* 1. **Introduction to Electrical System**

Energy is the basic necessity for the economic development of a country. Energy exists in different forms in nature but the most important form is the electrical energy. The modern society is so much dependent upon the use of electrical energy that it has become a part and parcel of our life. Energy may be needed as heat, as light, as motive power etc. The present day advancement in science and technology has made it possible to convert electrical energy into any desired form.

The conveyance of electric power from a power station to consumers’ premises is known as electric supply system. Electric power supply system in a country comprises of generating units that produce electricity; high voltage transmission lines that transport electricity over long distances; distribution lines that deliver the electricity to consumers; substations that connect the pieces to each other; and energy control centers to coordinate the operation of the components.

The Figure 1.1 shows a simple electric supply system with transmission and distribution network and linkages from electricity sources to end-user.



Fig 1.1 Typical electric power supply system

**Power Generation Plant**

Bulk electric power is produced by special plants known as power generation plant or power plant. Depending upon the form of energy converted into electrical energy, the power plants are classified as under:

(i) Steam power plants (ii) Hydroelectric power plants

(iii) Diesel power plants (iv) Nuclear power plants

The fossil fuels such as coal, oil and natural gas, nuclear energy, and falling water (hydel) are commonly used energy sources in the power generating plant. A wide and growing variety of unconventional generation technologies and fuels have also been developed, including cogeneration, solar energy, wind generators, and waste materials. About 70 % of power generating capacity in India is from coal based thermal power plants. The principle of coal-fired power generation plant is shown in Figure 1.2. Energy stored in the coal is converted in to electricity in thermal power plant. Coal is pulverized to the consistency of talcum powder. Then powdered coal is blown into the water wall boiler where it is burned at temperature higher than 1300°C. The heat in the combustion gas is transferred into steam. This

high-pressure steam is used to run the steam turbine to spin. Finally turbine rotates the generator to produce electricity.



**Figure 1.2 Principle of Thermal Power Generation**

In India, for the coal based power plants, the overall efficiency ranges from 28% to 35% depending upon the size, operational practices and capacity utilization. Where fuels are the source of generation, a common term used is the “HEAT RATE” which reflects the efficiency of generation. “HEAT RATE” is the heat input in kilo Calories or kilo Joules, for generating ‘one’ kilo Watt-hour of electrical output. One kilo Watt hour of electrical energy being equivalent to 860 kilo Calories of thermal energy or 3600 kilo Joules of thermal energy. The “HEAT RATE” expresses in inverse the efficiency of power generation.

**Tariff and Economic Consideration**

The economics of electrical power has a great importance as a consumer will use electric power only if it is supplied at reasonable rate. Therefore power engineers have to find convenient methods to produce electric power as cheap as possible so that consumers are tempted to use electrical energy.

The total cost of electrical energy generated can be divided into three parts as follows.

(i) Fixed cost: It is due to the annual cost of central organization, interest on capital cost of land and salaries of high officials.

(ii) Semi-fixed cost: It is directly proportional to the maximum demand on power station and is on account of annual interest and depreciation on capital investment of building and equipment, taxes, salaries of management and clerical staff. It is independent of units generated.

(iii) Running cost: The running cost is on account of annual cost of fuel, lubricating oil, maintenance, repairs and salaries of operating staff. It depends only upon the number of units generated.

The rate at which electrical energy is supplied to a consumer is known as tariff.

The electrical energy produced by a power station is delivered to a large number of consumers. The consumers can be persuaded to use electrical energy if it is sold at reasonable rates. The tariff cannot be same for all type of consumers, because the cost of production depends to a considerable extent upon the magnitude of electrical energy consumed by the user and his load condition. Therefore, in all fairness, due consideration has to be given to different types of consumers (e.g. industrial, domestic, commercial) while fixing the tariff.

The supply company has to ensure that electrical energy is sold at such a rate so that it not only returns the cost but also earns reasonable profit. Therefore, a tariff should include the following items:

1. Recovery of cost of producing electrical energy at the power plant.
2. Recovery of cost on the capital investment in transmission and distribution systems.
3. Recovery of cost of operation and maintenance of supply of electrical energy e.g. metering equipment, billing etc.
4. A suitable profit on the capital investment.

There are several types of tariff. However, the following are the commonly used types of tariff.

1. Simple tariff: When there is a fixed rate per unit of energy consumed, it is called a simple or uniform rate tariff. In this type of tariff, the price charged per unit is constant i.e. it does not vary with increase or decrease in number of units consumed.

2. Flat rate tariff: When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff. Here, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate.

3. Block rate tariff: When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a block rate tariff. In this tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block. The price per unit in the first block is the highest and it is progressively reduced for the succeeding blocks of energy.

4. Two part tariff: When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two part tariff. The total charge to be made from the consumer is split into two parts viz. fixed charges and running charges. The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer.

Total charges = Rs(b×kW+c×kWh)

Where, b=charge per kW of maximum demand

c=charge per kWh of energy consumed

5. Maximum demand tariff: it is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer.

6. Power factor tariff : The tariff in which power factor of the consumer’s load is taken into consideration is known as power factor tariff.

7. Three part tariff: When the total charge to be made from the consumer is split into three parts viz. fixed charge, semi-fixed charge and running charge, it is known as a three part tariff.

Total charge = Rs(a + b × kW + c × kWh)

Where, a = fixed charge made during each billing period. It includes interest and

depreciation on the cost of secondary distribution and labour cost of

collecting revenues

b = charge per kW of maximum demand

c = charge per kWh of energy consumed

The electricity billing by utilities for medium & large enterprises, in High Tension (HT) category, is often done on two-part tariff structure, i.e. one part for capacity (or demand) drawn and the second part for actual energy drawn during the billing cycle. Capacity or demand is in kVA (apparent power) or kW terms. The reactive energy (i.e.) kVArh drawn by the service is alsorecorded and billed for in some utilities, because this would affect the load on the utility. Accordingly, utility charges for maximum demand, active energy and reactive power drawn (as reflected by the power factor) in its billing structure. In addition, other fixed and variable expenses are also levied.

The tariff structure generally includes the following components:

a) *Maximum demand Charges*

These charges relate to maximum demand registered during month/billing period and corresponding rate of utility.

b) *Energy Charges*

These charges relate to energy (kilowatt hours) consumed during month / billing period and corresponding rates, often levied in slabs of use rates. Some utilities now charge on the basis of apparent energy (kVAh), which is a vector sum of kWh and kVArh.

c) *Power factor* penalty or bonus rates, as levied by most utilities, are to contain reactive power drawn from grid.

d) *Fuel cost* adjustment charges as levied by some utilities are to adjust the increasing fuel expenses over a base reference value.

e) *Electricity duty charges* levied w.r.t units consumed.

f) *Meter rentals*

g) *Lighting and fan power consumption* is often at higher rates, levied sometimes on slab basis or on actual metering basis.

h) *Time Of Day (TOD)* rates like peak and non-peak hours are also prevalent in tariff structure provisions of some utilities.

i) *Penalty for exceeding contract demand*

j) *Surcharge if metering is at LT side in some of the utilities*

Analysis of utility bill data and monitoring its trends helps energy manager to identify ways for electricity bill reduction through available provisions in tariff framework, apart from energy budgeting.

The utility employs an electromagnetic or electronic trivector meter, for billing purposes. The minimum outputs from the electromagnetic meters are

• Maximum demand registered during the month, which is measured in preset time intervals (say of 30 minute duration) and this is reset at the end of every billing cycle.

• Active energy in kWh during billing cycle

• Reactive energy in kVArh during billing cycle and

• Apparent energy in kVAh during billing cycle

It is important to note that while maximum demand is recorded, it is not the instantaneous demand drawn, as is often misunderstood, but the time integrated demand over the predefined recording cycle.

**T&D Losses**

In India, average T & D (Transmission & Distribution) losses, have been officially indicated as 23 percent of the electricity generated. However, as per sample studies carried out by independent agencies including TERI, these losses have been estimated to be as high as 50 percent in some states. With the setting up of State Regulatory Commissions in the country, accurate estimation of T&D Losses has gained importance as the level of losses directly affects the sales and power purchase requirements and hence has a bearing on the determination of electricity tariff of a utility by the commission.

Components of T&D losses

Energy losses occur in the process of supplying electricity to consumers due to technical and commercial losses. The technical losses are due to energy dissipated in the conductors and equipment used for transmission, transformation, sub-transmission and distribution of power. These technical losses are inherent in a system and can be reduced to an optimum level. The losses can be further sub grouped depending upon the stage of power transformation & transmission system as Transmission Losses (400kV/220kV/132kV/66kV), as Sub transmission losses (33kV /11kV) and Distribution losses (11kV/0.4kv). The commercial losses are caused by pilferage, defective meters, and errors in meter reading and in estimating unmetered supply of energy.

Level of T& D Losses

The officially declared transmission and distribution losses in India have gradually risen from about 15 percent up to the year 1966-67 to about 23 percent in 1998-99. The continued rising trend in the losses is a matter of serious concern and all out efforts are required to contain the them. According to a study carried out by Electric Power Research Institute (EPRI) of the USA some time back, the losses in various elements of the T & D system usually are of the order as indicated below:

System element

Power Losses (%)

Minimum Maximum

○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○

Step-up transformers & EHV transmission system

Transformation to intermediate voltage level, transmission system & step down to sub-transmission voltage level

Sub-transmission system & step-down to distribution voltage level

Distribution lines and service connections

Total Losses

0.5

1.5

2.0

3.0

7.0

1.0

3.0

4.5

7.0

15.5

Reasons for high T&D Losses

Experience in many parts of the world demonstrates that it is possible to reduce the losses in a reasonably short period of time and that such investments have a high internal rate of return. A clear understanding on the magnitude of technical and commercial losses is the first step in the direction of reducing T&D losses. This can be achieved by putting in place a system for accurate energy accounting. This system is essentially a tool for energy management and helps in breaking down the total energy consumption into all its components. It aims at accounting for energy generated and its consumption by various categories of consumers, as well as, for energy required for meeting technical requirement of system elements. It also helps the utility in bringing accountability and efficiency in its working.

Reasons for high technical losses

The following are the major reasons for high technical losses in our country: -

* Inadequate investment on transmission and distribution, particularly in sub-transmission and distribution. While the desired investment ratio between generation and T&D should be 1:1, during the period 1956 -97 it decreased to 1:0.45. Low investment has resulted in overloading of the distribution system without commensurate strengthening and augmentation.
* Haphazard growths of sub-transmission and distribution system with the short-term objective of extension of power supply to new areas.
* Large scale rural electrification through long 11kV and LT lines.
* Too many stage of transformations.
* Improper load management.
* Inadequate reactive compensation
* Poor quality of equipment used in agricultural pumping in rural areas, cooler air-conditioners and industrial loads in urban areas.

Reasons for commercial losses

Theft and pilferage account for a substantial part of the high transmission and distribution losses in India. Theft / pilferage of energy is mainly committed by two categories of consumers i.e. non-consumers and bonafide consumers.

Antisocial elements avail unauthorized/unrecorded supply by hooking or tapping the bare conductors of L.T. feeder or tampered service wires. Some of the bonafide consumers willfully commit the pilferage by way of damaging and / or creating disturbances to measuring equipment installed at their premises. Some of the modes for illegal abstraction or consumption of electricity are given below:

* Making unauthorized extensions of loads, especially those having “H.P.” tariff.
* Tampering the meter readings by mechanical jerks, placement of powerful magnets or disturbing the disc rotation with foreign matters.
* Stopping the meters by remote control.
* Willful burning of meters.
* Changing the sequence of terminal wiring.
* Bypassing the meter.
* Changing C.T.ratio and reducing the recording.
* Errors in meter reading and recording.
* Improper testing and calibration of meters.

Measures for reducing technical losses

Short term measures

* Identification of the weakest areas in the distribution system and strengthening /improving them so as to draw the maximum benefits of the limited resources.
* Reducing the length of LT lines by relocation of distribution sub stations/ installations of additional distribution transformers (DTs).
* Installation of lower capacity distribution transformers at each consumer premises instead of cluster formation and substitution of DTs with those having lower no load losses such as amorphous core transformers.
* Installation of shunt capacitors for improvement of power factor.

Long term measures

* Mapping of complete primary and secondary distribution system clearly depicting the various parameters such as conductor size line lengths etc.
* Compilation of data regarding existing loads, operating conditions, forecast of expected loads etc.
* Carrying out detailed distribution system studies considering the expected load development during the next 8-10 years.
* Preparation of long-term plans for phased strengthening and improvement of the distribution systems along with associated transmission system.
* Estimation of the financial requirements for implementation of the different phases of system improvement works.
* Formulation of comprehensive system improvement schemes with detailed investment program so as to meet system requirement for first 5 years period.

Measures for reducing non-technical losses

According to the International Utilities Revenue Protection Association. (IURPA), research carried out on utilities worldwide indicates that service quality, customer relationships, and overall service satisfaction can minimize revenue losses. This has been demonstrated in Pakistan where rampant power theft has contributed financial crisis for WAPDA (Water & Power Development Authority). The World Bank and Asian Development Bank which had supplied the bulk of WAPDA’s development loans wanted the authority to recover its unpaid dues, cut power theft and reduce its T&D Losses. Accordingly WAPDA was forced to raise power rates.

But instead of improving the financial situation, this action resulted in increased financial crisis of WAPDA due to increased incidence of theft and unpaid bills. In view of this, the authority applied extreme measures to curb power theft. The Chairman of the authority (a serving army officer) deployed 35,000 troops to tackle the crisis. The troops were instructed to identify and arrest people responsible for power theft. As a result of this more than 36 military courts began trying cases of power theft. There are a range of methods being employed by utilities the world over to mitigate power theft. Some of these measures are given below.

* Set up vigilance squads to check and prevent pilferage of energy.
* Severe penalties may be imposed on those tampering with the meter seals etc.
* Energy audits should be introduced and personal responsibility should be fixed on the district officers (executive engineers) for energy received and energy sales in each area.
* Installation of tamper-proof meter boxes and use of tamper-proof numbered seals.
* Providing adequate meter testing facilities. A time bound program should be chalked out for checking the meters, and replacement of defective meters with tested meters.
  1. **Electrical load management and maximum demand control**

Electric Load Management, from now on simply called Load Management (LM), can be defined as any action taken by the customer and/or the electricity supplier to change the load profile in order to gain from reduced total system peak load, increased load factor and improved utilisation of valuable resources like fuels or generation, transmission and distribution capacity.

**Need for Electrical Load Management**

In a macro perspective, the growth in the electricity use and diversity of end use segments in time of use has led to shortfalls in capacity to meet demand. As capacity addition is costly and only a long time prospect, better load management at user end helps to minimize peak demands on the utility infrastructure as well as better utilization of power plant capacities.

The utilities (State Electricity Boards) use power tariff structure to influence end user in better load management through measures like time of use tariffs, penalties on exceeding allowed maximum demand, night tariff concessions etc. Load management is a powerful means of efficiency improvement both for end user as well as utility.

As the demand charges constitute a considerable portion of the electricity bill, from user angle too there is a need for integrated load management to effectively control the maximum demand.

**Impact of Load Management on the Total Electricity System**

First of all, it is important to be aware of the following facts:

* Short duration production of electrical energy to meet peak demand is expensive, as it requires a plant which can react rapidly to changing demand patterns.
* A plant operated to meet peak demand contributes to a high marginal cost of power consumed at peak periods, which is necessarily passed on via suppliers tariff rates to the customer.

Customer demand coincident with system peak demand is therefore more expensive.

In addition, customer demand coincident with peak demand at various levels of the network determines the capacity requirements of the distributor and therefore determines the element of electricity charges related to transmission and distribution.

If a customer can reduce his demand coincident with system peak demand and reduce the requirement for network capacity (rated demand), then the customer reduces the total electricity charges by saving costs to the supplier, distributor and producer.

An individual customer’s demand is aggregated with others to create demand patterns at various levels in the network. Ultimately, the customer’s demand contributes towards the total system demand seen by producers.

Control of demand coincident with the peak demand at various levels in the electricity supply chain can yield savings to the supplier and the customer. Savings achieved by the customer must offset the cost of achieving load control, such as production scheduling, advanced control and use of energy storage mediums. From the customers’ point of view, savings are realised through the major elements of the bill:

* Production costs are reflected in the maximum demand (kW) or the energy (kWh) cost element of the bill, i.e. the contribution that the customers’ demand makes towards the generating capacity at various times of the day.
* Transmission costs (high voltage, system-wide network costs) are reflected in the Transmission Use of System element of the bill, often expressed in terms of maximum demand coincident with system peak demand, i.e. the contribution that the customers’ demand makes towards the required capacity of the Transmission System.
* Distribution costs (lower voltage, local network costs) are reflected in the Distribution Use of System element of the bill, either as a kWh rate or as maximum demand charge expressed in kVA or kW i.e. the contribution that the customers’ demand makes towards the required capacity of the local distribution network.
* In addition to the above costs, customers who demand a new connection or an expansion of existing capacity may be asked to contribute towards the direct costs of the distribution system reinforcement at the local level.

**Step By Step Approach for Maximum Demand Control**

**1. Load Curve Generation**

Presenting the load demand of a consumer against time of the day is known as a ‘load curve’. If it is plotted for the 24 hours of a single day, it is known as an ‘hourly load curve’ and if daily demands plotted over a month, it is called daily load curves. A typical hourly load curve for an engineering industry is shown in Figure 1.3. These types of curves are useful in predicting patterns of drawl, peaks and valleys and energy use trend in a section or in an industry or in a distribution network as the case may be.

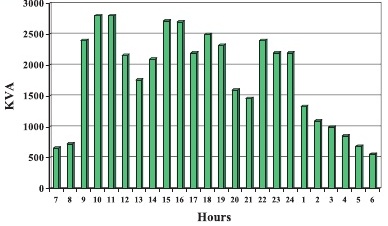


Fig 1.3 Maximum demand (daily load curve,hourly kVA)

**2. Rescheduling of Loads**

Rescheduling of large electric loads and equipment operations, in different shifts can be planned and implemented to minimize the simultaneous maximum demand. For this purpose, it is advisable to prepare an operation flow chart and a process chart. Analyzing these charts and with an integrated approach, it would be possible to reschedule the operations and running equipment in such a way as to improve the load factor which in turn reduces the maximum demand.

**3. Storage of Products/in process material/ process utilities like refrigeration**

It is possible to reduce the maximum demand by building up storage capacity of products/ materials, water, chilled water / hot water, using electricity during off peak periods. Off peak hour operations also help to save energy due to favorable conditions such as lower ambient temperature etc.

Example: Ice bank system is used in milk & dairy industry. Ice is made in lean period and used in peak load period and thus maximum demand is reduced.

**4. Shedding of Non-Essential Loads**

When the maximum demand tends to reach preset limit, shedding some of non-essential loads temporarily can help to reduce it. It is possible to install direct demand monitoring systems, which will switch off non-essential loads when a preset demand is reached. Simple systems give an alarm, and the loads are shed manually. Sophisticated microprocessor controlled systems are also available, which provide a wide variety of control options like:

■ Accurate prediction of demand

■ Graphical display of present load, available load, demand limit

■ Visual and audible alarm

■ Automatic load shedding in a predetermined sequence

■ Automatic restoration of load

■ Recording and metering

**5. Operation of Captive Generation and Diesel Generation Sets**

When diesel generation sets are used to supplement the power supplied by the electric utilities, it is advisable to connect the D.G. sets for durations when demand reaches the peak value. This would reduce the load demand to a considerable extent and minimize the demand charges.

**6. Reactive Power Compensation**

The maximum demand can also be reduced at the plant level by using capacitor banks and maintaining the optimum power factor. Capacitor banks are available with microprocessor based control systems. These systems switch on and off the capacitor banks to maintain the desired Power factor of system and optimize maximum demand thereby.

**1.3 Role of power factor and its improvement**

The electrical energy is almost exclusively generated, transmitted and distributed in the form of alternating current. Therefore, the question of power factor immediately comes into picture. In all industrial electrical distribution systems, the major loads are resistive and inductive. Resistive loads are incandescent lighting and resistance heating. In case of pure resistive loads, the voltage (V), current (I), resistance (R) relations are linearly related, i.e.

V = I x R and Power (kW) = V x I

Typical inductive loads are A.C. Motors, induction furnaces, transformers and ballast-type lighting. Inductive loads require two kinds of power: a) active (or working) power to perform the work and b) reactive power to create and maintain electro-magnetic fields.

Active power is measured in kW (Kilo Watts). Reactive power is measured in kVAr (Kilo Volt-Amperes Reactive).

The vector sum of the active power and reactive power make up the total (or apparent) power used. This is the power generated by the SEBs for the user to perform a given amount of work. Total Power is measured in kVA (Kilo Volts-Amperes).



Fig 1.4 kW, kVAr and kVA vector

The active power (shaft power required or true power required) in kW and the reactive power required (kVAr) are 90° apart vectorically in a pure inductive circuit i.e., reactive power

kVAr lagging the active kW. The vector sum of the two is called the apparent power or kVA, as illustrated above and the kVA reflects the actual electrical load on distribution system.

The ratio of kW to kVA is called the power factor which is equal to cosine of the angle between voltage and current. In order to ensure most favorable conditions for a supply system from engineering and economical standpoint, it is important to have power factor as close to unity as possible.

Disadvantages of low power factor

1. Large kVA rating of equipment: The electrical machinery (e.g. alternators, transformers, switchgear) is always rated in kVA.

kVA = kW/cosϕ

It is clear that kVA rating of the equipment is inversely proportional to power factor. The smaller the power factor, the larger is the kVA rating. Therefore, at low power factor, the kVA rating of the equipment has to be made more, making the equipment larger and expensive.

2. Greater conductor size: To transmit or distribute a fixed amount of power at constant voltage, the conductor will have to carry more current at low power factor. This necessitates large conductor size.

3. Large copper loss: The large current at low power factor causes more losses in all the elements of the supply system. This results in poor efficiency.

4. Poor voltage regulation: The large current at low lagging power factor causes greater voltage drops in alternators, transformers, transmission lines and distributors. This results in the decreased voltage available at the supply end, thus impairing the performance of utilization devices.

5. Reduced handling capacity of system: The lagging power factor reduces the handling capacity of all the elements of the system. It is because the reactive component of current preventsthe full utilization of installed capacity.

**Improving Power Factor**

The solution to improve the power factor is to add power factor correction capacitors to the plant power distribution system. They act as reactive power generators, and provide the needed reactive power to accomplish kW of work. This reduces the amount of reactive power, and thus total power, generated by the utilities.

**Example:**

A chemical industry had installed a 1500 kVA transformer. The initial demand of the plant was 1160 kVA with power factor of 0.70.

The % loading of transformer was about 78% (116**~** 0/1500 = 77.3%). To improve the power factor and to avoid the penalty, the unit had added about 410 kVAr in motor load end. This improved the power factor to 0.89, and reduced the required kVA to 913, which is the vector sum of kW and kVAr (see Figure 1.5).

**Figure 1.5 Power factor before and after Improvement**

After improvement the plant had avoided penalty and the 1500 kVAtransformer now loaded only to 60% of capacity. This will allow the addition of more load in the future to be supplied by the transformer.

**The advantages of PF improvement by capacitor addition**

a) Reactive component of the network is reduced and so also the total current in the system from the source end.

b) power losses are reduced in the system because of reduction in current.

c) Voltage level at the load end is increased.

d) kVA loading on the source generators as also on the transformers and lines upto the capacitors reduces giving capacity relief. A high power factor can help in utilising the full capacity of your electrical system.

**Cost benefits of PF improvement**

While costs of PF improvement are in terms of investment needs for capacitor addition the benefits to be quantified for feasibility analysis are:

a) Reduced kVA (Maximum demand) charges in utility bill

b) Reduced distribution losses (KWH) within the plant network

c) Better voltage at motor terminals and improved performance of motors

d) A high power factor eliminates penalty charges imposed when operating with a low power factor

e) Investment on system facilities such as transformers, cables, switchgears etc for delivering load is reduced.

**Selection and location of capacitors Direct relation for capacitor sizing.**

kVAr Rating = kW [tan φ1 – tan φ2]

where kVAr rating is the size of the capacitor needed, kW is the average power drawn, tan φ1

is the trigonometric ratio for the present power factor, and tan φ2 is the trigonometric ratio for

the desired PF.

φ1 = Existing (PF1) and φ2 = Improved ( PF2)

**Location of Capacitors**

The primary purpose of capacitors is to reduce the maximum demand. Additional benefits are derived by capacitor location. The Figure 1.6 indicates typical capacitor locations. Maximum benefit of capacitors is derived by locating them as close as possible to the load. At this location, its kVAr are confined to the smallest possible segment, decreasing the load current. This, in turn, will reduce power losses of the system substantially. Power losses are proportional to the square of the current. When power losses are reduced, voltage at the motor increases; thus, motor performance also increases.

Locations C1A, C1B and C1C of Figure 1.6 indicate three different arrangements at the load. Note that in all three locations extra switches are not required, since the capacitor is either switched with the motor starter or the breaker before the starter. Case

C1A is recommended for new installation, since the maximum benefit is derived and the size of the motor thermal protector is reduced. In Case C1B, as in Case C1A, the capacitor is energized only when the motor is in operation. Case C1B is recommended in cases where the installation already exists and the thermal protector does not need to be re-sized. In position C1C, the capacitor is permanently connected to the circuit but does not require a separate switch, since capacitor can be disconnected by the breaker before the starter.



**Figure 1.6: Power Distribution Diagram Illustrating**

**Capacitor Locations**

It should be noted that the rating of the capacitor should not be greater than the no-load magnetizing kVAr of the motor. If this condition exists, damaging over voltage or transient torques can occur. This is why most motor manufacturers specify maximum capacitor ratings to be applied to specific motors.

The next preference for capacitor locations as illustrated by Figure 1.9 is at locations C2 and

C3. In these locations, a breaker or switch will be required. Location C4 requires a high voltage breaker. The advantage of locating capacitors at power centres or feeders is that they can be grouped together. When several motors are running intermittently, the capacitors are permitted to be on line all the time, reducing the total power regardless of load.

From energy efficiency point of view, capacitor location at receiving substation only helps the utility in loss reduction. Locating capacitors at tail end will help to reduce loss reduction within the plants distribution network as well and directly benefit the user by reduced consumption. Reduction in the distribution loss % in kWh when tail end power factor is raised from PF1 to a new power factor PF2, will be proportional to

[1-]×100

**Capacitors for Other Loads**

The other types of load requiring capacitor application include induction furnaces, induction heaters and arc welding transformers etc. The capacitors are normally supplied with control gear for the application of induction furnaces and induction heating furnaces. The PF of arc furnaces experiences a wide variation over melting cycle as it changes from 0.7 at starting to 0.9 at the end of the cycle. Power factor for welding transformers is corrected by connecting capacitors across the primary winding of the transformers, as the normal PF would be in the range of

0.35.

**Performance Assessment of Power Factor Capacitors**

**Voltage effects:** Ideally capacitor voltage rating is to match the supply voltage. If the supply voltage is lower, the reactive kVAr produced will be the ratio where V1 is the actual supply voltage, V2 is the rated voltage.

On the other hand, if the supply voltage exceeds rated voltage, the life of the capacitor is adversely affected.

**Material of capacitors:** Power factor capacitors are available in various types by dielectric material used as; paper/ polypropylene etc. The watt loss per kVAr as well as life vary with respect to the choice of the dielectric material and hence is a factor to be considered while selection.

**Connections:** Shunt capacitor connections are adopted for almost all industry/ end user applications, while series capacitors are adopted for voltage boosting in distribution networks.

**Operational performance of capacitors:** This can be made by monitoring capacitor charging current vis- a- vis the rated charging current. Capacity of fused elements can be replenished as per requirements. Portable analyzers can be used for measuring kVAr delivered as well as charging current. Capacitors consume 0.2 to 6.0 Watt per kVAr, which is negligible in comparison to benefits.

Some checks that need to be adopted in use of capacitors are:

i) Nameplates can be misleading with respect to ratings. It is good to check by charging currents.

ii) Capacitor boxes may contain only insulated compound and insulated terminals with no capacitor elements inside.

iii) Capacitors for single phase motor starting and those used for lighting circuits for voltage boost, are not power factor capacitor units and these cannot withstand power system conditions.

**1.4 Electric power system analysis**

Structure of power system

Generating stations, transmission lines and distribution system are the main components of a electric power system. Generating stations and distribution system are connected through transmission lines, which also connect one power system (grid, area) to another. A distribution system connects all the loads in a particular area to transmission lines.

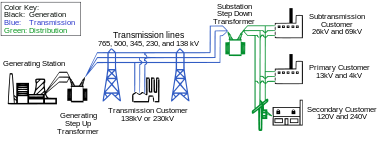


Fig 1.7 Power system structure

**Electric supply system**

The electric power supply system consists of the three main components generating stations, transmission lines and distribution system. The electric supply system can broadly be classified into (i) d.c. or a.c. system, (ii) overhead or underground system. Now-a-days, 3-phase 3-wire system is universally adopted for generation and transmission of electric power and 3-phase 4-wire for distribution of electric power. The underground system is more expensive is than the overhead system. Therefore, overhead system is mostly adopted in India for transmission and distribution of electric power.

**Comparison of d.c. and a.c. transmission**

Both a.c. and d.c. transmission has its own merits and demerits.

D.C. transmission:

Advantages:

1. It requires only two conductors as compared to three for a.c. transmission.
2. There is no inductance, capacitance, phase displacement and surge problems in d.c. transmission.
3. D.C. transmission line has better voltage regulation.
4. For the same working voltage, the potential stress on the insulation is less in case of d.c. system than that in a.c. system. So a d.c. line requires less insulation.
5. The high voltage d.c. transmission is free from the dielectric losses.
6. In d.c. transmission, there are stability problem and synchronizing difficulties.
7. There is no skin effect. So entire cross-section of the line conductor is utilized.

Disadvantages:

1. Electric power cannot be generated at high d.c. voltage due to commutation problem.
2. The d.c. voltage cannot be stepped up for transmission of power at high voltages.
3. The d.c. switches and circuit breakers have their own limitations.

A.C. transmission:

Advantages:

1. The power can be generated at high voltages.
2. The maintenance of a.c. sub-stations is easy and cheaper.
3. The a.c. voltage can be stepped up or stepped down by transformers with ease and efficiency. This permits to transmit power at high voltages and distribute it at safe potentials.

Disadvantages:

1. An a.c. line requires more copper than a d.c. line.
2. The construction of a.c. transmission line is more complicated compared to d.c. line.
3. Due to skin effect in a.c. system, the effective resistance of the line is increased.
4. An a.c. line has capacitance. Therefore, there is a continuous loss of power due to charging current even when the line is open.

**Elements of a transmission line**

Due to economic reasons, electric power is transmitted at high voltage by 3-phase 3-wire overhead system. The principal elements of a high voltage transmission line are:

1. Conductors: usually three conductors are used for a single circuit line and six for a double circuit line. The usual material is aluminum reinforced with steel.
2. Step-up and step-down transformers: step-up transformers are generally located at generating stations and step-down transformers are used for transmission and distribution.
3. Line insulator: mechanically support the line conductors and isolate them electrically from the ground.
4. Support: which are generally steel towers and provide support to the conductors.
5. Protective devices: such as ground wires lightning arrestors, circuit breakers, relay etc. They ensure the satisfactory service of the transmission line.
6. Voltage regulation devices: which maintain the voltage at receiving end within permissible limit.

**Economics of power transmission**

While designing any scheme of power transmission, the engineer must design the various parts of transmission scheme in a way that maximum economy is achieved. The following two closely influence the electrical design of a transmission line:

**(i)** **Economic choice of conductor size**: The most economical area of conductor is that for which the total annual cost of transmission line is minimum. The total annual cost of transmission line can be divided broadly into two parts.

**Annual charge on capital outlay**: This is on account of interest and depreciation on the capital cost of complete installation of transmission line. In case of overhead system, it will be the annual interest and depreciation on the capital cost of conductors, supports and insulators and the cost of erection. For an overhead line, insulator cost is constant, the conductor cost is proportional to the area of cross section and the cost of support and their erection is partly constant and partly proportional to the cross sectional area of the conductor.

**Annual cost of energy wasted**: This is on account of energy lost mainly in the conductor due to losses. Assuming a constant current throughout the year, the energy lost in the conductor is proportional to resistance. As resistance is inversely proportional to the area of cross-section of the conductor, therefore, the energy lost in the conductor is inversely proportional to the area of cross-section.

The total annual cost of transmission line will be minimum if variable part of annual charge is equal to annual cost of energy wasted.

**(ii) Economic choice of transmission**: If transmission voltage is increased, the volume of conductor material required is reduced. This decreases the expenditure on the conductor material. But as the transmission voltage is increased, the cost of insulating the conductors, cost of transformers, switchgear and other terminal apparatus also increases. Therefore, for every transmission line in a 3-phase a.c. system, there is optimum transmission voltage which is given by

Where *V*= line voltage in kV

*P*= maximum kW per phase to be delivered to single circuit

*l*= distance of transmission line in km

Distribution system

The part of power system which distributes electric power for local use is known as distribution system. In general, distribution system is the electrical system between the sub-station fed by the transmission system and the consumers’ meters. It generally consists of feeders, distributors and the service mains.

A feeder is a conductor which connects the sub-station to the area where power is to be distributed. Generally, no tappings are taken from the feeder so that current in it remains the same throughout.

A distributor is a conductor from which tappings are taken for supply to the consumers. The current through a distributor is not constant.

A service main is generally a small cable which connects the distributor to the consumers’ terminals.

**A.C. distribution**

Electrical energy is generated, transmitted and distributed in the form of alternating current due to the fact that a.c. can be conveniently changed in magnitude by means of a transformer. In general, the a.c. distribution system is the electrical system between the step-down substation fed by transmission system and the consumers’ meters. The a.c. distribution system is classified into primary distribution system and secondary distribution system.

(i) Primary distribution system: It is that part of a.c. distribution system which operates at voltages somewhat higher than general utilization and handles large blocks of electrical energy than the average low-voltage consumer uses. The voltage used for primary distribution depends upon the amount of power to be conveyed and the distance of the substation required to be fed. The most commonly used primary distribution voltages are 11 kV, 6.6 kV and 3.3 kV. Due to economic considerations, primary distribution is carried out by 3-phase 3-wire system.

(ii) Secondary distribution system: It is that part of a.c. distribution system which includes the range of voltages at which the ultimate consumer utilizes the electrical energy delivered to him. The secondary distribution employs 400/230 V, 3-phase, 4-wire system.

**D.C. distribution**

Now-a-days, electrical energy is generated, transmitted and distributed in the form of a.c. as an economical proposition. However, for certain applications, d.c. supply is absolutely necessary. For example, d.c. supply is required for the operation of variable speed machinery, electro-chemical work and electric traction. For this purpose, a.c. power is converted into d.c. power at the sub-station using converting machinery. The d.c. supply from the sub-station is conveyed to the required places for distribution.

D.C. distributors can be classified according to the way they are fed by feeders.

(i) Distributor fed at one end: In this type of feeding, the distributor is connected to the supply at one end and loads are taken at different points along the length of the distributor.

(ii) Distributor fed at both end: In this type of feeding, the distributor is connected to the supply mains at both ends and loads are tapped off at different points along the length of the distributor. The voltage at feeding points mayor may not be equal.

(iii) Distributor fed at the centre: in this type of feeding, the centre of the distributor is connected to the supply mains. It is equivalent to two singly fed distributors, each distributor having a common feeding point and length equal to half of the total length.

(iv) Ring mains: In this type, the distributor is in the form of a closed ring. It is equivalent to a straight distributor fed at both ends with equal voltages, the two ends being brought together to form a closed ring. The distributor ring may be fed at one or more than one point.

**Overhead versus underground system**

The distribution system can be overhead or underground. The choice between overhead and underground system depends upon a number of widely differing factors. Therefore, it is desirable to make a comparison between the two.

1. Public safety: The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.
2. Initial cost: The initial cost of underground system is more than that of overhead system which may be five to ten times of an overhead system due to the high cost of trenching, conduits, cables, manholes and other equipments.
3. Flexibility: The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines etc. are permanently placed once installed and the load expansion can only be met by laying new lines. However, on an overhead system, poles, wires, transformers etc. can easily be shifted to meet the changes in load conditions.
4. Faults: The chances of fault in underground system are very rare as compared to overhead system. But if a fault does occur, it is difficult to locate and repair on an underground system.
5. Current carrying capacity and voltage drop: An overhead distribution conductor has a higher current carrying capacity than an underground cable of the same material and cross-section. On the other hand, less voltage drop occur in underground cables as they have much lower inductive reactance than that of overhead conductors.
6. Useful life: The useful life of underground system is much longer than that of overhead system.
7. Maintenance cost: The maintenance cost of underground system is very low as compared with that of overhead system because of less chance of faults and service interruptions from wind, ice, and lighting as well as from traffic hazard.

**Substation**

The assembly of apparatus used to change some characteristics (e.g. voltage, a.c. to d.c., frequency, p.f. etc.) of electric supply is called a substation. Substations are important part of power system. The continuity of supply depends to a considerable extent upon the successful operation of substations. The following are the important points which must be kept in view while laying out of a substation:

1. It should be located at a proper site. As far as possible, it should be located at the centre of gravity of load.
2. It should provide safe and reliable arrangement. For safety, consideration must be given to the maintenance of regulation clearances, facilities for carrying out repairs and maintenance, abnormal occurrences such as possibility of explosion or fire etc. For reliability, consideration must be given for good design and construction, the provision of suitable protective gear etc.
3. It should be easily operated and maintained.
4. It should involve minimum capital cost.

Classification of substations

The two most important ways of classifying substations are according to (1) service requirement and (2) constructional features.

1. According to service requirement: A substation may be called upon to change voltage level or improve power factor or convert a.c. power into d.c. power etc. According to service requirement, substations may be classified into:
2. Transformer substations where voltage level of electric supply is changed.
3. Switching substations which simply perform the switching operations of power lines.
4. Power factor correction substations which improve the power factor of the system. Such substations are generally located at the receiving end of the transmission lines.
5. Frequency changer substations which change the supply frequency. Such a frequency change may be required for industrial utilization.
6. Converting substations which convert a.c. power into d.c. power.
7. According to constructional features: A substation has many components (e.g. circuit breakers, switches, fuses, instruments etc.) which must be housed properly to ensure continuous and reliable service. According to constructional features, the substations are classified as:
8. Indoor substation
9. Outdoor substation
10. Underground substation
11. Pole-mounted substation

The majority of substations in the power system are concerned with the changing of voltage level of electric supply. These are called transformer substations because transformer is the main component employed to change the voltage level. Depending upon the purpose served, these substations may be classified into:

1. Step-up substation: The generation voltage (11 kV) is stepped up to high voltage (220 kV) to affect economy in transmission of electric power.
2. Primary grid substation: From step-up substation, electric power at 220 kV is transmitted by 3-phase 3-wire overhead system. Electric power received by primary grid substation is reduced to 66 kV for secondary transmission.
3. Secondary substation: At a secondary substation, the voltage is further stepped down to 11 kV. Big consumers are generally supplied power at 11 kV for further handling with their own substation.
4. Distribution substation: These substations are located near the consumers localities and step-down the voltage to 400 V, 3-phase, 4-wire for supplying to consumers.

Equipment in a transformer substation

1. Bus-bars: When a number of lines operating at the same voltage have to be directly connected electrically, bus-bars used as common electrical component. These are copper or aluminium bars and operate at constant voltage.
2. Insulators: The insulators serve two purposes. They support the conductors and bus-bars and confine the current to the conductors. There are several types of insulators such as pin type, suspension type, post insulator etc. and their use in the substation will depend upon the service requirement.
3. Isolating switches: isolating switches or isolators are used to disconnect a part of the system for general maintenance and repairs. An isolator is essentially a knife switch and is designed to open a circuit under no load condition.
4. Circuit breaker: A circuit breaker is an equipment which can open or close a circuit under normal as well as fault condition. It can be operated manually under normal condition and automatically under fault condition.
5. Power transformer: A power transformer is used in a substation to step up or step down the voltage.
6. Instrument transformers: the function of instrument transformer is to transfer voltages or currents in the power lines to values which are convenient for the operation of measuring instruments and relays which are designed to operate at low voltage and current. There are two types of instrument transformers viz. current transformer (C.T.) and potential transformer (P.T.).
7. Metering and indicating instruments: There are several metering and indicating instruments like ammeter, voltmeter, energy meter etc. installed in a substation to maintain watch over the circuit quantities.
8. Miscellaneous equipments such as fuses, carrier-current equipment, substation auxiliary supplies.

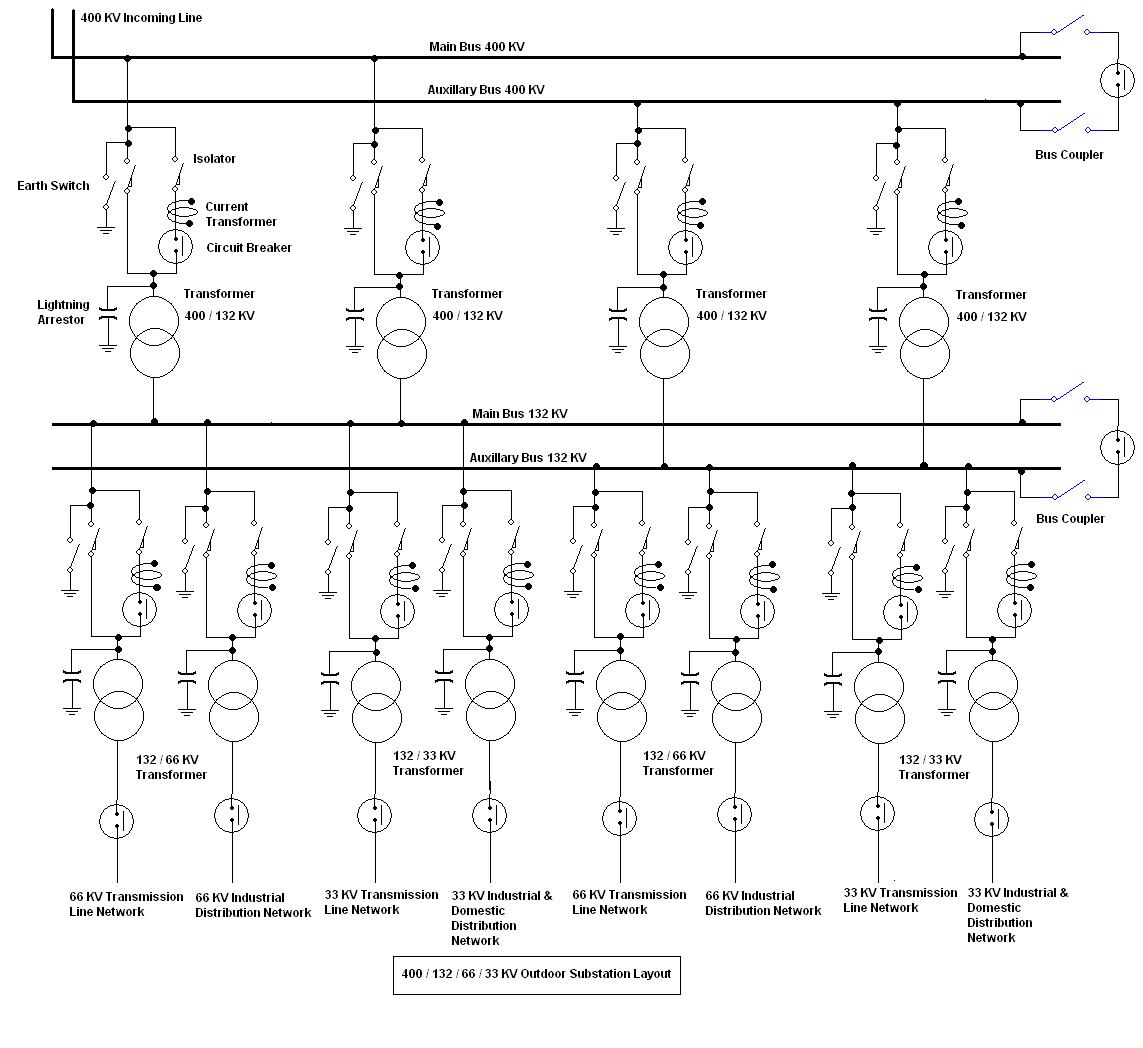


Fig 1.8 A 400/33 kV substation layout

**1.5 Energy Efficient Technologies in Electrical System**

Electricity is one of the most vital infrastructure inputs for economic development of a country. The demand for electricity in India is enormous and is growing steadily. This growth has been slower than country’s economic growth. To balance this demand and supply of electricity, it is the time for electric utilities to go for energy efficient electrical equipment for huge savings as this would be utilized for future needs.

The Ministry of Power has outlined its mission for 11th Five Year Plan – “Power For All: 2012”. In the next 5 years, India will require 66,000 MW of new generation capacity with matching investments in transmission and distribution networks. For every 1 MW of new capacity that comes up, about 7 – 8 MVA transformers (approximately) are used across Generation, Transmission and Distribution segments. This implies a demand of about 5,00,000 MVA of transformers unfolding over next 5 years, resulting in an annual demand of about 100,000 MVA, which would mean that there would be approximately a demand for 2.25 Million Transformer units (approx. 30% for distribution) of average rating of 63 kVA. Besides fresh demand, some replacement demand of 15,000MVA (approximately) will also be coming up, as transformers usually have a life of 20 – 30 years.

With the worsening power scenario and acute power shortage, the Indian Economy cannot sustain the growth momentum but has to look for aggressively augmenting power supply. The strategy developed to make power available to all by 2012 includes promotion of energy efficient products and its conservation in the country, which is found to be the least cost option to augment the gap between demand and supply.

**Maximum Demand Controllers**

High-tension (HT) consumers have to pay a maximum demand charge in addition to the usual charge for the number of units consumed. This charge is usually based on the highest amount of power used during some period (say 30 minutes) during the metering month. The maximum demand charge often represents a large proportion of the total bill and may be based on only one isolated 30 minute episode of high power use.

Considerable savings can be realised by monitoring power use and **turning off or reducing non-essential loads** during such periods of high power use.

Maximum Demand Controller (See Figure1.9) is a device designed to meet the need of industries conscious of the value of load management. Alarm is sounded when demand approaches a preset value. If corrective action is not taken, the controller switches off non-essential loads in a logical sequence. This sequence is predetermined by the user and is programmed jointly by the user and the supplier of the device. The plant equipments selected for the load management are stopped and restarted as per the desired load profile. Demand control scheme is implemented by using suitable control contactors. Audio and visual annunciations could also be used.



Fig 1.9 Maximum Demand Controller

**Automatic Power Factor Controller**

Automatic power factor controller not only controls the maximum demand but also improves the power factor. Various types of automatic power factor controls are available with relay / microprocessor logic. Two of the most common controls are: Voltage Control and kVAr Control.

**Voltage Control**

Voltage alone can be used as a source of intelligence when the switched capacitors are applied at point where the circuit voltage decreases as circuit load increases. Generally, where they are applied the voltage should decrease as circuit load increases and the drop in voltage should be around 4 – 5 % with increasing load.

Voltage is the most common type of intelligence used in substation applications, when maintaining a particular voltage is of prime importance. This type of control is independent of load cycle. During light load time and low source voltage, this may give leading PF at the substation, which is to be taken note of.

**KILOVAR Control**

Kilovar sensitive controls are used at locations where the voltage level is closely regulated and not available as a control variable. The capacitors can be switched to respond to a decreasing power factor as a result of change in system loading. This type of control can also be used to avoid penalty on low power factor by adding capacitors in steps as the system power factor begins to lag behind the desired value. Kilovar control requires two inputs - current and voltage from the incoming feeder, which are fed to the PF correction mechanism, either the microprocessor or the relay.

**Automatic Power Factor Control Relay**

It controls the power factor of the installation by giving signals to switch on or off power factor correction capacitors. Relay is the brain of control circuit and needs contactors of appropriate rating for switching on/off the capacitors. There is a built-in power factor transducer, which measures the power factor of the installation and converts it to a DC voltage of appropriate polarity. This is compared with a reference voltage, which can be set by means of a knob calibrated in terms of power factor.

When the power factor falls below setting, the capacitors are switched on in sequence. The

relays are provided with First in First out (FIFO) and First in Last Out (FILO) sequence. The

capacitors controlled by the relay must be of the same rating and they are switched on/off in linear sequence. To prevent over correction hunting, a dead band is provided. This setting determines the range of phase angle over which the relay does not respond; only when the PF goes beyond this range, the relay acts. When the load is low, the effect of the capacitors is more pronounced and may lead to hunting. Under current blocking (low current cut out) shuts off the relay, switching off all capacitors one by one in sequence, when load current is below setting.

Special timing sequences ensure that capacitors are fully discharged before they are switched in. This avoids dangerous over voltage transient. The solid state indicating lamps (LEDS) display

various functions that the operator should know and also and indicate each capacitor switching stage.

**Intelligent Power Factor Controller (IPFC)**

This controller determines the rating of capacitance connected in each step during the first hour of its operation and stores them in memory. Based on this measurement, the IPFC switches on the most appropriate steps, thus eliminating the hunting problems normally associated with capacitor switching.

**Energy Efficient Transformers**

Most energy loss in dry-type transformers occurs through heat or vibration from the core. The new high-efficiency transformers minimise these losses. The conventional transformer is made up of a silicon alloyed iron (grain oriented) core. The iron loss of any transformer depends on the type of core used in the transformer.

The transformer supplies power to all the power consuming items and remains energized for 24 hours. Being supply equipment, it does not, by itself, consume any power. But the process of transformation involves certain inherent losses especially in the core, having to run continuously for all the 24 hours of the day and 365 days of the year. Hence we need to turn our attention to low loss designs and latest technologies in quality of core material to promote energy efficiency. In this context “amorphous metal core” material offers great advantage, as no load losses are less. The expected reduction in energy loss over conventional (Si Fe core) transformers is roughly around 70%, which is quite significant. By using an amorphous core- with unique physical and magnetic properties- these new types of transformers have increased efficiencies even at low loads – 98.5% efficiency at 35% load.

Electrical distribution transformers made with amorphous metal cores provide excellent opportunity to conserve energy right from the installation. Though these transformers are a little costlier than conventional iron core transformers, the overall benefit towards energy savings will compensate for the higher initial investment. At present amorphous metal core transformers are available up to 1600 kVA.

**Electronic Ballast**

**Role of Ballast**

In an electric circuit the ballast acts as a stabilizer. Fluorescent lamp is an electric discharge lamp. The two electrodes are separated inside a tube with no apparent connection between them. When sufficient voltage is impressed on these electrodes, electrons are driven from one electrode and attracted to the other. The current flow takes place through an atmosphere of lowpressure mercury vapour.

Since the fluorescent lamps cannot produce light by direct connection to the power source, they need an ancillary circuit and device to get started and remain illuminated. The auxillary circuit housed in a casing is known as ballast.

**Conventional Vs Electronic Ballasts**

The conventional ballasts make use of the kick caused by sudden physical disruption of current in an inductive circuit to produce the high voltage required for starting the lamp and then rely on reactive voltage drop in the ballast to reduce the voltage applied across the lamp. On account of the mechanical switch (starter) and low resistance of filament when cold the uncontrolled filament current, generally tend to go beyond the limits specified by Indian standard specifications. With high values of current and flux densities the operational losses and temperature rise are on the higher side in conventional choke.

The high frequency electronic ballast overcomes the above drawbacks. The basic functions of electronic ballast are:

1. To ignite the lamp

2. To stabilize the gas discharge

3. To supply the power to the lamp

The electronic ballasts make use of modern power semi-conductor devices for their operation. The circuit components form a tuned circuit to deliver power to the lamp at a high resonant frequency (in the vicinity of 25 kHz) and voltage is regulated through an inbuilt feedback mechanism. It is now well established that the fluorescent lamp efficiency in the kHz range is higher than those attainable at low frequencies. At lower frequencies (50 or 60 Hz) the electron density in the lamp is proportional to the instantaneous value of the current because the ionisation state in the tube is able to follow the instantaneous variations in the current. At higher frequencies (kHz range), the ionisation state cannot follow the instantaneous variations of the current and hence the ionisation density is approximately a constant, proportional to the RMS (Root Mean Square) value of the current. Another significant benefit resulting from this phenomenon is the absence of stroboscopic effect, thereby significantly improving the quality of light output.

One of largest advantages of electronic ballast is the enormous energy savings it provides.

This is achieved in two ways. The first is its amazingly low internal core loss, quite unlike old fashioned magnetic ballasts. And second is increased light output due to the excitation of the lamp phosphors with high frequency. If the period of frequency of excitation is smaller than the light retention time constant for the gas in the lamp, the gas will stay ionized and, therefore, produce light continuously. This phenomenon along with continued persistence of the phosphors at high frequency will improve light output from 8–12 percent. This is possible only with high frequency electronic ballast.

**Energy Efficient Lighting Controls**

**Occupancy Sensors**

Occupancy-linked control can be achieved using infra-red, acoustic, ultrasonic or microwave sensors, which detect either movement or noise in room spaces. These sensors switch lighting on when occupancy is detected, and off again after a set time period, when no occupancy movement detected. They are designed to override manual switches and to prevent a situation where lighting is left on in unoccupied spaces. With this type of system it is important to incorporate a built-in time delay, since occupants often remain still or quiet for short periods and do not appreciate being plunged into darkness if not constantly moving around.

**Timed Based Control**

Timed-turnoff switches are the least expensive type of automatic lighting control. In some cases, their low cost and ease of installation makes it desirable to use them where more efficient controls would be too expensive.

**Types and Features**

The oldest and most common type of timed-turnoff switch is the "dial timer," a spring-wound mechanical timer that is set by twisting the knob to the desired time.

Typical units of this type are vulnerable to damage because the shaft is weak and the knob is not securely attached to the shaft. Some spring-wound units make an annoying ticking sound as they operate. Newer types of timed-turnoff switches are completely electronic and silent. Electronic switches can be made much more rugged than the spring-wound dial timer. These units typically have a spring-loaded toggle switch that turns on the circuit for a preset time interval.

Some electronic models provide a choice of time intervals, which you select by adjusting a knob located behind the faceplate. Most models allow occupants to turn off the lights manually. Some models allow occupants to keep the lights on, overriding the timer. Timed-turnoff switches are available with a wide range of time spans. The choice of time span is a compromise. Shorter time spans waste less energy but increase the probability that the lights will turn off while someone is in the space. Dial timers allow the occupant to set the time span, but this is not likely to be done with a view toward optimising efficiency. For most applications, the best choice is an electronic unit that allows the engineering staff to set a fixed time interval behind the cover plate.

**Daylight Linked Control**

Photoelectric cells can be used either simply to switch lighting on and off, or for dimming. They may be mounted either externally or internally. It is however important to incorporate time delays into the control system to avoid repeated rapid switching caused, for example, by fast moving clouds. By using an internally mounted photoelectric dimming control system, it is possible to ensure that the sum of daylight and electric lighting always reaches the design level by sensing the total light in the controlled area and adjusting the output of the electric lighting accordingly. If daylight alone is able to meet the design requirements, then the electric lighting can be turned off.

The energy saving potential of dimming control is greater than a simple photoelectric switching system. Dimming control is also more likely to be acceptable to room occupants.

**Localized Switching**

Localized switching should be used in applications which contain large spaces. Local switches give individual occupants control over their visual environment and also facilitate energy savings.

By using localized switching it is possible to turn off artificial lighting in specific areas, while still operating it in other areas where it is required, a situation which is impossible if the lighting for an entire space is controlled from a single switch.

**Energy Efficient Motors**

Energy-efficient electric motors reduce energy losses through improved design, better materials, and improved manufacturing techniques. Replacing a motor may be justifiable solely on the electricity cost savings derived from an energy-efficient replacement. This is true if the motor runs continuously, power rates are high, the motor is oversized for the application, or its nominal efficiency has been reduced by damage or previous rewinds. Efficiency comparison for standard and high efficiency motors is shown in Figure 1.10



Fig 1.10 **Efficiency Range for Standard and**

**High Efficiency Motors**

**Technical aspects of Energy Efficient Motors**

**Energy-efficient motors last longer,** and may require less maintenance. At lower temperatures, bearing grease lasts longer; required time between re-greasing increases. Lower temperatures translate to long lasting insulation. Generally, motor life doubles for each 10°C reduction in operating temperature.

**Select energy-efficient motors** with a 1.15 service factor, and design for operation at 85% of the rated motor load.

**Electrical power problems,** especially poor incoming power quality can affect the operation of energy-efficient motors.

**Speed control** is crucial in some applications. In polyphase induction motors, slip is a measure of motor winding losses. The lower the slip, the higher the efficiency. Less slippage in energy efficient motors results in speeds about 1% faster than in standard counterparts.

**Starting torque** for efficient motors may be lower than for standard motors. Facility managers should be careful when applying efficient motors to high torque applications.

**Variable Speed Drives**

**Speed Control of Induction Motors**

Induction motor is the workhorse of the industry. It is cheap rugged and provides high power to weight ratio. On account of high cost-implications and limitations of D.C. System, induction motors are preferred for variable speed application, the speed of which can be varied by changing the supply frequency. The speed can also be varied through a number of other means, including, varying the input voltage, varying the resistance of the rotor circuit, using multi speed windings, using *Scherbius* or *Kramer* drives, using mechanical means such as gears and pulleys and eddy-current or fluid coupling, or by using rotary or static voltage and frequency converters.

**Variable Frequency Drive**

The VFD operates on a simple principle. The rotational speed of an AC induction motor depends on the number of poles in that stator and the frequency of the applied AC power. Although the number of poles in an induction motor cannot be altered easily, variable speed can be achieved through a variation in frequency. The VFD rectifies standard 50 cycle AC line power to DC, then synthesizes the DC to a variable frequency AC output.

Motors connected to VFD provide variable speed mechanical output with high efficiency. These devices are capable of up to a 9:1 speed reduction ratio (11 percent of full speed), and a 3:1 speed increase (300 percent of full speed).

In recent years, the technology of AC variable frequency drives (VFD) has evolved into highly sophisticated digital microprocessor control, along with high switching frequency IGBTs (Insulated Gate Bi Polar Transistors) power devices. This has led to significantly advanced capabilities from the ease of programmability to expanded diagnostics. The two most significant benefits from the evolution in technology have been that of cost and reliability, in addition to the significant reduction in physical size.

**Eddy Current Drives**

This method employs an eddy-current clutch to vary the output speed. The clutch consists of a primary member coupled to the shaft of the motor and a freely revolving secondary member coupled to the load shaft. The secondary member is separately excited using a DC field winding. The motor starts with the load at rest and a DC excitation is provided to the secondary member, which induces eddy-currents in the primary member. The interaction of the fluxes produced by the two currents gives rise to a torque at the load shaft. By varying the DC excitation the output speed can be varied to match the load requirements. The major disadvantage of this system is relatively poor efficiency particularly at low speeds.



Fig 1.11 Eddy current drive

**Slip Power Recovery Systems**

Slip power recovery is a more efficient alternative speed control mechanism for use with slip ring motors. In essence, a slip power recovery system varies the rotor voltage to control speed, but instead of dissipating power through resistors, the excess power is collected from the slip rings and returned as mechanical power to the shaft or as electrical power back to the supply line. Because of the relatively sophisticated equipment needed, slip power recovery tends to be economical only in relatively high power applications and where the motor speed range is 1:5 or less.