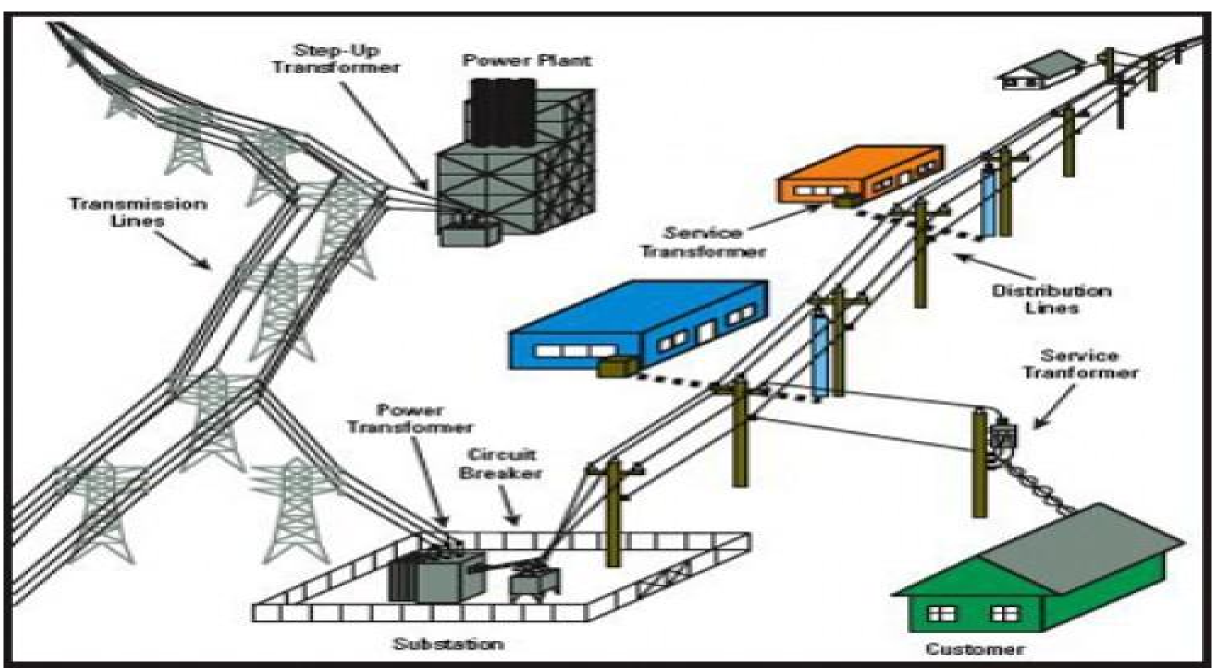


Fig1.1: Step Down or Distribution Electrical Power Substations.

Basis of Service Rendered

1.4 Transformer Substation

Transformers are installed on such Substations to transform the power from one voltage level to other voltage level.

1.4.1 Switching Substation

Switching substations are meant for switching operation of power lines without transforming the voltages. At these Substations different connections are made between various transmission lines. Different Switching Schemes are employed depends on the application to transmit the power in more reliable manner in a network.

1.4.2 Converting Substation

Such Substations are located where AC to DC conversion is required. In HVDC transmission Converting Substations are employed on both sides of HVDC link for converting AC to DC and again converting back from DC to AC. Converting Power Substations are also employed where frequency is to be converted from higher to lower and lower to higher. This type of frequency conversion is required in connecting to Grid Systems.

1.5 Based on Substation Design

1.5.1 Outdoor Electrical Power Substations

In Outdoor Power Substations, the various electrical equipments are installed in the switchyard below the sky. Electrical equipment is mounted on support structures to obtain sufficient ground clearance.

Figure 1.2: Outdoor substation

1.5.2 Indoor Electrical Power Substation

In Indoor Power Substations the apparatus is installed within the substation building. Such substations are usually for the rating of 66kV. Indoor Substations are preferred in heavily polluted areas and Power Substations situated near the seas (saline atmosphere causes Insulator Failures results in Flashovers)

Fig1.3: Indoor Substation

1.6 Based on Design Configuration

1.6.1Air Insulated Electrical Power Substation

In Air Insulated Power Substations busbars and connectors are visible. In this Power Substations Circuit Breakers and Isolators, Transformers, Current Transformers, Potential Transformers etc are installed in the outdoor. Busbars are supported on the post Insulators or Strain Insulators. Substations have galvanized Steel Structures for supporting the equipment, insulators and incoming and outgoing lines. Clearances are the primary criteria for these substations and occupy a large area for installation.

1.6.2 Gas Insulated Electrical Power Substation

In Gas Insulated Substation Various Power Substation equipments like Circuit Breakers, Current Transformers, Voltage Transformers, Bus bars, Earth Switches, Surge Arresters, Isolators etc are in the form of metal enclosed SF6 gas modules. The modules are assembled in accordance with the required Configuration. The various Live parts are enclosed in the metal enclosures (modules) containing SF6 gas at high pressure. Thus the size of Power Substation reduces to 8% to 10% of the Air Insulated Power Substation.

1.6.3 Hybrid Electrical Power Substation

Hybrid Substations are the combination of both Conventional Substation and Gas Insulated Substation. Some bays in a Power Substation are gas insulated type and some are air insulated type. The design is based on convenience, local conditions available, area available and cost.

Chapter – 2
Elements of a Substation

2.1 Transformer

Transformer is a static electrical device, involving no continuously moving parts, used in electric power systems to transfer power between circuits through the use of electromagnetic induction

There are three principle operations of transformers:

2.1.1 Power transformer

The term power transformer is used to refer to those transformers used between the generator and the distribution circuits, and these are usually rated at 500 kVA and above. Power systems typically consist of a large number of generation locations, distribution points, and interconnections within the system or with nearby systems, such as a neighboring utility. The complexity of the system leads to a variety of transmission and distribution voltages. Power transformers must be used at each of these points where there is a transition between voltage levels. Power transformers are selected based on the application, with the emphasis toward custom design being more apparent the larger the unit. Power transformers are available for step-up operation, primarily used at the generator and referred to as generator step-up (GSU) transformers, and for step-down operation, mainly used to feed distribution circuits. Power transformers are available as single-phase or three-phase apparatus. The construction of a transformer depends upon the application. Transformers intended for indoor use are primarily of the dry type but can also be liquid immersed. For outdoor use, transformers are usually liquid immersed. Here focuses on the outdoor, liquid-immersed transformers, such as shown in figure 2.1.

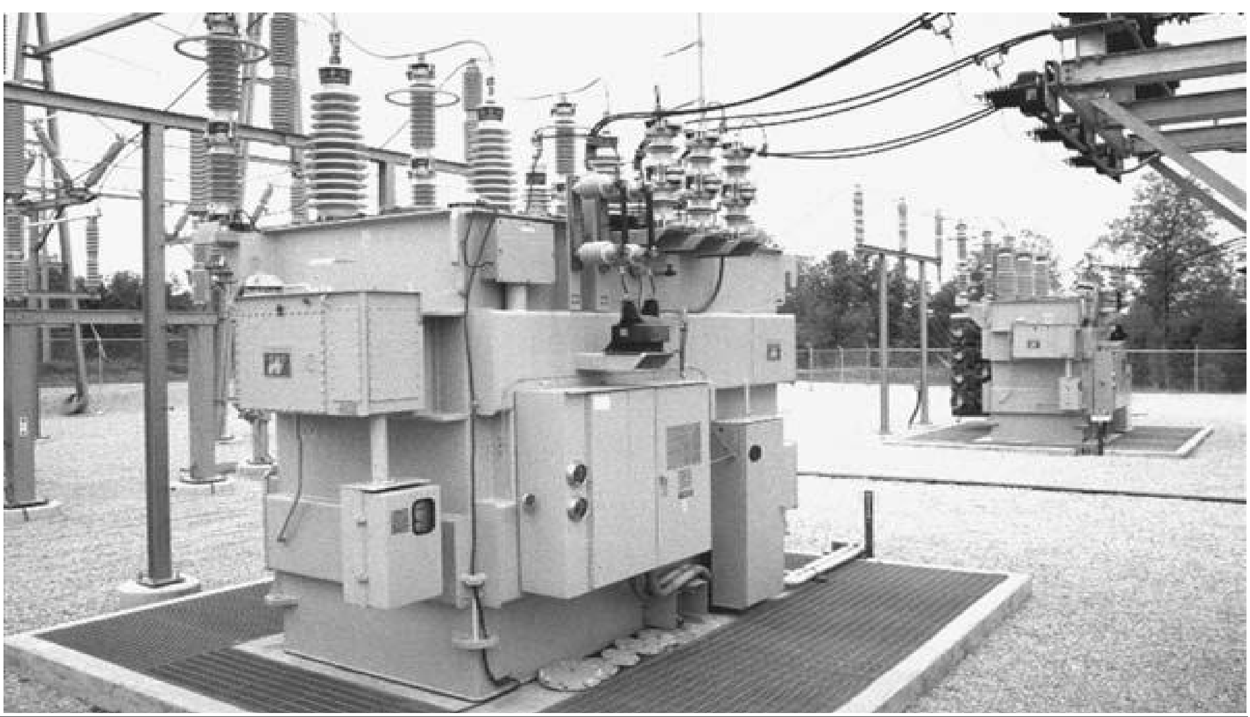


Fig2.1. Liquid immersed power transformer

Power transformers have been loosely grouped into three market segments based on size ranges. These three segments are:

1. Small power transformers: 500 to 7500 kVA
2. Medium power transformers: 7500 to 100 MVA
3. Large power transformers: 100 MVA and above

2.1.2 Distribution Transformer

Any transformer that takes voltage from a primary distribution circuit and "steps down" or reduces it to a secondary distribution circuit or a consumer's service circuit is a distribution transformer. Although many industry standards tend to limit this definition by kVA rating (e.g. 5 to 500 kVA), distribution transformers can have lower ratings and can have ratings of 5000 kVA or even higher, so the use of kVA ratings to define transformer types is being discouraged.

Fig 2.2: Distribution Transformer

2.1.3 Instrument Transformer

In order to measure high alternating currents and voltage, we employ specially designed transformer, called instrument transformer.
There are two types of instrument transformer as given below:

2.1.3.1 Current Transformer

In electrical engineering, a current transformer (CT) is used for measurement of electric currents. Current transformers, together with voltage transformers (VT) (potential transformers (PT)), are known as instrument transformers. When current in a circuit is too high to directly apply to measuring instruments, a current transformer produces a reduced current accurately proportional to the current in the circuit, which can be conveniently connected to measuring and recording instruments. A current transformer also isolates the measuring instruments from what may be very high voltage in the monitored circuit. Current transformers are commonly used in metering and protective relays in the electrical power industry.

Design

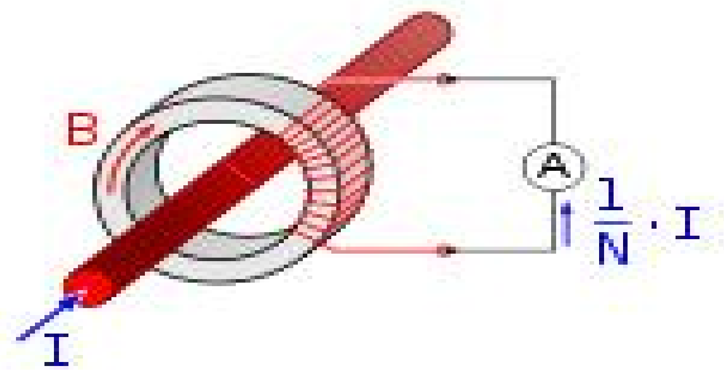


Fig 2.3: Current Transformers.

Current transformers used in metering equipment for three-phase 400 ampere electricity supply. Like any other transformer, a current transformer has a primary winding, a magnetic core, and a secondary winding. The alternating current flowing in the primary produces a magnetic field in the core, which then induces a current in the secondary winding circuit. A primary objective of current transformer design is to ensure that the primary and secondary circuits are efficiently coupled, so that the secondary current bears an accurate relationship to the primary current.

The most common design of CT consists of a length of wire wrapped many times around a silicon steel ring passed over the circuit being measured. The CT's primary circuit therefore consists of a single 'turn' of conductor, with a secondary of many tens or hundreds of turns. The primary winding may be a permanent part of the current transformer, with a heavy copper bar to carry current through the magnetic core. Window-type current transformers are also common, which can have circuit cables run through the middle of an opening in the core to provide a single-turn primary winding. When conductors passing through a CT are not centered in the circular (or oval) opening, slight inaccuracies may occur.

Shapes and sizes can vary depending on the end user or switchgear manufacturer. Typical examples of low voltage single ratio metering current transformers are either ring type or plastic molded case. High-voltage current transformers are mounted on porcelain bushings to insulate them from ground. Some CT configurations slip around the bushing of a high-voltage transformer or circuit breaker, which automatically centers the conductor inside the CT window.

The primary circuit is largely unaffected by the insertion of the CT. The rated secondary current is commonly standardized at 1 or 5 amperes. For example, a 4000:5 CT would provide an output current of 5 amperes when the primary was passing 4000 amperes. The secondary winding can be single ratio or multi ratio, with five taps being common for multi ratio CTs. The load, or burden, of the CT should be of low resistance. If the voltage time integral area is higher than the core's design rating, the core goes into saturation towards the end of each cycle, distorting the waveform and affecting accuracy.

Usage

Current transformers are used extensively for measuring current and monitoring the operation of the power grid. Along with voltage leads, revenue-grade CTs drive the electrical utility's watt-hour meter on virtually every building with three-phase service and single-phase services greater than 200 amp.
The CT is typically described by its current ratio from primary to secondary. Often, multiple CTs are installed as a "stack" for various uses. For example, protection devices and revenue metering may use separate CTs to provide isolation between metering and protection circuits, and allows current transformers with different characteristics (accuracy, overload performance) to be used for the devices.

Safety precautions

Care must be taken that the secondary of a current transformer is not disconnected from its load while current is flowing in the primary, as the transformer secondary will attempt to continue driving current across the effectively infinite impedance. This will produce a high voltage across the open secondary (into the range of several kilovolts in some cases), which may cause arc. The high voltage produced will compromise operator and equipment safety and permanently affect the accuracy of the transformer.

Accuracy

The accuracy of a CT is directly related to a number of factors including:

1. Burden
2. Burden class/saturation class
3. Rating factor
4. Load

Burden

The load, or burden, in a CT metering circuit is the (largely resistive) impedance presented to its secondary winding. Typical burden ratings for IEC CTs are 1.5 VA, 3 VA, 5 VA, 10 VA, 15 VA, 20 VA, 30 VA, 45 VA & 60 VA. As for ANSI/IEEE burden ratings are B-0.1, B-0.2, B-0.5, B-1.0, B-2.0 and B-4.0. This means a CT with a burden rating of B-0.2 can tolerate up to 0.2 Ω of impedance in the metering circuit before its output current is no longer a fixed ratio to the primary current. Items that contribute to the burden of a current measurement circuit are switch-blocks, meters and intermediate conductors. The most common source of excess burden in a current measurement circuit is the conductor between the meter and the CT. Often, substation meters are located significant distances from the meter cabinets and the excessive length of small gauge conductor creates a large resistance. This problem can be solved by using CT with 1 ampere secondary's which will produce less voltage drop between a CT and its metering devices.

2.1.3.2 Potential Transformer

Voltage transformers or potential transformers are used for measurement and protection. Accordingly, they are either measuring type or protective type voltage transformers. They may be either single phase or three phase units. Voltage transformers are necessary for voltage, directional, distance protection. The primary of voltage transformer is connected to power circuit between phase and ground. The volt ampere rating of voltage transformers is similar as compared with that of power transformer. There are two types of construction:

- Electromagnetic potential transformer, in which primary and secondary are wound on magnetic core like in usual transformer.
- Capacitor potential transformer, in which primary voltage is applied to a series capacitor group.

Figure2.4: Potential Transformer.

Voltage transformers (VT) or potential transformers (PT) are another type of instrument transformer, used for metering and protection in high-voltage circuits. They are designed to present negligible load to the supply being measured and to have a precise voltage ratio to accurately step down high voltages so that metering and protective relay equipment can be operated at a lower potential. Typically the secondary of a voltage transformer is rated for 69 V or 120 V at rated primary voltage, to match the input ratings of protection relays.

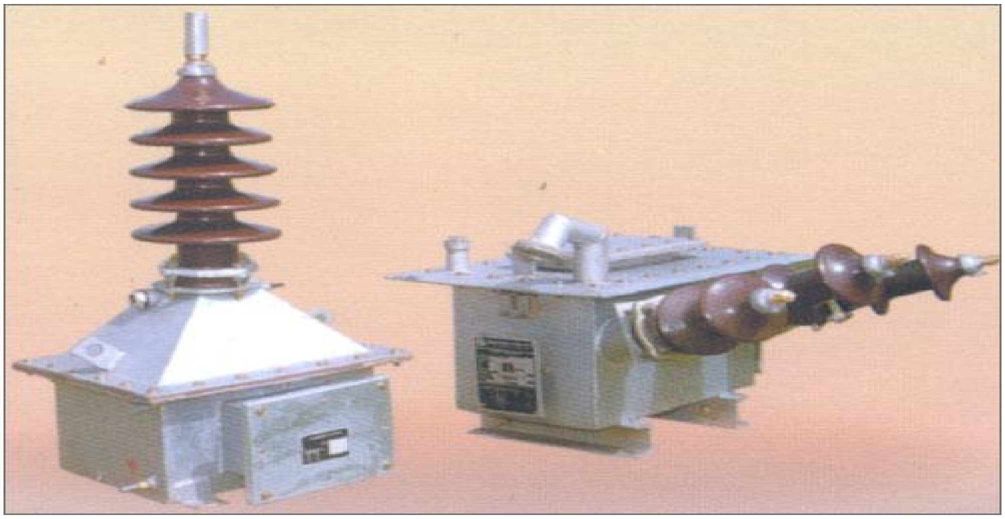


Fig2.5: Deferent types of Potential Transformer or PT.

The transformer winding high-voltage connection points are typically labeled as H_1, H_2 (sometimes H_0 if it is internally grounded) and X_1, X2 and sometimes an X_3 tap may be present. Sometimes a second isolated winding (Y_1, Y_2, Y_3) may also be available on the same voltage transformer. The high side (primary) may be connected phase to ground or phase to phase. The low side (secondary) is usually phase to ground.

The terminal identifications (H_1, X_1, Y_1, etc.) are often referred to as polarity. This applies to current transformers as well. At any instant terminals with the same suffix numeral have the same polarity and phase. Correct identification of terminals and wiring is essential for proper operation of metering and protection relays.

While VTs were formerly used for all voltages greater than 240 V primary, modern meters eliminate the need VTs for most secondary service voltages. VTs are typically used in circuits where the system voltage level is above 600 V. Modern meters eliminate the need of VT's since the voltage remains constant and it is measured in the incoming supply. This is mostly used in H.V.

2.2 Protective Equipments of a Substation

Protection is the major part of an electrical substation. So there is some requirement of protective equipments as listed below:

2.3 CIRCUIT BREAKER

A circuit breaker is an automatically-operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation.

Fig.2.6- Common trip circuit breaker

Fig2.7-Vaccum tube Circuit Breaker.

Circuit breakers are made in varying sizes, from small devices that protect an individual household appliance up to large switchgear designed to protect high voltage circuits feeding an entire city

2.3.1 Operation

Circuit breakers have common features in their operation, although details vary substantially depending on the voltage class, current rating and type of the circuit breaker.

The circuit breaker must detect a fault condition; in low-voltage circuit breakers this is usually done within the breaker enclosure. Circuit breakers for large currents or high voltages are usually arranged with pilot devices to sense a fault current and to operate the trip opening mechanism. The trip solenoid that releases the latch is usually energized by a separate battery, although some high-voltage circuit breakers are self-contained with current transformers, protection relays, and an internal control power source.

Once a fault is detected, contacts within the circuit breaker must open to interrupt the circuit; some mechanically stored energy within the breaker is used to separate the contacts, although some of the energy required may be obtained from the fault current itself. The stored energy may be in the form of springs or compressed air. Small circuit breakers may be manually operated; larger units have solenoids to trip the mechanism, and electric motors to restore energy to the springs.

The circuit breaker contacts must carry the load current without excessive heating, and must also withstand the heat of the arc produced when interrupting the circuit. Contacts are made of copper or copper alloys, silver alloys, and other materials. Service life of the contacts is limited by the erosion due to interrupting the arc. Miniature circuit breakers are usually discarded when the contacts are worn, but power circuit breakers and high-voltage circuit breakers have replaceable contacts.

2.3.2 Types of Circuit Breaker

1. Oil circuit Breaker
2. SF_6 Circuit Breaker
3. Air Blast Circuit Breaker
4. Vacuum Circuit Breaker

2.3.3 Oil Circuit Breakers (OCB)

The oil in OCB serves two purposes. It insulates between the phases and between the phases and the ground, and it provides the medium for the extinguishing of the arc. When electric arc is drawn under oil, the arc vaporizes the oil and creates a large bubble that surrounds the arc. The gas inside the bubble is around 80% hydrogen, which impairs ionization. The decomposition of oil into gas requires energy that comes from the heat generated by the arc. The oil surrounding the bubble conducts the heat away from the arc and thus also contributes to deionization of the arc.

Main disadvantage of the oil circuit breakers is the flammability of the oil, and the maintenance necessary to keep the oil in good condition (i.e. changing and purifying the oil).

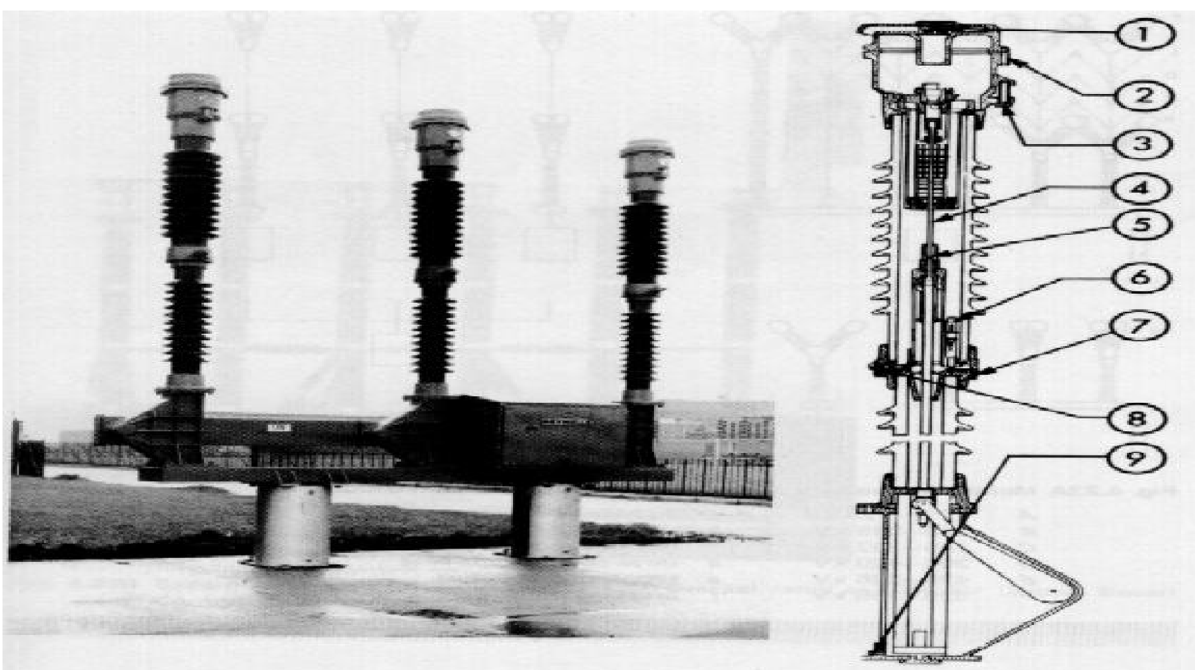


Fig. 2.8- Minimum Oil circuit breaker

1. Vent valve
2 .Terminal pad
3 .Oil level indicator
4. Moving contact
5. Lower fixed contact
6. Separating piston
7 .Terminal pad
8. Upper drain valve
9. Lower drain valves

2.3.4 Sulfur Hexafluoride (SF6) high-voltage circuit-breakers

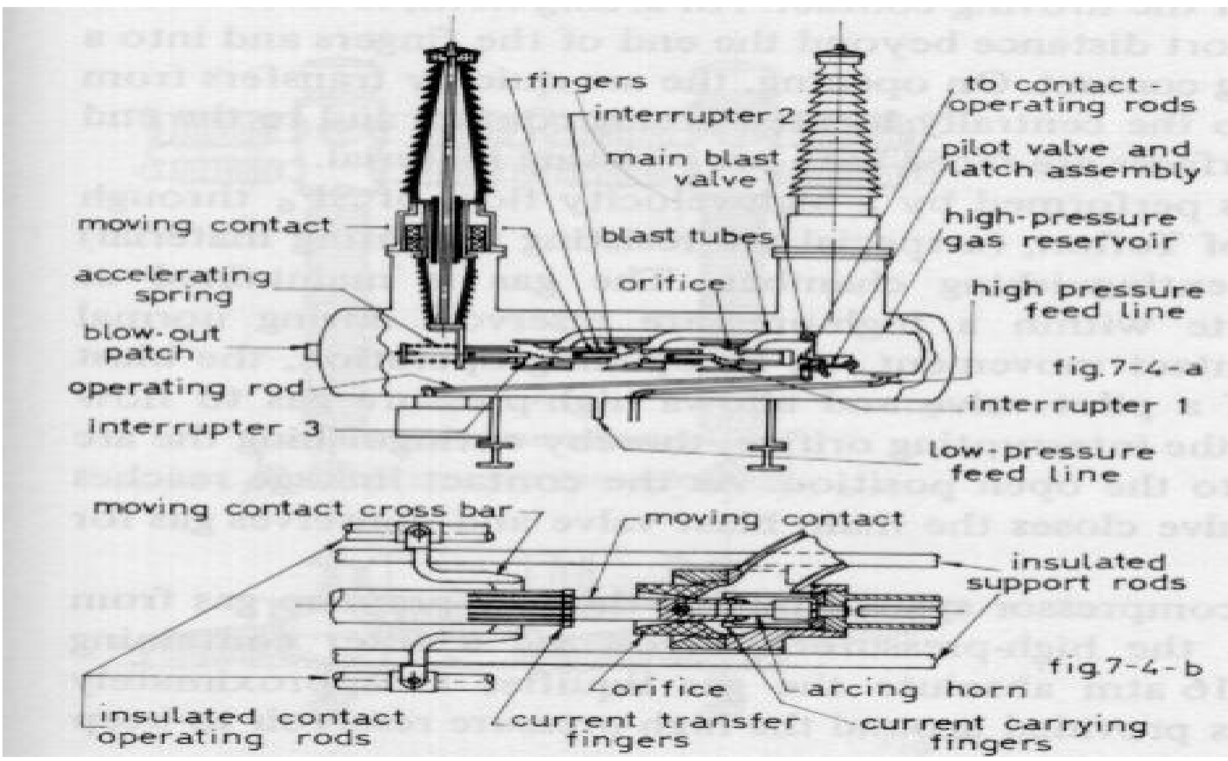


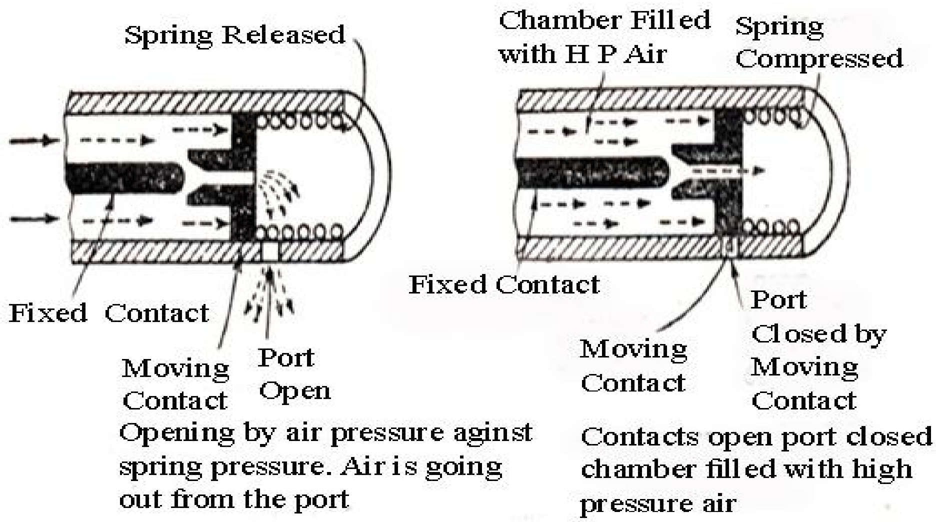
Fig.2.9:SF_6 circuit Breakers.

High-voltage circuit-breakers have greatly changed since they were first introduced about 40 years ago, and several interrupting principles have been developed that have contributed successively to a large reduction of the operating energy. These breakers are available for indoor or outdoor applications, the latter being in the form of breaker poles housed in ceramic insulators mounted on a structure.

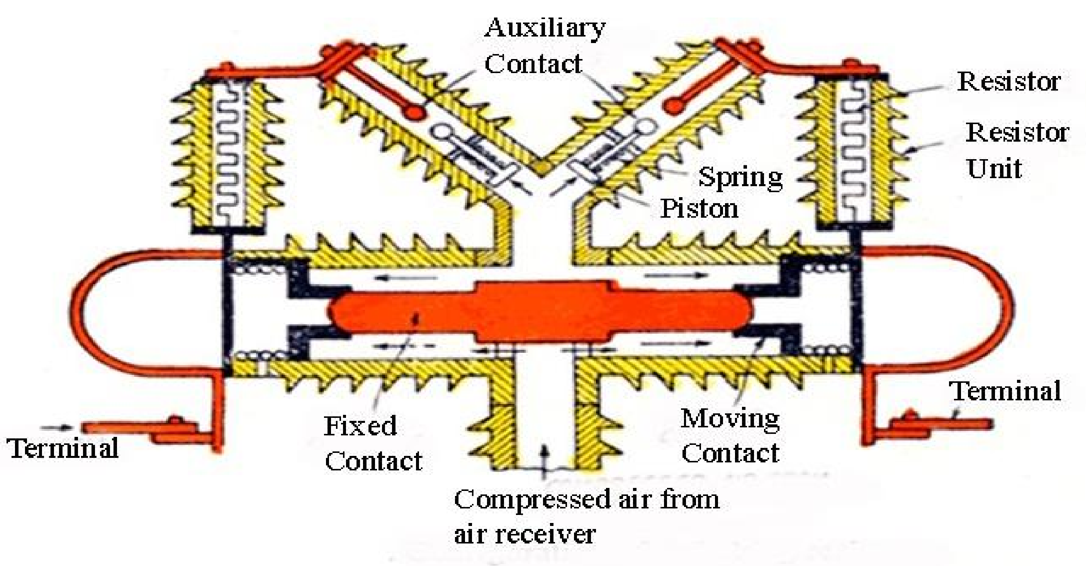
Current interruption in a high-voltage circuit-breaker is obtained by separating two contacts in a medium, such as SF_6, having excellent dielectric and arc quenching properties. After contact separation, current is carried through an arc and is interrupted when this arc is cooled by a gas blast of sufficient intensity.Gas blast applied on the arc must be able to cool it rapidly so that gas temperature between the contacts is reduced from 20,000 K to less than 2000 K in a few hundred microseconds, so that it is able to withstand the transient recovery voltage that is applied across

the contacts after current interruption. Sulfur hexafluoride is generally used in present high-voltage circuit-breakers (of rated voltage higher than 52 kV).
In the 1980s and 1990s, the pressure necessary to blast the arc was generated mostly by gas heating using arc energy. It is now possible to use low energy spring-loaded mechanisms to drive high-voltage circuit-breakers up to 800 kV.

2.3.5 Air Blast Circuit Breaker



(a) Sequence of operation in ABCD



Confugration of switching resistors

Fig: 2.10-Air Blast Circuit Breaker

2.3.6.1 Operation

Fast operations, suitability for repeated operation, auto reclosure, unit type multi break constructions, simple assembly, and modest maintenance are some of the main features of air blast circuit breakers. A compressors plant necessary to maintain high air pressure in the air receiver. The air blast circuit breakers are especially suitable for railways and arc furnaces, where the breaker operates repeatedly. Air blast circuit breakers are used for interconnected lines and important lines where rapid operation is desired.
High pressure air at a pressure between 20 to 30 kg/ cm2 stored in the air reservoir. Air is taken from the compressed air system. Three hollow insulator columns are mounted on the reservoir with valves at their basis. The double arc extinguished chambers are mounted on the top of the hollow insulator chambers. The current carrying parts connect the three arc extinction chambers to each other in series and the pole to the neighboring equipment. Since there exists a very high Voltage between the conductor and the air reservoir, the entire arc extinction chambers assembly is mounted on insulators.

2.3.7 Vacuum circuit breakers

Vacuum circuit breakers are circuit breakers which are used to protect medium and high voltage circuits from dangerous electrical situations. Like other types of circuit breakers, vacuum circuit breakers literally break the circuit so that energy cannot continue flowing through it, thereby preventing fires, power surges, and other problems which may emerge. These devices have been utilized since the 1920s, and several companies have introduced refinements to make them even safer and more effective.

Fig: 2.11- Vacuum circuit breaker.

2.3.7.1 Operation

In a vacuum circuit breaker, two electrical contacts are enclosed in a vacuum. One of the contacts is fixed, and one of the contacts is movable. When the circuit breaker detects a dangerous situation, the movable contact pulls away from the fixed contact, interrupting the current. Because the contacts are in a vacuum, arcing between the contacts is suppressed, ensuring that the circuit remains open. As long as the circuit is open, it will not be energized.
Vacuum reclosers will automatically reset when conditions are safe again, closing the circuit and allowing electricity to flow through it. Reclosers can usually go through several cycles before they will need to be manually reset. Other types of vacuum circuit breakers require resetting every time the breaker trips. Before a manual reset, the person doing the resetting needs to check the system to determine what caused the unsafe conditions in the first place, and make sure that they have been addressed.
Vacuum circuit breakers are very durable, and they are designed to last for an extended period of time. These electrical safety devices can be made with a variety of materials, depending on the need and the preference of the manufacturer. As with other devices used to interrupt current for safety, vacuum circuit breakers are given a rating which indicates the kind of conditions they can handle. When people install circuit breakers, they must confirm that the breaker they are using is suitable for the conditions; a breaker which is rated too low can fail catastrophically.
Other techniques can be used for arc suppression with medium and high voltage electrical systems, such as filling circuit breakers with inert gases to suppress arcing. Arc suppression is a major concern with heavy duty power systems because if an arc forms, it can override the circuit breaker and create very dangerous and very undesirable conditions. Companies which develop circuit breakers for these applications usually test their breaker designs extensively to confirm that they are safe.

2.4 RELAY

Relay is a protective device that detects the fault and initiatives the operation of the circuit breaker to isolate the defective element from the rest of the system

Classification of relay:

According to construction and principle of operation:

1. Electromagnetic relays.
2. Induction relays.
3. Buchholz relay.

According to application:

1. Directional reverses current relays.
2. Directional reverse power relays.
3. Differential relay.

4. Impedance relay.
5. Reactance relay.

According to speed:

1. Instantaneous relay.
2. Definite time lag relay.
3. Inverse time lag relay
4. Inverse definite minimum time lag relay.

A protective relay is a device that detects the fault and initiatives the operation of the circuit breaker to isolate the defective element from the rest of the system.

2.4.1 Basic principle of relay

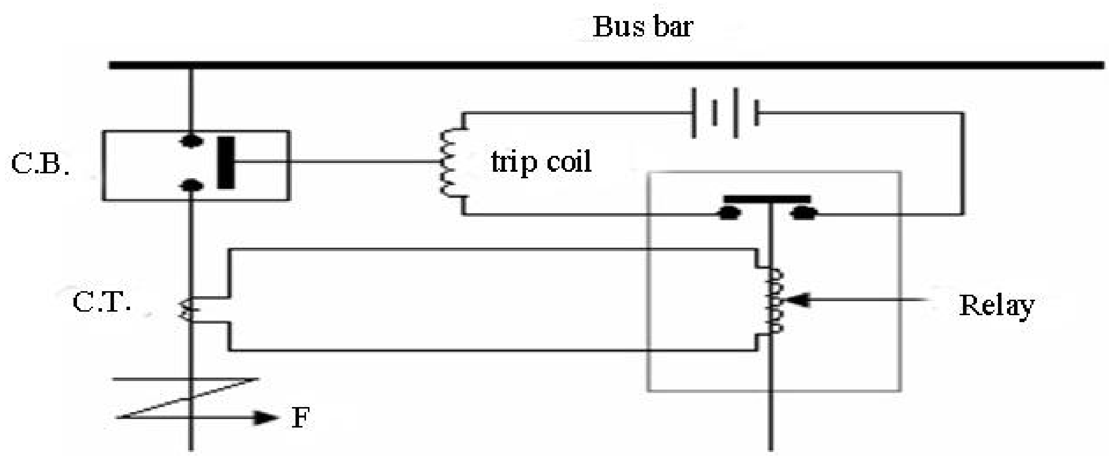


Figure-Basic principle of relay

This diagram has shown one phase of 3-phase system for simplicity. The relay circuit Connections can be divided into three parts.

1. First part is the primary wiring of a current transformer. Which is connected in series with the line to be protected?

2. Second part consists of secondary winding of C.T. and the relay operating coil.

3. The third part is tripping circuit which may be either ac or dc. When a short circuit occurs of on the transmission line, the current flowing in the line increasing to an enormous value This results in a heavy current flow through the relay coil causing the relay to operate by closing its

contacts. This in turn closes the trip circuit of the breaker, making the circuit breaker open and isolating the faulty section from the rest of the system.

2.4.2 Important terms of the relay

1. Pick up current:

It is the minimum current in the relay coil at which the starts to operate.
Pick up current =Rated secondary current of CT ×Current setting

2. Current setting:

It is often desirable to adjust the pick – up current to any required value. This is known as current setting and is usually achieved by the use of taping on the relay operating coil.

3. Time –setting multiplier

A relay is generally provided with control to adjust the time of operation. This adjustment is known as time – setting multiplier.

5. Gas operated (buchholz) relay

Buchholz relay is a gas – actuated relay installed in oil immersed transformer for protection against all kinds of fault .It used to give an alarm in case incipient. When fault is disconnect the transformer from this supply in this system .It is usually installed in the pipe connecting the conservator to the main tank. It is use for excess of 750KVA.

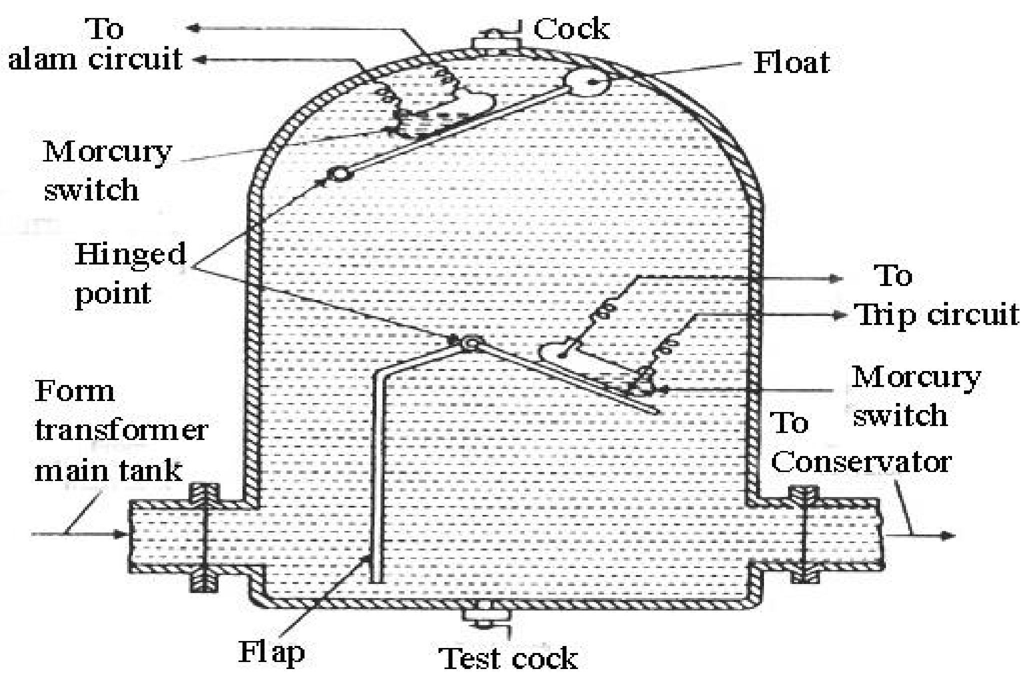


Fig: 2.12- Gas operated (Buchholz) relay

2.4.3 Directional over current relay

The Directional power relay is unsuitable for use as a directional protective relay under short circuit conditions. When a short circuit occurs the system voltage for to a low value and there may be insufficient torque developed in the relay to cause it operation. This difficulty is overcome in the directional over current relay, which is designed to be almost independent of system voltage and power factor. Under normal operating condition, power flows in the normal direction in the circuit protected by the relay. Therefore, directional power relay does not operate, thereby keeping the over current element unenergized.

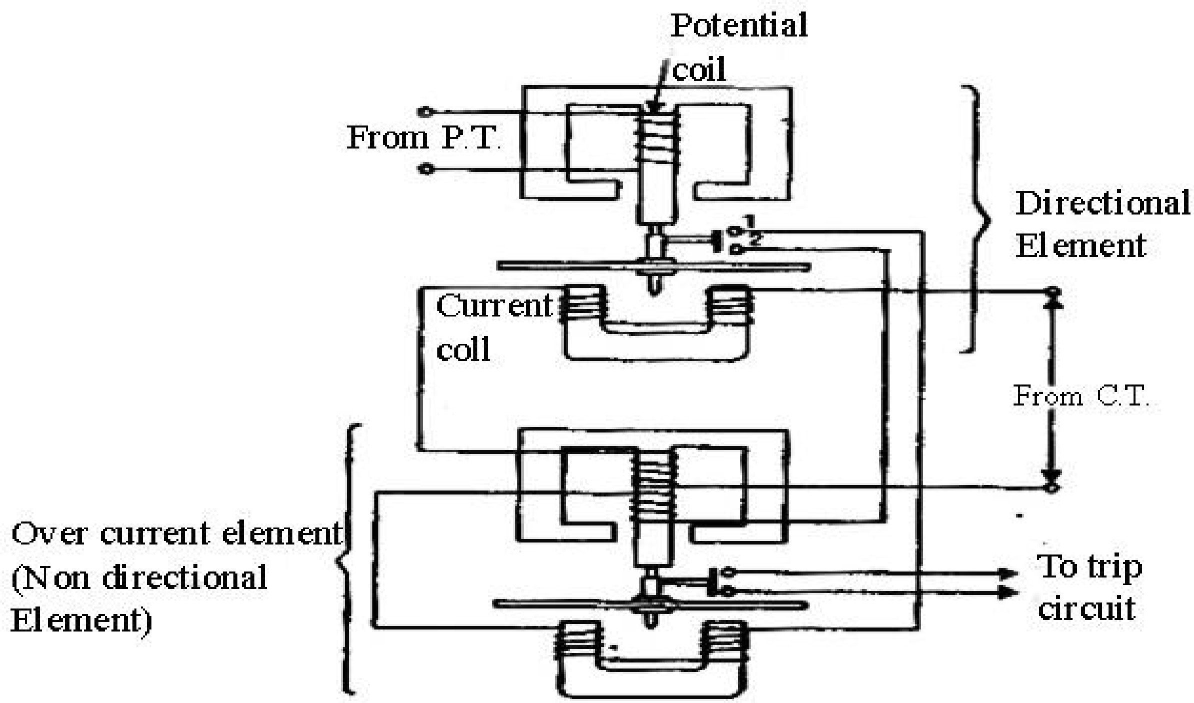


Fig: 2.13- Induction directional over current relay.

However, when a short circuit occurs, thereby keeping the over current element rotates to bridge the reverse direction. Should this element rotate and the moving contact attached to it closes the trip circuit. This operates the circuit breaker which isolates the faulty section.

2.5 FUSE

A fuse is a short piece of metal, inserted in the circuit which is melt when excessive current flows through it thus break the circuit. The fuse element generally made of materials having melting point & conductivity.

Important terms of fuse element: It is the current which the fuse element can normally carry with over heating or melting. It is depends upon the temperature rise of the contacts of the fuse holder, fuse material and the surrounding of the fuse.

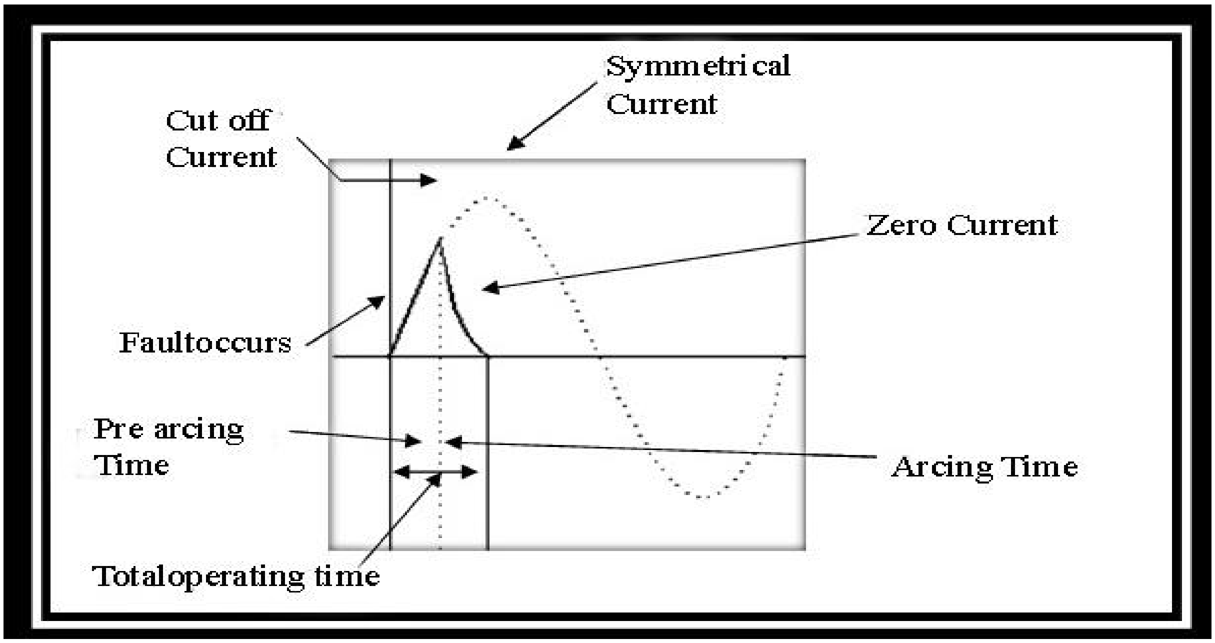


Fig: 2.14-Cut off characteristics of fuse.

2.5.1 Type of Fuse

a. Low voltage Fuse.

b. Semi enclosed rewires able Fuse.

c. High rupturing capacity cartridge fuse.

2.5.1.1High voltage fuses

a. Cartridge type fuses.

b. Liquid type fuse.

c. Metal clod fuse.

2.5.1.2 High rupturing capacity (H.R.C.) cartridge fuse

The H.R.C. fuse consist of a heat resisting ceramic body having metal end cap to which is welded silver current –carrying element .The space within the body surrounding the element is completely packed with a filling powder. The filling material may be chalk, plaster of pairs, quartz or marble dust and acts as an arc quenching and cooling medium. Under normal condition, the fuse element is at a temperature below its melting point, it carries normal current without overheating. When fault occurs the current increases and the fuse element melts.

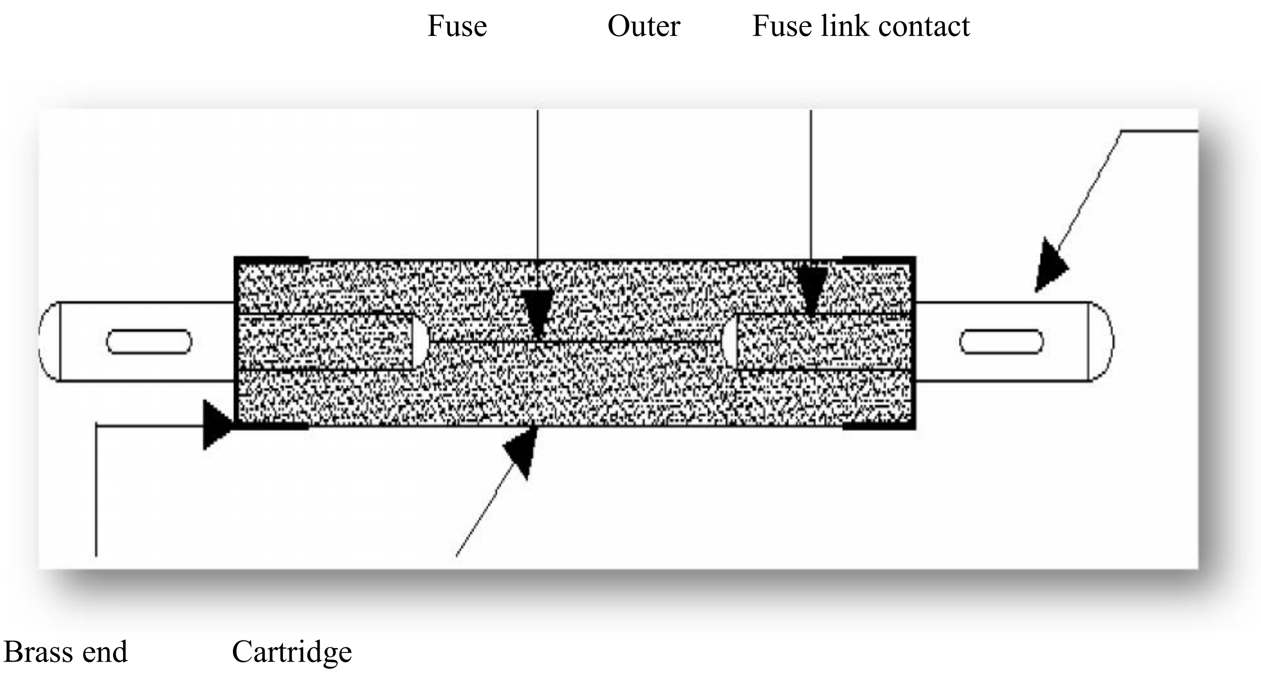


Fig: 2.15- High rupturing capacity (HRC) Cartridge fuse.

2.5.2 Advantage of High rupturing capacity (H.R.C.) cartridge fuse

- They are capable of clearing high as well as low fault currents.
- They have high speed of operation.
- They provide reliable discrimination.
- They require no maintenance.
- They provide reliable discrimination
- They permit consistent performance.

2.5.3 Disadvantage of High rupturing capacity (H.R.C.) cartridge fuse

- Heat produced by the arc may affect the associated switches.
- They have to be replaced after each operation.

2.6 LIGHTNING ARRESTER

An early type of Lightning dissipater-arrester, which the patent states to prevent and safely dissipate lightning strikes.

Fig. 2.16- Different type of arrester that are used to protect our power system.

2.6.1 Protection against Lightning

The most commonly used device for protection against lightning surges are

1. Earthing screen

2. Overhead ground wires

3. Lightning arresters or surges diverters.

2.6.2 Types of lightning arrester

1. Road gap lightning arrester.
2. Horn gap lightning arrester.
3. Multi gap lightning arrester.
4. Expulsion type lightning arrester.
5. Valve type lightning arrester.
6. Oxide film lightning arrester.
7. Electrolyte lightning arrester.
8. Burke lightning arrester.

2.7 AUTO RECLOSURE

Many fault an overhead transmission lines are transient in nature. Statically evidence shows that about 90% of faults an overhead transmission lines are caused by lightning or by passing of object near or through lines. These condition results in arcing faults and the arc in the fault can be extinguished by the simultaneous opening of circuit breakers on both ends of the lines or a one end of the line. Since the cause of transient faults mentioned above disappears after a short time the circuit breaker can be recluse as soon as the arc in fault has been extinguished. The autos re-closure trips open three times when circuit has any fault.

2.7.1 Operating sequence of auto Re-closure

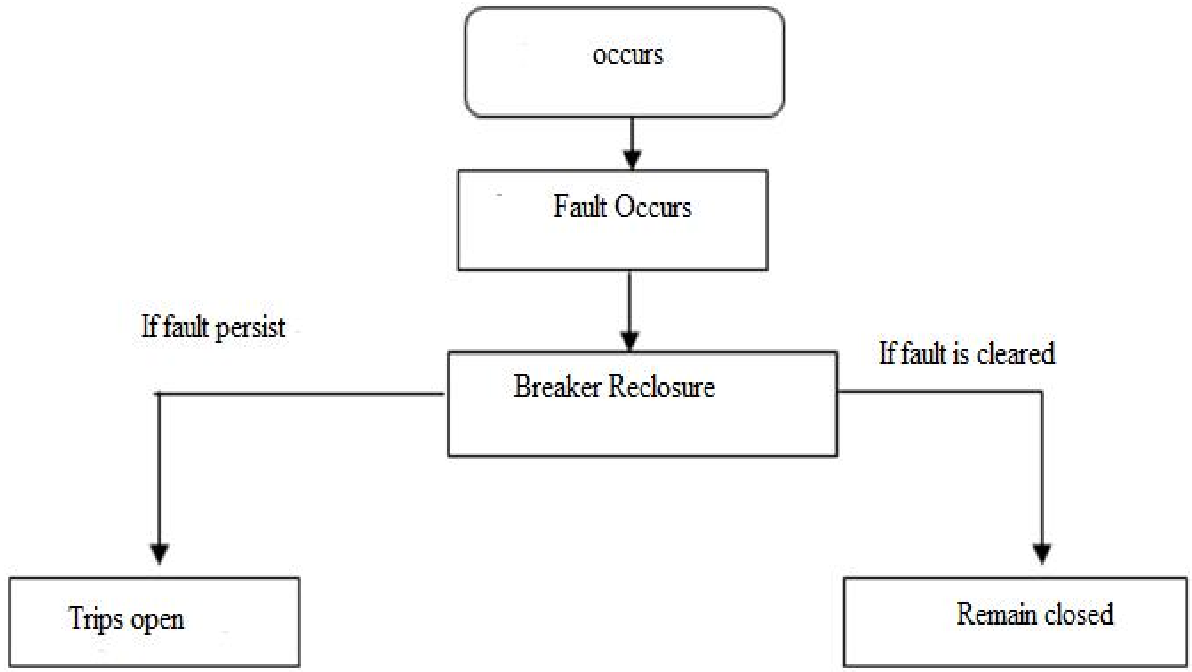


Figure2.17: Auto re-closures operation system.

2.8 ISOLATOR

Isolator is a disconnecting switch which operates under no load conditions, ithas no specified current breaking capacity. Isolator is not even used for breaking current. In some case isolator are used for breaking charging current of transmission lines. Isolator is used in addition to circuit breaker is opened first then isolator. While closing a circuit the isolator is necessary on the supply side of circuit breakers in order to ensure isolation of the circuit breaker from live parts of the purpose of maintenance

The operating mechanism manual plus one of the following.

- Electrical motor mechanism
- Pneumatic mechanism

2.8.1 Types of construction of Isolators

- Vertical break type
- Horizontal break type, either center-break or double –break

2.9 EARTHING

Earthling or Grounding is most important and simple protection of electrical system earthling is mainly two types.

1. Alternator and X-former neutral earthling.
2. Noncurrent carrying / metallic body.

2.9.1 Alternator and X-former neutral earthling

Alternator and X-former neutral is earthling directly or body by resistance or inductance. These earthlings reduced or minimize traveling wave, any surge voltage and unbalanced voltage.

2.9.2 Non Current Carrying / Metallic body

Metallic body means the body of motor , generator , x-former, metal tank tower and pole earthling .This earthling protects any abnormal current as a result protective relay and fuse operate easy .

2.9.3 Earthling Electrode

The earthling electrodes are two types:

1. Pipe electrode
2. Plate electrode

Chapter -3
Power factor improvement

3.1 Introduction to power

Power is the time rate of expanding or absorbing energy.

For DC the power is defined by

$$P=VI$$

Where V is direct voltage, I is direct current. There is no phase angle between voltage and current.

But for AC the power is defined by

Apparent power, $S=VI$

Active power, $P=VI\cos\emptyset$

And reactive power, $Q= VI\sin\emptyset$

These powers can be expressed in a triangle known as power triangle.

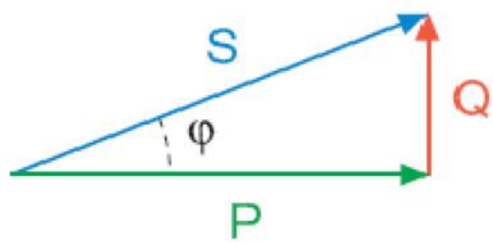


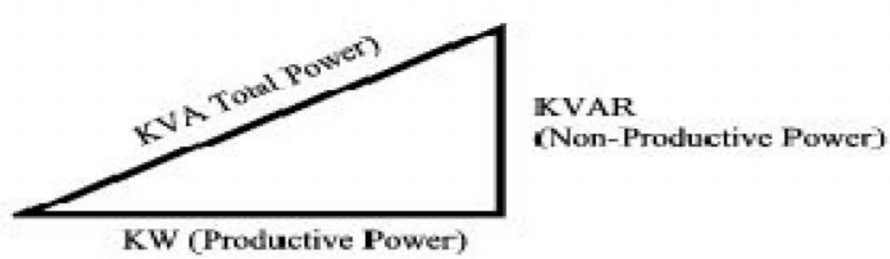
Figure3.1 power triangle

In the figure Q is the imaginary part & p is the real part. These two powers constitute apparent power.

So we can write by triangle formula, $S^2 = p^2 + Q^2$

The apparent power is given by, $S= \sqrt{p^2 + Q^2}$

The unit of the real power is W or KW, reactive part is VAR or KVAR & for apparent power is VA/KVA (volt-ampere or kilovolt-ampere).



So we can also write, KVA= $\sqrt{KW^2 + KVAR^2}$

But all the powers are not useful for our electrical appliances. Only active power or real power is useful one. Most of our electrical appliances take apparent power (Total power). But it use only real power and wastages reactive power as hit or other form of energy.

For this extra power (reactive power) extra current is taken by appliances. And this is only for the lack of electrical efficiency for the appliances. A factor between active power and apparent power is responsible for this lacking. This factor is known as power factor.

3.2 Power factor

Power factor is the percentage of electricity that is being used to do useful work. It is defined as ratio of active or actual power used in the circuit to the apparent power.

Power factor, cosØ $= \frac{\text{Active power}}{\text{Apparent power}}$ or $\frac{\text{Kw}}{\text{KVA}}$

Depending on Load power factor can be classified as:

i. Lagging

ii. ii. Leading

iii. Unity

Lagging power factor

Most of our electrical appliances are inductive. For this inductive load, current lags the applied voltage. Thus we get lagging power factor. There is a phase difference (Ø) between voltage and current.

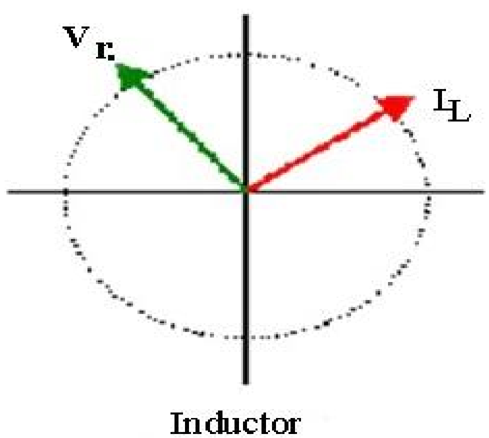


Figure3.2: Phasor diagram

In figure we see an inductor where current lags the voltage and it gives lagging power factor.

Leading power factor

We get leading power factor when current leads the applied voltage. In figure we see a capacitive load where current leads the applied voltage. Thus from capacitive load we get leading power factor. There is also a phase difference (Ø) between voltage and current.

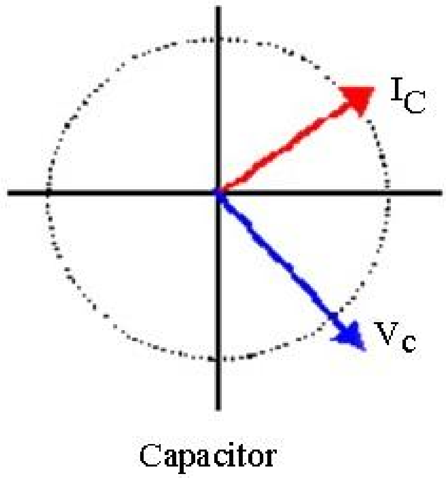


Figure3.3: Phasor diagram.

Unity power factor

It is about impossible to get unity power factor. But in purely resistive load we get unity power factor.
There is no phase difference between voltage and current as shown in figure. It is the maximum value of power factor that is 1.

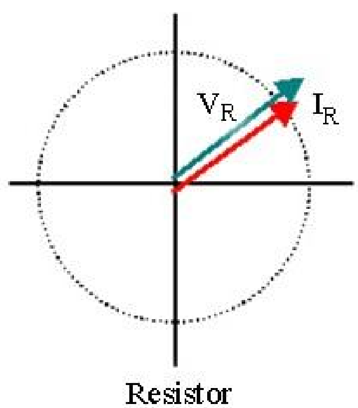


Figure3.4: Phasor diagram.

The power factor is 1 means it has 100% efficiency. But our appliances are not purely resistive. They are either inductive or capacitive whose power factor is always less than 1. It is better to use appliances which have power factor 1 or near 1. So we try to improve power factor up to 1 so that we get better efficiency.

3.3 Equipment Creating Poor Power Factor

It is useful to have an idea of the value of the power factor of commonly used electrical equipment. This will give an idea as to the amount of reactive energy that the network will have to carry.

Some electrical appliances those use low power factor are listed below:

Lighting

- **Incandescent Lamps:** The power factor is equal to unity.
- **Fluorescent Lamps:** Usually have a low power factor, for example, 50% power factor would not be unusual. They are sometimes supplied with a Compensation device to correct low power factor.
- **Mercury Vapor Lamps:** The power factor of the lamp is low; it can vary between 40% to 60%, but the lamps are often supplied with correction devices.

Distribution Transformer

The power factor varies considerably as a function of the load and the design of the transformer. A completely unloaded transformer would be very inductive and have a very low power factor.

Electrical Motors

Induction Motors

The power factor varies in accordance with the load. Unloaded or lightly loaded motors exhibit a low power factor. The variation can be 30% to 90%.

Synchronous Motors

Very good power factor when the excitation is properly adjusted. Synchronous motors can be over excited to exhibit a leading power factor and can be used to compensate a low power system.

Industrial Heating

With resistance, as in ovens or dryers, the power factor is often closed to 100%.

Welding

Electric arc welders generally have a low power factor, around 60%.

Other types of machinery or equipment those are likely to have a low power factor include:

Typical Un-improved Power Factor by Equipment

Equipment	Power Factor
Air Compressor & Pumps (External Motors)	75-80
Hermetic Motors (compressors)	50-80
Arc Welding	35-60
Resistance Welding	40-60
Machining	40-65
Arc Furnaces	75-90
Induction Furnaces (60Hz)	100
Standard Stamping	60-70
High Speed Stamping	45-60
Spraying	60-65

3.4 The causes of low power factor

From the above list, we can see that a low power factor can be a result of the design of the equipment, as in the case of welders, or it can be result from the operating conditions under which the equipment is used, as in lightly loaded induction motors which are probably the worst offenders.

Equipment Design

In an old installation, one is limited by the inefficiency of the existing system. However, given the opportunity to expand and purchase new equipment, one should consider some of the Energy efficient electric motors that is available today.

Operating Conditions

Load

The power factor of an electrical motor reaches its maximum value under full load. The power factor decreases rapidly when the load decreases. The figure below symbolically Illustrates the effect of the load on the power factor of a motor.

Motor Load Factor	Power Factor
Unloaded	17%
1/4 Loaded	55%
½ Loaded	73%
¾ Loaded	80%
Fully Loaded	84%
Overloaded (25%)	86%

Line voltage

Increasing the line voltage on motors and transformers above the rated voltage will increase the consumption of reactive energy. The result will be reduction of power factor.
For example, an increase of 10% on the rated voltage can result in 20% reduction of the power factor.

3.5 Disadvantages of low power factor

Many of us are oblivious about low power factor. We view it only as a direct charge on their electrical bill, and only when stated as such. Low power factor is a direct cost to the utility company and must be paid for.

Direct costs of low power factor

Power factor may be billed as one of or combination of the following:

- A penalty for power factor below and a credit for power factor above a predetermined value.
- An increasing penalty for decreasing power factor.
- A charge on monthly KVAR Hours.
- KVA demand: A straight charge is made for the maximum value of KVA used during the month. Included in this charge is a charge for KVAR since KVAR increase the amount of KVA.

Indirect costs of low power factor

Loss in efficiency of the equipment

When an installation operates with a low power factor, the amount of useful power available inside the installation at the distribution transformers is considerably reduced due to the amount of reactive energy that the transformers have to carry. The figure below indicates the available actual power of distribution equipment designed to supply 1000 KW.

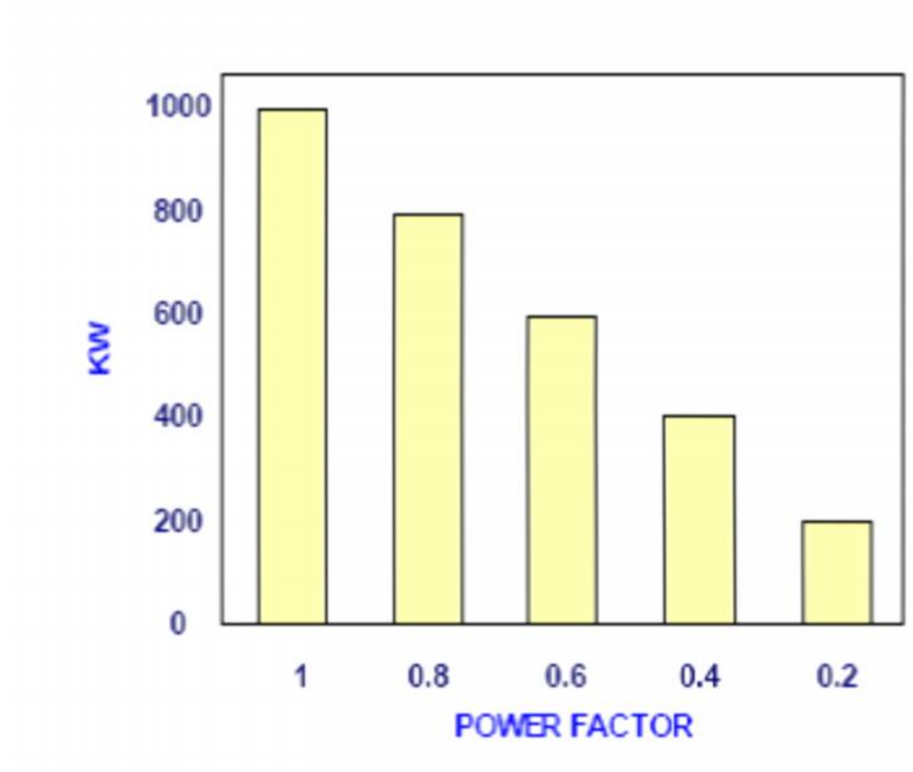
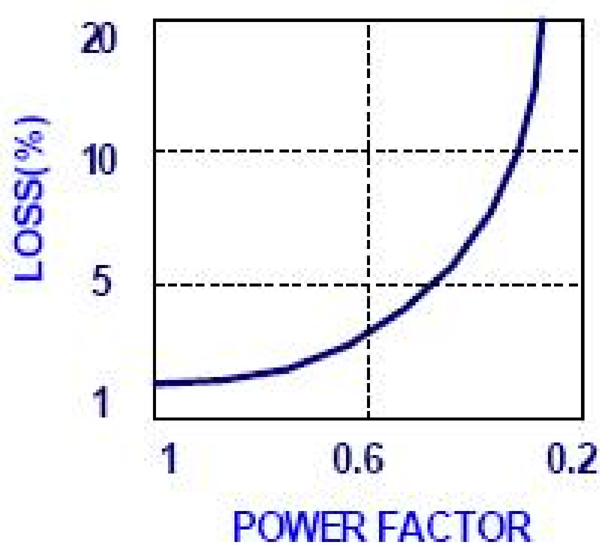


Fig3.5: kW vs p.f

Loss in distribution capacity

The figure below graphically displays the variation of the I^2 R losses in feeders and branches. Losses are expressed in percent as a function of power factor.



Larger Investment

In case of expansion, a larger investment is required in the equipment needed to increase distribution capability of the installation, such as oversized transformers and switchgears. Transformers For an installation which requires 800KW, the transformer should be approximately:

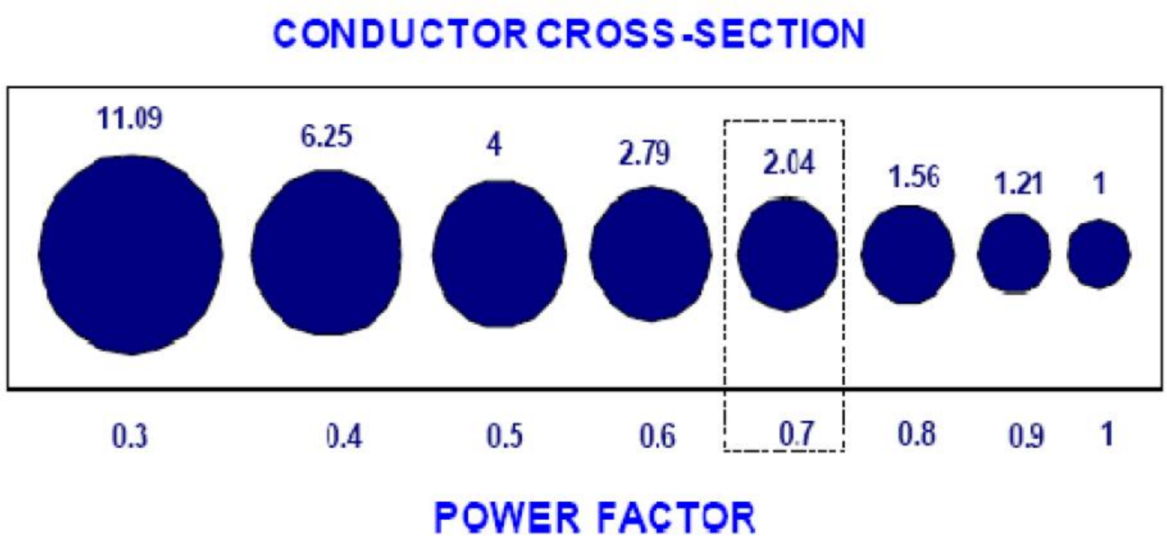
800KVA for power factor = 100%

1000 KVA for power factor = 80%

1600 KVA for power factor = 50%

Large size conductors

The figure below shows a variation of a cross section of a conductor as a function of the power factor for a given useful power. This illustrates that when the power factor of an Installation is low; the surcharge on the electricity bill is only part of the problem.
For instance, in an installation where no correction has been made and which has a power factor of 70%, the cross-section of the conductor must be twice as large as it would be if the Power factor were 100%.



Practically speaking, when an installation uses its rated power capacity, the distribution cables within the installation are rapidly loaded to their full carrying capacity if the power factor decreases. Most often, as the need for energy in an installation expands, the first reaction is to double the distribution system although it would be less expensive to perform a correction of power factor on each load or group of loads.

The loads we use are responsible for these disadvantages. If we use the appliances improving power factor will minimize these disadvantages. After all it will reduce the consumer monthly electricity bill and will increase system stability. It is very profitable to use electrical appliances improving power factor by connecting power factor correction equipments rather than paying extra bill.

3.6 Improvement of the power factor

Power factor improvement means to improve power factor from its low value to high value. Our loads are either inductive or capacitive. For capacitive load to improve power factor we need inductor. But most of the appliances are inductive so here only lagging power factor improvement will be discussed.

3.7 Benefits of Power Factor Correction

Benefit 1 - Reduce Utility Power Bills

In areas where a KVA demand clause or some other form of low power factor penalty is incorporated in the electric utility's power rate structure, removing system KVAR improves the power factor; reduce power bills by reducing the KVA. Most utility bills are influenced by KVAR usage.
Consider practical consumption electricity by using power factor plant:

P=82.88 KW

$\cos\varphi_1 = 0.70$ $\tan\varphi_1 = 1.02$

$\cos\varphi_2 = 0.95$ $\tan\varphi_2 = 0.32868$

KVAR taken by capacitors = $P(\tan\varphi_1 - \tan\varphi_2)$
= 82.88(1.02-0.32868)

= 57.29

Annual cost before correction

Max. KVA demand = 82.88/0.7

=118.4 KVA

KVA demand charges = (118.4×1100)

=130240

Units consumed /year = 5.20×248640

=1292928 Tk

Total annual cost = (130240+1292928)

= 1423168

Annual cost after p.f correction

Max.KVA demand = 82.88/0.95

= 87.24

KVA demand charges = 87.24×1100

= 95966

KW charges/year = 1292928

Total annual cost = (95966+1292928)

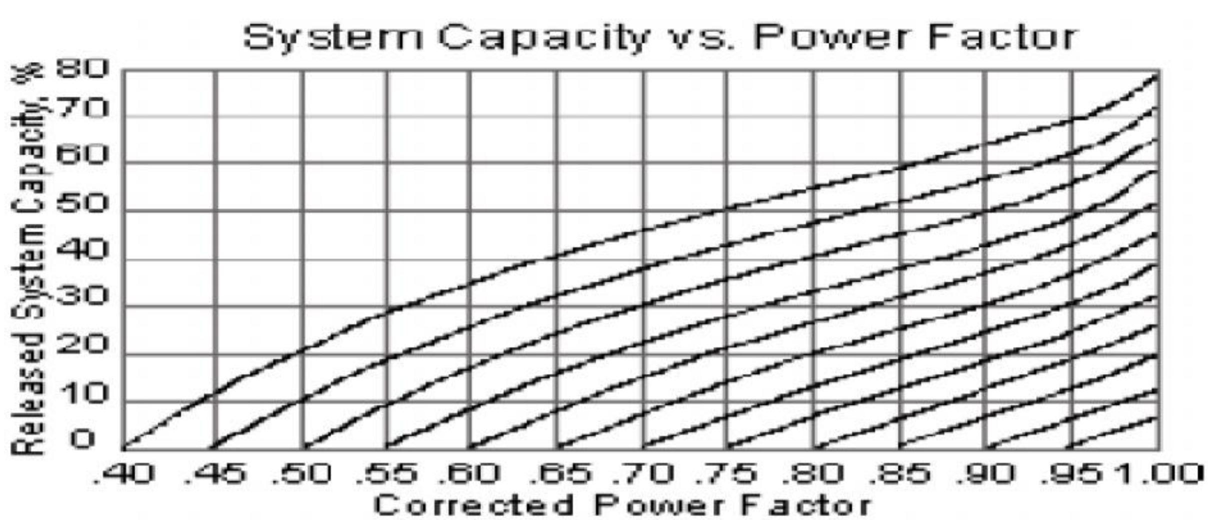
= 1388894

Annual Savings = 1423168-1388894

= 34274

Benefit 2 – Increase System Capacity

The power factor improvement releases system capacity and permits additional loads(motors, lighting, etc.) to be added without overloading the system. In a typical system with a 0.80 PF, only 800 KW of productive power is available out of 1000 KVA installed. By correcting the system to unity (1.0 PF), the KW = KVA. Now the corrected system will support 1000 KW, versus the 800 KW at the .80 PF uncorrected condition; an increase of 200 KW of productive power. This is achieved by adding capacitors which furnish the necessary magnetizing current for induction motors and transformers. Capacitors reduce the current drawn from the power supply; less current means lesser load on transformers and feeder circuits. Power factor correction through devices such as capacitors can avoid an investment in more expensive transformers, switchgear and cable, otherwise required to serve additional load. The figure below shows the empirical relationship of system capacity vs. power factor. From the figure one can see that improving power factor from .8 to .9 or .8 to .95 shall release approximately 12% or 20% system capacity respectively.



Benefit 3 - Improve System Operating Characteristics (Gain Voltage)

A good power factor (0.95) provides a "stiffer" voltage, typically a 1-2% voltage rise can be expected when power factor is brought to +\-0.95. Excessive voltage drops can make the motors sluggish, and cause them to overheat. Low voltage also interferes with lighting, the proper application of motor controls and electrical and electronic instruments. Motor performance is improved and so is production.

An estimate of voltage rise from the improved power factor with the installation of power capacitors can be made using following equation:

$$\%\ \text{Voltage Rise} = \frac{\text{KVAR Of Capacitors} \times \%\ \text{Impedence of Transformer}}{\text{KVA of Transformer}}$$

Benefit 4 - Improve System Operating Characteristics (Reduce Line Losses)

Improving power factor at the load points shall relieve the system of transmitting reactive current. Less current shall mean lower losses in the distribution system of the facility since losses are proportional to the square of the current. Therefore, fewer kilowatt-hours need to be purchased from the utility.

An estimate of reduction of power losses can be made using following equation:

$$\%\ \text{Reduction of power losses} = 100 - 100\left(\frac{\text{Original power factor}}{\text{Improved powerfactor}}\right)^2$$

Consider facility system wide losses = 5% with a current power factor of 0.80. Estimate the reduction in losses when the power factor correction is made at the load points to unity.

Solution

Improving power factor at the load points shall relieve the system of transmitting reactive current. Less current shall mean lower losses in the distribution system of the facility since losses are proportional to the square of the current (I2R). Therefore, fewer kilowatt-hours need to be purchased from the utility. An estimate of reduction of power losses can be made using equation:
%Reduction of power losses= 100 - 100(.80 / 1.0) 2

= 100 - 100(.64)

= 36%

The original facility system losses of 5% are reduced by 5 x 36/100 = 1.8%

3.8 Power Factor Correction method

Power factor correction can be made in two ways

3.8.1 Reduce the amount of reactive energy

- Eliminate unloaded motors and transformers
- Avoid supplying equipment with voltage in excess of the rated voltage.

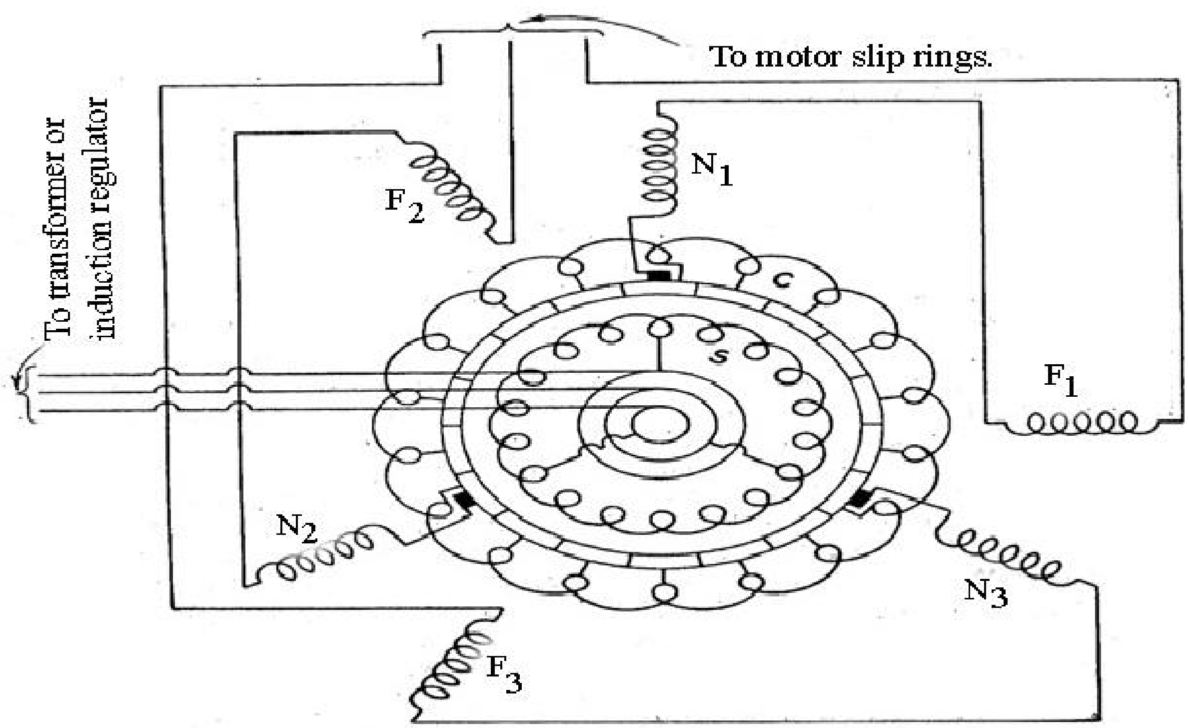
3.8.2 Compensate artificially for the consumption of reactive energy with power factor capacitors. In practice, two type of equipment are available for power factor correction

a. Rotary Equipment

Phase advancers, synchronous motors and synchronous condensers. Where auto-synchronous motors are employed the power factor correction may be a secondary function.

Phase advancers

Power factor of induction motors can be improved by having phase advancers. The stator winding of induction motor draws the exciting current which lags behind the voltage by 90º. So this can be improved by having exciting ampere turns from the other AC source, which can be placed the same shaft of induction motor and connected rotor circuit of motor. This produces exciting ampere turns to the rotor circuit at slip frequency. Also the induction motor can be made to over excited synchronous motor by providing more amperes turns results in leading power factor



Frg.1.—Diagram of the expedor-susceptor phase advacer

Synchronous condenser

The Synchronous Condenser (SC) dynamically provides power factor correction without the use of static components. As it is dynamic, the precise operation of the_Synchronous_Condenser (SC) excitation field will produce the required p.f VAR needed to correct the power factor to the set level or desired amount without switching transients. Also, as it is a Dynamic device, there is no problem with harmonic currents produces by (VFD's), dirty loads or static (solid state) drives. The Synchronous Condenser (SC) uses rotary technology which improves overall power quality by reducing voltage transients and eliminating problems associated with harmonic distortion.

b. Capacitors

Simply put, a capacitor is an electric device that can store electric charge for later release.
Generally, capacitors are used in one of the three ways: to store and release energy, to discriminate between DC (direct current) and AC (alternating current) frequencies, and to discriminate between higher and lower AC frequencies.

A simple capacitor consists of two metal plates that are held parallel to each other with a small place between them. An insulating material called dielectric occupies the space. This insulating material can be made of many materials including oil, paper, glass, ceramics, and
Mica, plastic, or even air. Capacitance is a measure of the energy that a capacitor is capable of storing. The capacitance of a device is directly proportional to the surface areas of the plates and inversely proportional to the plates' separation.

Power factor correction is achieved by the addition of capacitors in parallel with the connected motor circuits and can be applied at the starter, or applied at the switchboard or distribution panel.

Capacitors connected at each starter and controlled by each starter is known as "Static Power Factor Correction" while capacitors connected at a distribution board and controlled independently from the individual starters is known as "Bulk Correction".

When installing equipment, the following points are normally considered:

- **3) Reliability of the equipment to be installed**
- **4) Probable life of such equipment**
- **5) Capital cost**
- **6) Maintenance cost**
- **7) Running cost**
- **8) Space required and ease of installation**

3.9 Reasons for choosing capacitors

Generally the cost of rotating machinery, both synchronous and phase advancing, makes its use uneconomical, except where one is using rotating plant for a dual function – drive and power factor correction. In addition the wear and tear inherent in all rotating machines involves additional expense for upkeep and maintenance.

Capacitors have none of these disadvantages. Compared with other forms of correction, the initial cost is very low, upkeep costs are minimal and they can be used with the same high efficiency on all sizes of installation. They are compact, reliable, highly efficient & convenient to install and lend themselves to individual, group or automatic method of correction. These facts indicate that generally speaking, power factor correction by means of capacitors is the most satisfactory and economical methods.

The static capacitor owing to its low losses, simplicity and high efficiency is now used almost universally for power factor correction. Now let us take a closer look at Capacitor bank.

3.10 Capacitor Bank

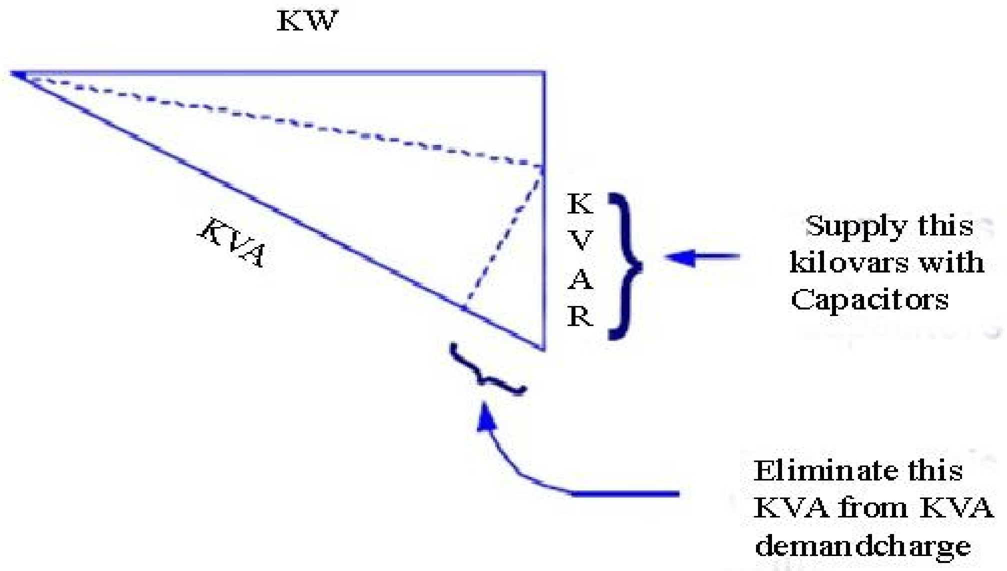
Capacitor, resistor and inductor banks are simply series and/or parallel combinations of components constructed for the purpose of increasing the capacitance, Parallel connected capacitors provide increased capacitance, increased stored energy and increased ripple current capacity for DC applications. For AC applications the kVAR and current ratings are increased. Series connected capacitors provide an increased voltage rating but reduced capacitance value.

3.10.1 Reason for the connection of Delta Connected Capacitor bank in most of 3- Phase power factor correction

Capacitors are paralleled with inductive loads in delta, wye and single phase AC power sources to correct power factors so that motors, transformers and other inductive loads appear to be resistive. Power factor correction is a process that cancels reactive current vectors leaving only a resistive current. Inductive loads pull currents that contain both resistive and reactive vectors. In power factor correction, a capacitor's reactive current is used to cancel the inductive reactive current created by magnetic coils in inductive devices. If the capacitor is sized correctly the current drawn by the capacitor will precisely cancel the inductive magnetization current pulled by an inductive load. The resulting motor current "seen" by the AC voltage source will then be only resistive. Since power companies charge for both reactive and resistive current, and since only the resistive current is required to provide horsepower and perform work, power factor correction reduces the current drawn by inductive loads which reduces the electrical operating expense. Hard to believe that applying an additional parallel load, a capacitor, will result in less total current but it works due to the capacitive reactive current leading at +90 degrees and the inductive reactive current lagging at -90 degrees, the two parallel currents sum at the voltage source to equal zero degrees and if the cap is sized correctly, zero amplitude.

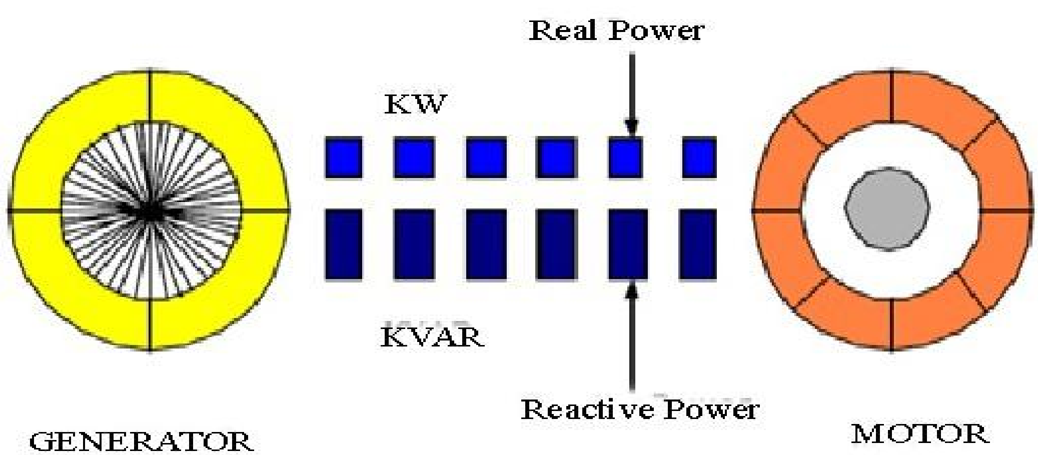
3.11 How Capacitors Work for power factor improvement

Induction motors, transformers and many other electrical loads require magnetizing current (KVAR) as well as actual power (KW). By representing these components of apparent power (KVA) as the sides of a right triangle, we can determine the apparent power from the right triangle rule: $KVA^2 = KW^2 + KVAR^2$. To reduce the KVA required for any given load, we must shorten the line that represents the KVAR. This is precisely what capacitors do.

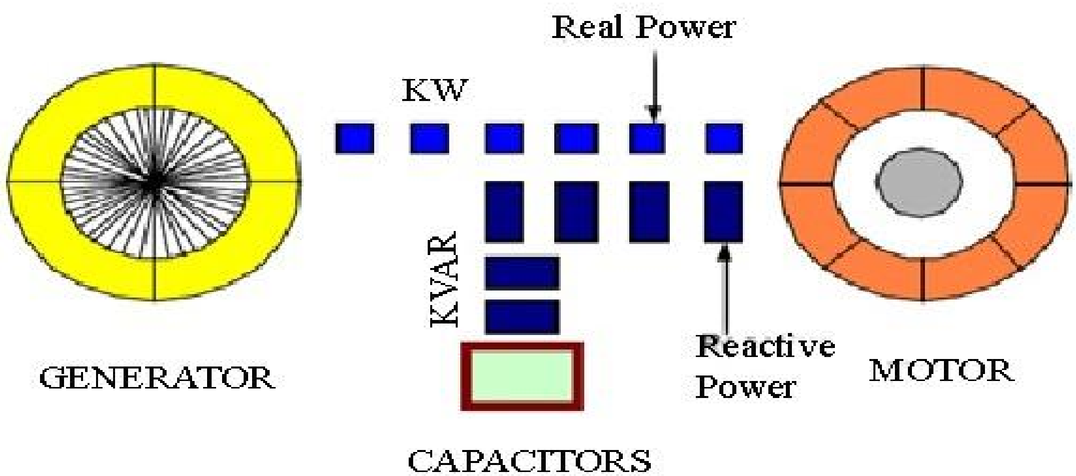


The capacitor performs the function of an energy storage device. By supplying KVAR right at the load, the capacitors relieve the utility of the burden of carrying the extra KVAR. This makes the utility transmission/distribution system more efficient; reducing cost for the utility and their customers.

The figure below shows an induction motor operating under partially loaded conditions without power factor correction. Here the feeder line must supply both magnetizing (reactive) and useful currents.



The figure below shows the results of installing a capacitor near the same motor to supply the magnetizing current required to operate it. The total current requirement has been reduced to the value of the useful current only, thus either reducing power cost or permitting the use of
More electrical equipment on the same circuit.



In the illustration above, addition of the capacitor has improved line power factor and subtracted the non-working current from the lines. Rather than transfer energy back and forth between load and generator, the reactive energy to supply the magnetizing current is now stored in a capacitor at the load, thus reducing the distribution requirements for excessive current. This reactive current supplied by the capacitor rather than the utility.

3.12 Correction Methods

3.12.1 Static or fixed Power Factor correction

Compensation on the load side of the AC motor starter (motor switched or "at the load"). Fixed capacitors provide a constant amount of reactive power to an electrical system.

Primarily, fixed capacitors are applied to individual motor loads, but they can also be applied to the main power bus with proper treatment. Fixed capacitors are suitable for indoor or outdoor use. Fixed capacitors are available in low voltages (832 volt and below), from .5VAR up to 400 KVAR (If more than 400 KVAR is required, smaller units are paralleled together).

3.12.2 Central or Bulk Power Factor correction

Central power factor compensation is applied for electrical systems with fluctuating loads. The central power factor correction is usually installed at the main power distribution. The capacitors are controlled by a microprocessor-based relay, which continuously monitors the power factor of the total current supplied to the distribution board. The relay then connects or disconnects capacitors to supply capacitance as needed in a fashion to maintain a power factor better than a preset limit (typically 0.95). Ideally, the power factor should be as close to unity as possible.

3.13 Power factor correction calculation

Let us consider a 100 Horsepower, 460 VAC, three phase motor. The motor draws 124 amps at full load. It runs at about 90 % efficiency.

Before power factor correction

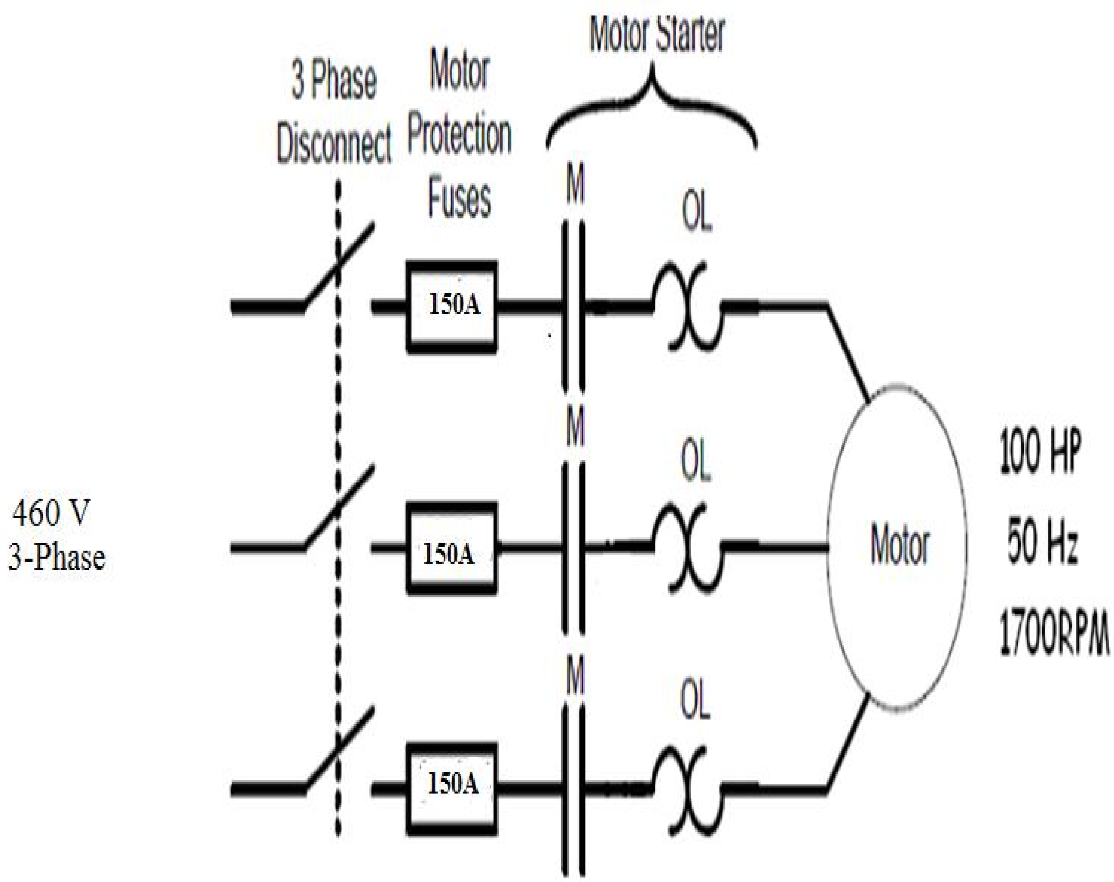


Fig 3.6: Before power factor correction of 100Hp Motor.

The input power to this motor is:

Pin = (100 HP * 746 watts/HP) / 0.9

= 82889 watts

=82.89 KW

The volt ampere or kilo-volt ampere is

VA = √3 * 460 * 124 = 98794 VA or 98.79 KVA

KVAR = $\sqrt{98.79^2 - 82.88^2}$

= 53.75kvar

The square of three appears because the power feeds a three phase motor. If we make a Power, Volt Ampere, Volt Ampere Reactive vector diagram, it will look like Figure (1).

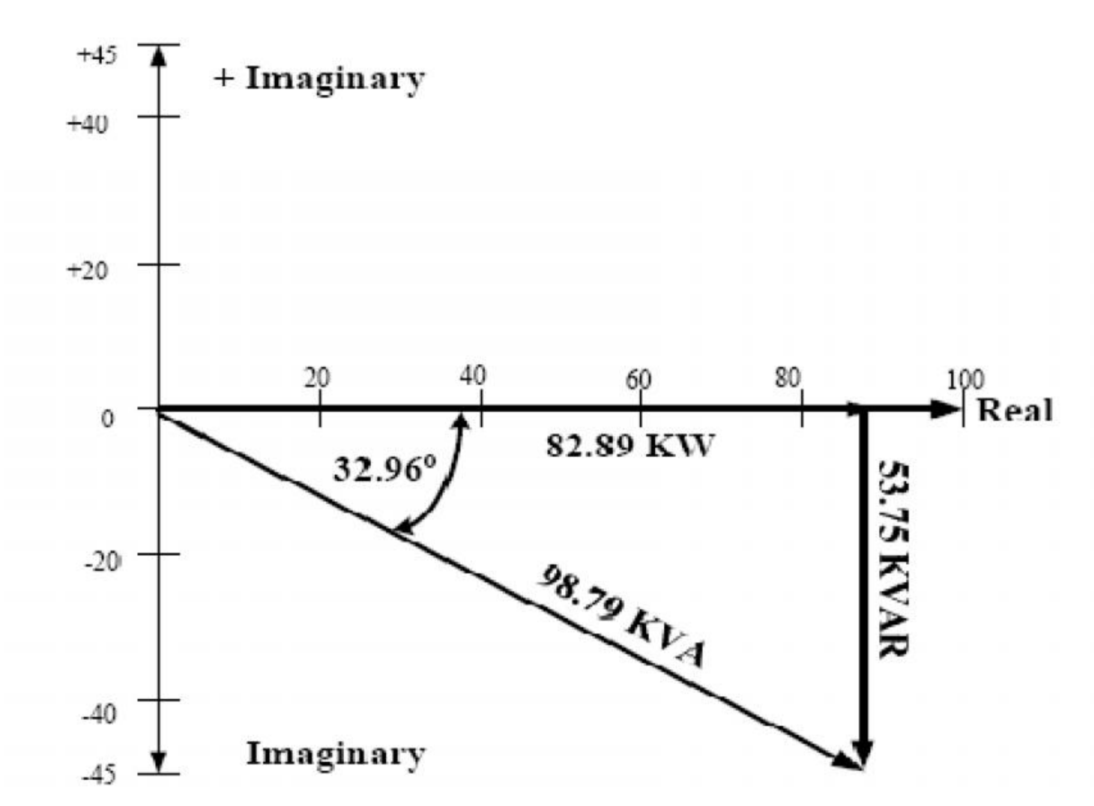


Figure 3.7: Power Vector Diagram for a 100 Horsepower, Three Phase Motor

KVA per phase 98.79/3 = 32.93

KVAR per phase 53.75/3 =17

After Power Factor Correction

Motor input 82.88 KW

KVAR required for the improvement of power factor up to 0.96 is

=P (tan Ø1-tan Ø2) cos Ø1 = 0.83

=82.88(tan33.90-tan 16.26) Ø1 = 33.90

= 30KVAR cosØ2 = 0.96

Ø2 = 16.26

KVAR required per phase = 30/3

= 10 KVAR

Total capacitance for power factor improvement = $Q/(V2 * 2 * \pi * f)$

$= 30*1000/460^2*2*3.14*50$

= 0.000450F

= 450μF

Capacitance required per phase 450/3 = 150μF

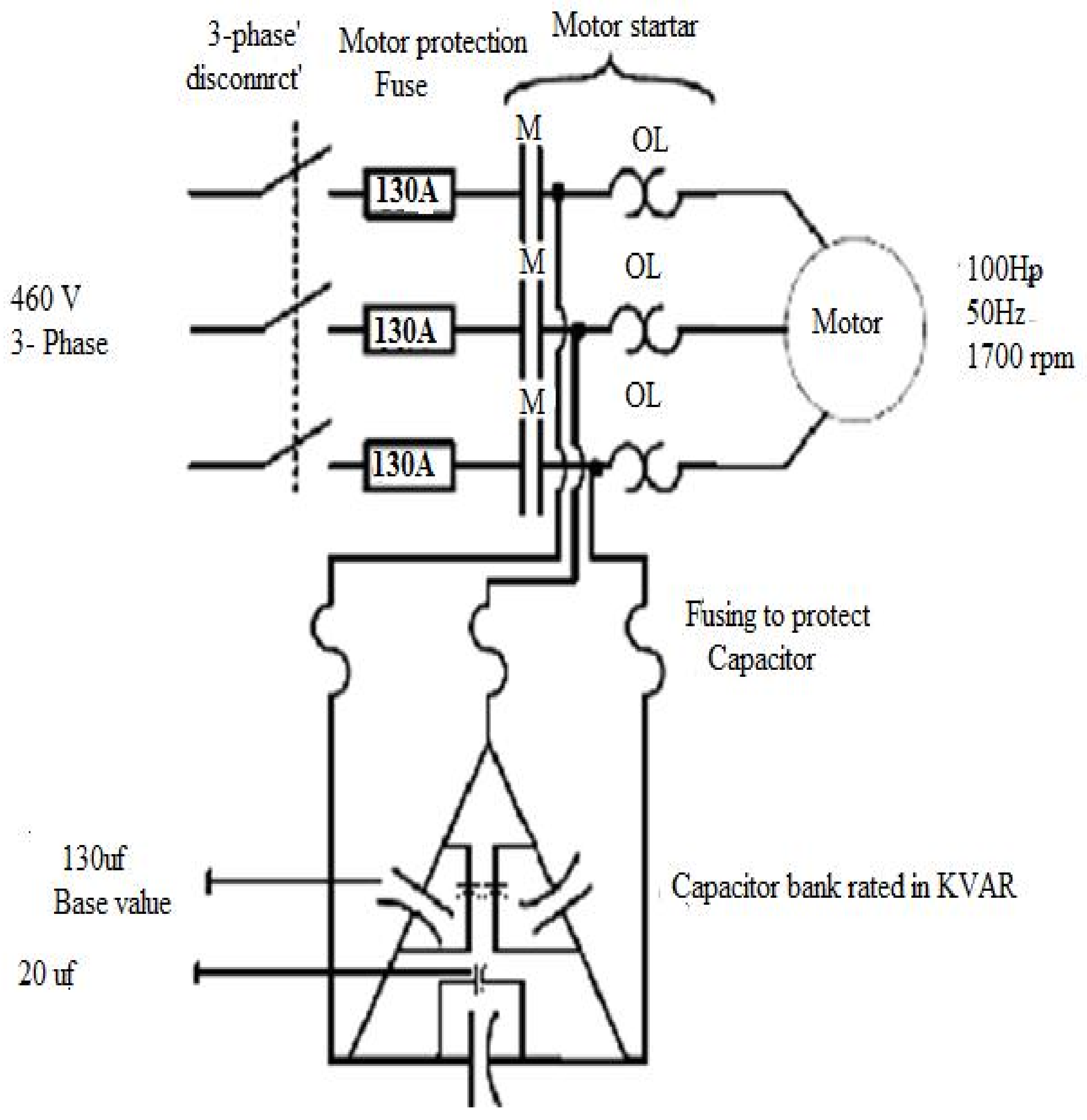


Fig 3.8: After power factor correction of 100Hp Motor.

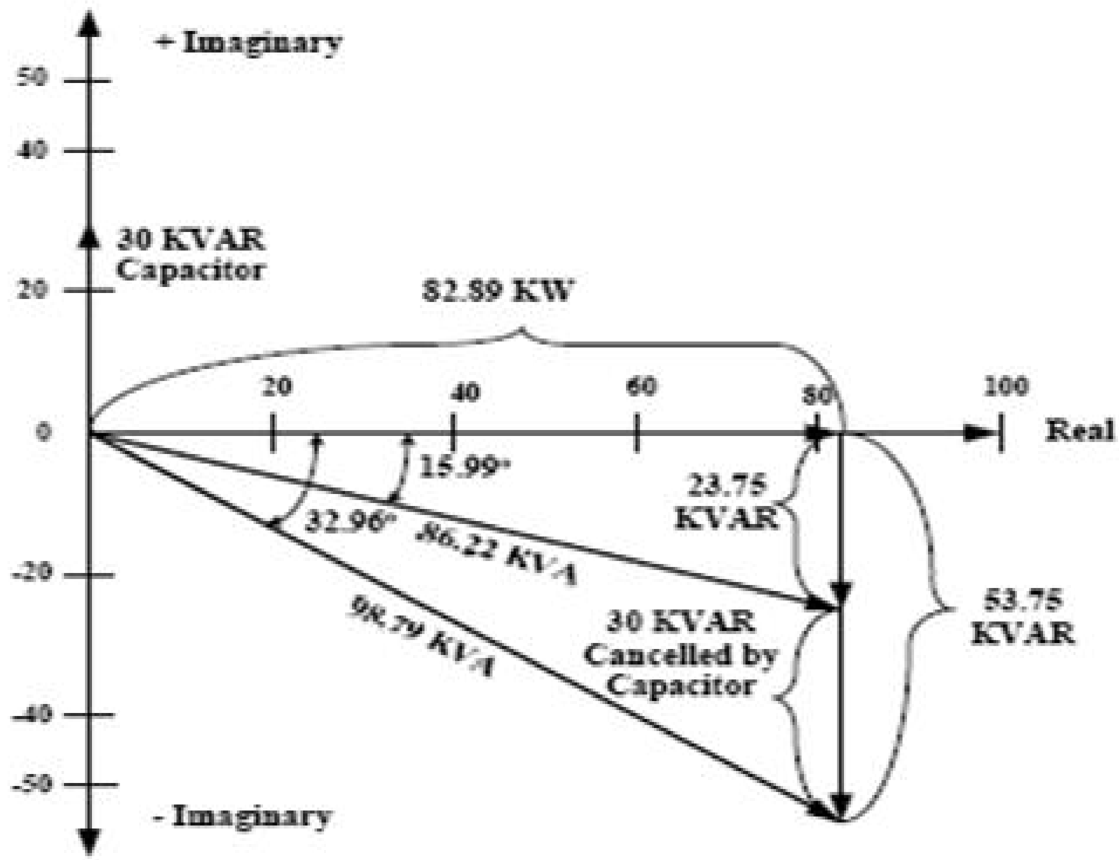


Fig 3.9: Power factor change by using the recommended capacitor for a 100 Hp Motor.

From vector diagram it is clear that the applied KVAR by capacitor bank reduce the reactive power and thus apparent power. So power factor has increased from 0.83 to 0.96.

Chapter – 4
Design and Details of a residential 200 KVA, 11/0.415 KV Indoor Substation

4.1 objectives

Our calculative total load for a 5 storied building with a ground floor is140 KW. If we increase our load in future, the total load will be

Load (total) in kW = present load + increasing load in future.

= 140 KW + 20 KW

=160 KW

Overall power factor of the loads is 0.8.

$$\text{The load in KVA} = \frac{KW}{\cos \O t}$$

$$= \frac{160}{0.8}$$

=200 KVA

So we should design a substation for 200 KVA.

4.2 Importance of indoor substation

In the indoor substation the electrical equipments is installed within the building of substation. Indoor substation of11kv/415V is quite installed in industrial areas and big cities where load requirement is heavy and continuity of supply is very important. Industrial units, continuous processing plants, important commercial complexes, railway stations, telephone exchange, universities, and cinema houses all employ such indoor substations.

4.3 General requirements

The substation building should be constructed providing the necessary accommodation for the transformer, high tension (HT) and low tension (LT) switchgear and cable trenches for incoming and outgoing cables. The building for housing the transformer should be spacious and should be sufficiently high. Adequate clearance between the walls and equipment and between different equipments should be provided to ensure safety of personal. Adequate provision for ventilation must be ensured, so that there is free circulation of air on all sides of the transformer and within the building.

4.4 Safety requirements

The major factor in the design of the indoor substation is the minimization of the fire risk. Fire resisting wall is usually necessary and fire extinguishing apparatus must be installed .Carbon-di-oxide is very effective fire extinguishing medium and causes no damage to sound equipment.

The main advantage of this gas is that it does not damage the insulation just like water. Moreover CO_2 has dielectric strength greater than air. The gas will be stored in cylinders at about 50 kg per sq. cm. The system automatically operates when the transformer rises at 150°F the fusible links will melt at this temperature and cause the carbon-dioxide to discharge.

4.5 Typical Layout of 200 KVA Substations:

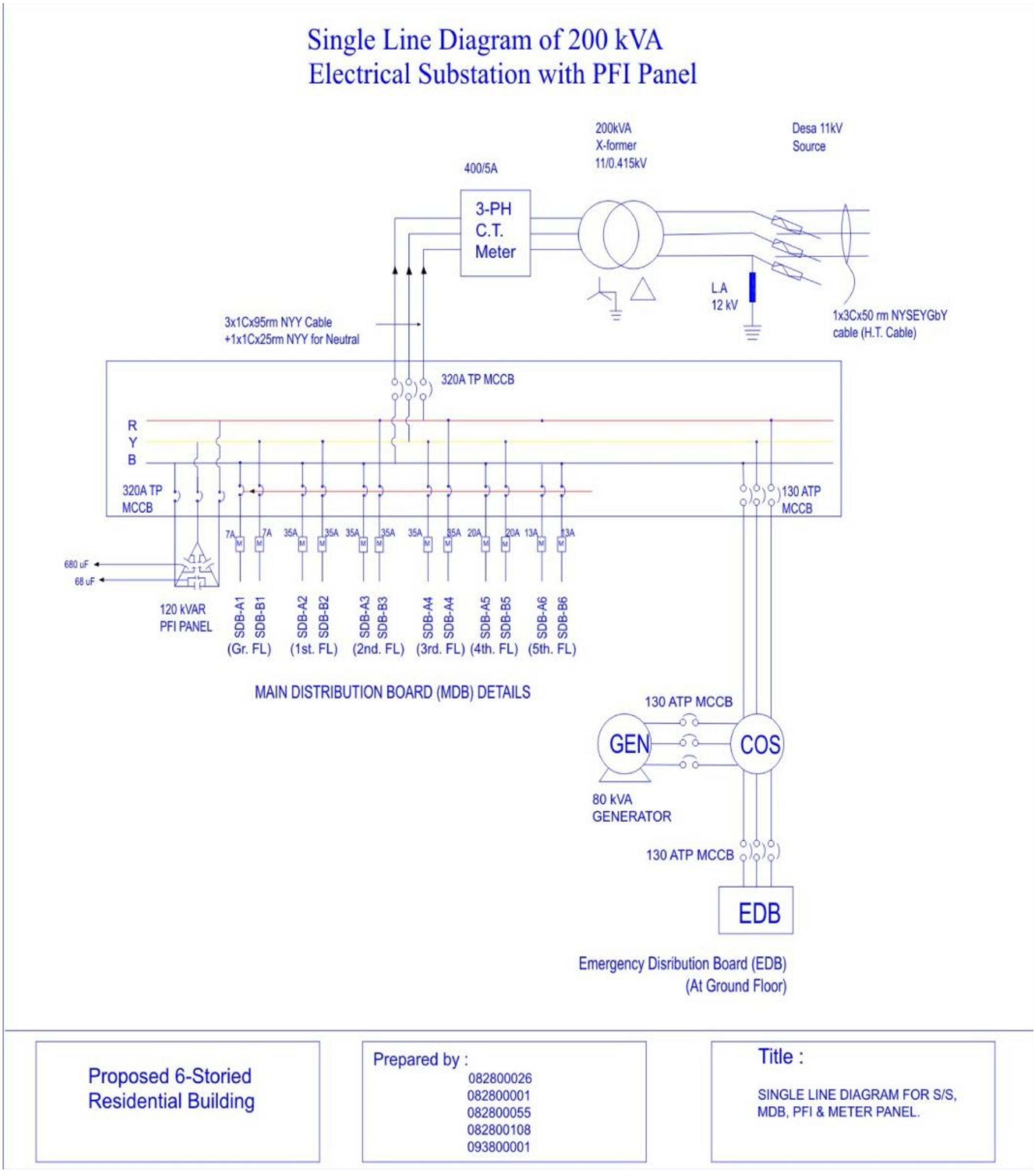


Fig 4.1: Main layout of Substation

As shown in layout11kv overhead lines from Desa terminates on a pole structure outside our indoor substation. An 11kv operating switch and lighting arrestor will be installed in it for isolation and protection respectfully. The supply from the over head lines will be brought inside substation through the hole of the wall using an outdoor cable box. The position of the 11kv circuit breaker will be determined by the phase where the incoming cable enters the substation building. Adequate space should be provided for the maintenance of the circuit breaker.
The function of lighting arrestor here at the time of occurrence it will discharge extra voltage but under normal condition it will remain off.

The transformer is the most important equipment in a substation. Our kVA is 200. So we have used here 200kva transformer. For our substation, the transformer should have cable boxes at the HT and LT ends.
Since it is a step down substation, step down transformer has been used in this substation. Here we have used delta-star connected transformer for stepping down. Delta is connected with high voltage side and star connected with low voltage side.
Here primary terminal (delta connected) is to be connected to HT circuit breaker. The secondary terminal(Y-connected) of the transformer is to be connected to circuit breaker unit using three and half core LT cables.
The transformer is rated as 200KVA, 11/0.415KV. Here 11 kV is delta side that is high voltage side.

Star connection has been grounded. If a fault occurs and over current flow the transformer release this current to the ground.
The output of the transformer is connected to the LT bus-bars through the circuit breaker. We have used here circuit breaker

- To carry the full load current continuously.
- To open and close the circuit on no load.
- To make and break the normal operating current.
- To make and break the short circuit currents of magnitude up to next.

The LT CB, LT bus-bars and other switch units feeding the local circuit will be installed in a medium voltage switchboard or panel board. This panel board should be properly located in the substation building for convenient operation and maintenance.

4.6 H.T. and L.T. Metering

A current transformer and potential transformer have been installed on the high voltage lines, with the 11kv OCB. The output of the CT and PT has been connected to metering devices. The meter not only record the power consumed but also give the indication of maximum demand and the power factor. For low voltage metering, supply is run directly to meters. The ratios of CT and PTs are selected by engineer.

The current rating of the secondary side of the transform can be found by,

$$\text{Current, I} = \frac{200 \times 1000}{\sqrt{3} \times 415}$$

$$= 278 \text{ A}$$

Suitable cable size can be selected by this current rating. The cable size should be 3.5 core 380 sq.mm PVC insulated cable taking into consideration of safety and future load requirements. This cable will be used from transformer secondary side to Bus-bars.
The circuit breaker should be used as rating greater than flowing normal current for the safety from danger.
There are arranged three bus-bars for three phases in a main distribution board (MDB). From this distribution board the lines are taken into every floor through circuit breaker and metering panel.

4.6.1Ground Floor

Here power is taken from Y and B bus bars to the ground floor distribution board.
Total load= 8 KW or 8.5 KVA
Current $I_{\text{Grond floor}}$=11.8 A
So $I_{\text{SDB A1}} = I_{\text{SDB B2}} = \frac{I_{\text{Ground}}}{2} = \frac{11.8}{2} = 5.9$
We will use miniature circuit breaker (MCB).
The rating of MCB is7
There is a Metering panel before subdivision board A1 and B1 for the measurement.
Note: Here A1 and B1 has same load so the rating of CB and cable should be similar.

4.6.2 1st floor

In this floor total load is about 40 KW.
Here power is taken from R and B bus bars to the first floor distribution board.
Total load= 40 KW or 43KVA

Current $I_{\text{ist floor}}$=60 A

$I_{\text{SDB A2}} = I_{\text{SDB B2}}$= 60/2=30 A

We will use miniature circuit breaker (MCB).
The rating of MCB is 35 A.
There is a Metering panel before subdivision board A2 and B2 for the measurement.
Note: Here A2 and B2 has same load so the rating of CB and cable should be similar.

4.6.3 2nd floor

In this floor total load is about 40 KW.
Here power is taken from Y and B bus bars to the first floor distribution board.
Total load= 40 KW or43 KVA
Current $I_{\text{2nd floor}}$=60A
$I_{\text{SDB A3}} = I_{\text{SDB B3}}$= 30 A

We will use miniature circuit breaker (MCB).
The rating of MCB is35 A

4.6.4 3rd floor

Arrangement of all equipments in this floor is similar as Ist and 2nd floor.
Total load= 40 KW or 43KVA
Current $I_{2nd\ floor}$=60A
$I_{SDB\ A3}$=$I_{SDB\ B3}$= 30 A
Rating of MCB: 35 A

4.6.5 4th floor

In this floor total load is about 22 KW.
Here power is taken from R and Y bus bars to the first floor distribution board.
Total load= 22 KW or 23KVA
Current $I_{4th\ floor}$=32
$I_{SDB\ A5}$=$I_{SDB\ B5}$= 16
We will use miniature circuit breaker (MCB).
The rating of MCB is 20A.

4.6.6 5th floor

In this floor total load is about 15 KW.
Here power is taken from Y and B bus bars to the 5th floor distribution board.
Total load= 15 KW or 16 KVA
Current $I_{5th\ floor}$=22
$I_{SDB\ A6}$=$I_{SDB\ B6}$= 11

We will use miniature circuit breaker (MCB).
The rating of MCB is 13.

4.7 A standby generator with the main distribution board (MDB)

During load shedding and at the time of disturbance in the three phase line we can get power supply by operating this generator. A standby generator supply emergency power to only the important equipment of household electrical devices..
The generator that has been used here is the rating of 80KVA and its power factor is o.8.
So we can get power from this generator is

$P = 80\times o.8$

$= 64$ KW

From generator the output is fed to COS board through module case circuit breaker (MCCB). From this COS board three phase are connected with the bus bars through MCB. Also from this distribution board the power lines are taken out to Emergency distribution board.

Description of emergency distribution board

Emergency distribution board is connected separately generator to a point. When an extreme Fault occurs in our main distribution line we can continue our supply by EDB. So EDB is necessary for a building substation.

4.8 Power factor improvement of this substation

We have discussed details about power factor in the previous chapter. But we will discuss here only about the power factor improvement for our substation. We know that our total load is 160 KW but in KVA it is 200. Although our electrical appliances are using only 160 KW but others have no any useful work. But we have to pay extra bill for this extra power. So we have taken into account to improve power factor. How much can we save annually it can be cleared by the following calculation?

P=160 KW

Annual cost before correction

Max. KVA demand = 160/0.8

= 200 KVA

KVA demand charges = (200×1100)

= 220,000 Tk

Units consumed /year = 160×3600(hours)

= 576000 KWh

Energy charges/year = 5.2×576000

= 2995200

Total annual cost = (220000+2995200)

= 3215200TK

But if we improve power factor up to 0.98

Annual cost after p.f correction

Max.KVA demand = 160/0.98

= 163KVA

KVA demand charges = 163×1100

=179591Tk

KW charges/year = 2995200

Total annual cost = (2995200+179591)

= 3174791Tk

Annual Savings = 3215200-3174791

= 40,409 Tk

Besides reducing the electricity bill the power factor improvement gives other benefits as we have discussed in the power factor improvement chapter. So it is very improvement to improve power factor in our substation.

We know our total load 160KW and power factor on our system is 0.8. We want to raise this power factor up to 0.95.

Now let's talk about procedure how much KVAR required increasing power factor up to 0.95 under full load condition.

Our original power factor, $\cos\varphi 1 = 0.8$

Our final power factor, $\cos\varphi 2 = 0.95$

KVAR required = P ($\tan Ø1 - \tan Ø2$)

= 160 (0.75-0.32)

= 68 KVAR

At least 88 KVAR required to improve our factor up to 0.95 under full load condition. So we will set a PFI panel above 68 KVAR. We will set here 120 KVAR Delta connected PFI panel. But 88 KVAR required at the time of full load condition. But our demand varies during the day.

The following chart shows the variable power factor, load in a day.

Time in hours	KW	KVAR(Before correction)	Original p.f	Corrected p.f	KVAR Required
1.00	30	22.5	0.8	0.95	9.50
2.00	25	18.5	0.81	0.95	9.88
3.00	20	14.81	0.81	0.95	7.90
4.00	15	18.5	0.81	0.95	5.92
5.00	20	14.81	0.82	0.95	7.38
6.00	25	18.30	0.82	0.95	9.23
7.00	30	21.95	0.82	0.95	11.07
8.00	30	22.5	0.8	0.95	12.64
9.00	50	37.5	0.8	0.95	21.07
10.00	55	40.75	0.81	0.95	21.74
11.00	80	58.5	0.82	0.95	29.54
12.00	140	103.70	0.81	0.95	55.34
13.00	130	96.30	0.81	0.95	51.38
14.00	120	87.80	0.82	0.95	44.31
15.00	120	88.88	0.81	0.95	47.43
16.00	110	80.50	0.82	0.95	40.59
17.00	100	74.07	0.81	0.95	39.52
18.00	130	96.30	0.81	0.95	51.38
19.00	140	102.45	0.82	0.95	51.70
20.00	140	103.70	0.81	0.95	51.70
21.00	140	103.70	0.81	0.95	51.70
22.00	110	81.48	0.82	0.95	40.64
23.00	100	74.07	0.81	0.95	39.52
24.00	70	52.5	0.8	0.95	29.50

Graphical Representation:

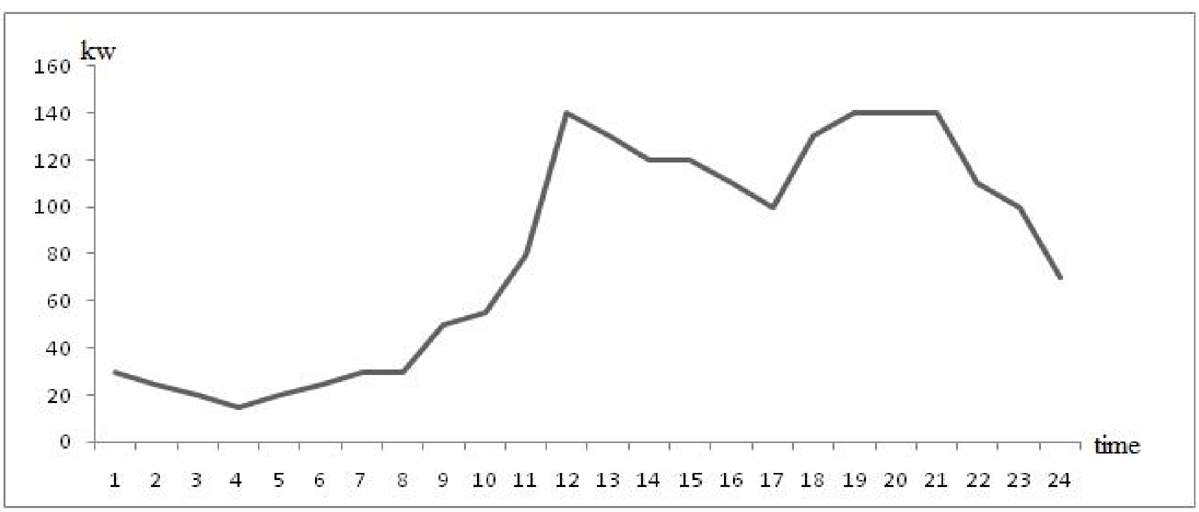


Fig 4.2.: kW vs Time

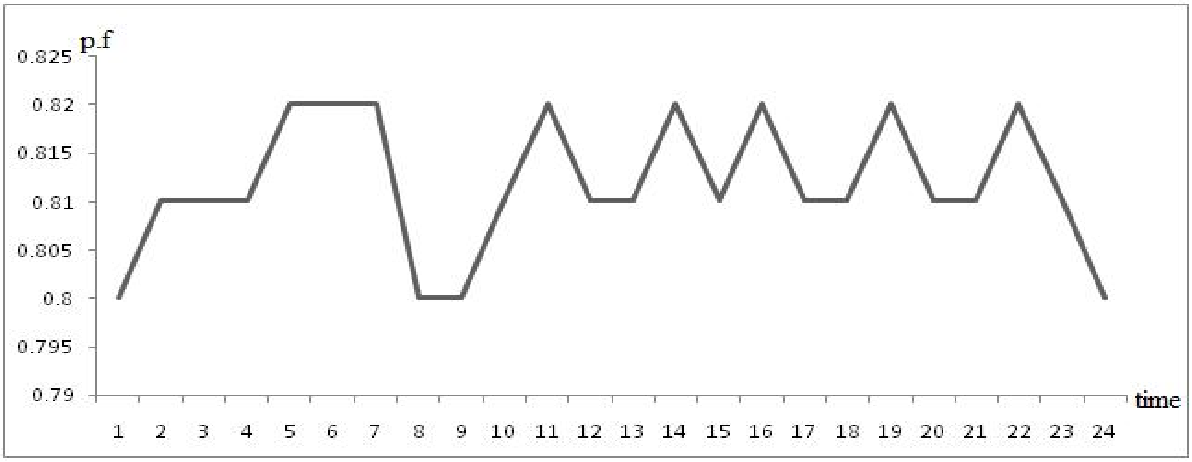


Fig 4.3: P.F vs Time

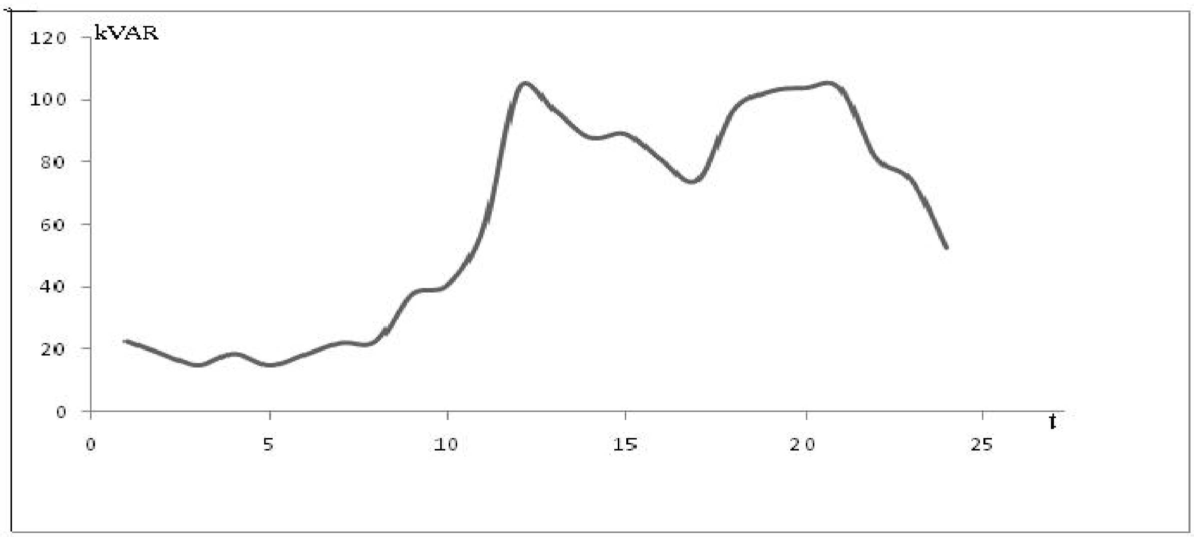


Fig 4.4: KVAR (before) vs Time

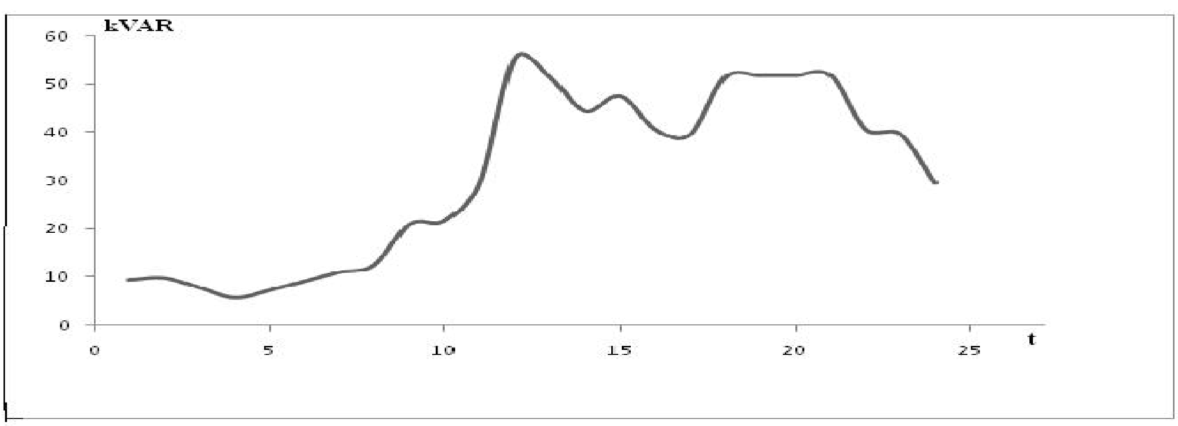


Fig 4.5: KVAR (after) vs Time

4.9 120 KVAR Automatic PFI Plant

Automatic power factor improvement plant, 120 KVAR in 6 steps. Sheet steel fabricated, floor mounting , tropical zed design ,indoor type , Low tension switchgear for three phase.4 wire, 50Hz,415V Ac system and shall be supplied complete with TP+N bus- bars suitably sized &properly insulated arranged to with stand & short current of 50 KA for 1 sec.

The boards are designed & constructed in accordance with BS54486/IEC439.
The panel shall fully comply regulation of the 15th edition IEE wiring regulation for isolation and switching.

4.10 The Panel Comprising

3×25 KVAR 415V, 50 Hz, 3 phase, dry type, self-healing compact PF capacitor bank with discharge resistor.

3×12.5 KVAR 415V, 50 Hz, Tp -DO-

1×7.5 KVAR 415V, 50 Hz, Tp (Fixed) -DO-

3×50 Amps, 220V, triple pole magnetic contractor.

3×32 Amps, 220V, triple pole magnetic contractor.

1-power factor & regulator with digital built in PF meter.

7-Set HRC fuses with base of adequate rating.

1-Set of control Fuse.

1-Set ON/OFF push button switches.

6-Nos.indicating lamps for magnetic contractor ON position.

1-Set TPN bus-bar suitable size.

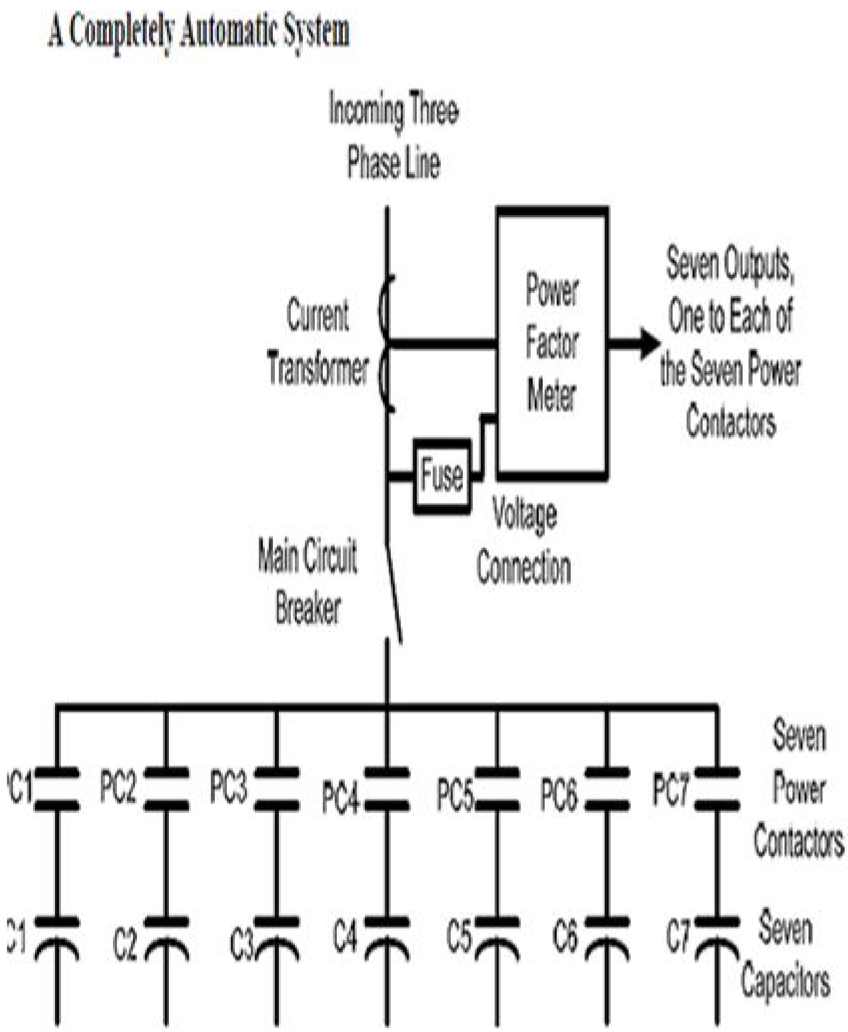


Fig-4.6 Single line diagram of completely automatic power factor correction system.

4.11 Technical Specification for 200 KVA 11/0.415 KV Sub-Station

4.11.1

11KV Drop out Fuse :	**1 Set**
Rated voltage (nominal)	11KV
Rated voltage maximum	15KV
Rated current (cont.) RMS	100A
Rated fuse rating	50A
Rated frequency	50Hz
Bill	75KV
Interrupt. Current RMS	10KA
Withstand test voltage Dry 1 minute	35KV
Wet 10sec	30KV

4.11.2

11KV Lighting arrester :	**1Set**
Type	LA9
Rated voltage	11KV
Rated maximum voltage	12 KV
Rated arrested voltage	9KV (rms)
Rated frequency	50Hz
Maximum spark over	14KV(rms)
Maximum spark over	40KV(rms)
Maximum impulse spark (crest) withstand test voltage	45 KV (Peak)
Power frequency dry 1 minute	28KV
Power frequency wet 10 sec	24KV
Discharge 33 kv (crest)	14KA
Impulse current withstand	14KA

4.11.3 200 kva Oil Immersed Transformer: 1 No

Three phase transformer ground mounted , oil immersed , with standard accessories , indoor use, designed and tested in accordance with NEMA/IEC/VDE/BS/BSS standard with 3 H.T and 4 L.T Bushing on tank top , conservator , oil level indicator , drain and filling valves , lifting lugs , bi- directional rollers , with first filling of oil in Transformer.

<u>Technical Data:</u>

Capacity	200 KVA
Voltage ratio at no load	11000/400/230 V
Vector group	DYN 11
Temperature rise	55º C
Insulation oil	60º C
Rated voltage	11KV
Bill	75 KV
Inter phase connection	Delta
Di electric strength	28 KV (For 1 minute)
Winding rated voltage	415/230 KV
Star natural	Fully instigated
Dielectric strength	3 KV (For 1 minute)
No load loss (iron loss)	380W
Full load loss (copper loss)	2050 W
Impedances voltage	6%
Wheels	1-set

4.11.4 L.T. Switchgear: 1 Set

Low tension switch-gear for 3 phase, 4 wire, 50 Hz, 415v AC system and shall be supplied complete with TP + N suitable sized & properly insulated arrange to withstand & short current of 50KA for 1 sec.

Incoming

1 set of current transformer ratio: 400 / 5 A with suitable accuracy and burden.
1 set of voltmeter (0 - 500 V) with selector switch.
1 set of Ammeter (0 - 400 A) with selector switch.
3-phase indication Lamp Red/Yellow/ Blue.
1 set control Fuse.
1 -No. 320A, 36 KA TB MCCB 50Hz 415 V with adjustable thermal overload & magnetic short- circuit releases.

Chapter – 5

Limitation, Conclusion, Future work

5.1 Limitations

This report has been prepared base on the substation design and protection system through which an electric company is maintaining substation related works such as installation, maintenance, protection which may give a very good export oriented service provider several advantage than others in the same field.

Therefore, it was not possible to present a complete report like- statistics, financial involvement, costing, etc regarding the topic or the opportunity. During the report, it had to be taken care of that the report does not contain any company confidential information and harm the organization in their strategic stance.

5.2 Future Work

- 1 .Our thesis knowledge, enable us to build a substation for building, industrial etc load.
- By introducing PFI panel on a three phase load the reactive power can be minimized. Hence Annual savings will be more.
- Knowledge about cost of installing a substation for a building or industrial load.
- We have knowledge about the protection equipment of a substation which will be necessary for installing a substation.
- We should expect that our theoretical observation can be implemented practically install in any kind of substation to increase the efficiency of the substation.

5.3 Conclusion

The Demand of electricity is increasing day by day. But the rate of increase in production of electricity is not sufficient with the demand in Bangladesh. Substation in a company like Powerman Bangladesh Ltd. is too much important not only for its own production but also it has a great impact in the economy of the whole country. Like other fast growing industry or residential area it has a good demand of power. There are some other aspects like incontinent source of energy. The local Electricity supply system is not secure to run the factory itself. So, it has become must to be self dependent substation to control flow of power like Powerman has its own. The practice should be done for the rest others of Bangladesh.

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