Centre of Excellence in Renewable Energy Education and Research,
New Campus, University of Lucknow,
Lucknow
M Sc. Renewable Energy
Semester IV, Second Year
Module REC-402: Energy Auditing and Conservation

Unit-3 (Contents)

Electrical Energy Auditing: Electrical energy conservation in various industries, Conservation methods; Energy management opportunities in electrical heating, Lighting system, Cable selection, Energy efficient motors: Factors involved in determination of motor efficiency, Adjustable AC drives. Application and its use – Variable speed drives/belt drives.

Energy efficiency in electrical systems: High tension (HT) power distribution; Control system in HT/LT side, Harmonics.

Electric Power Supply Systems

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

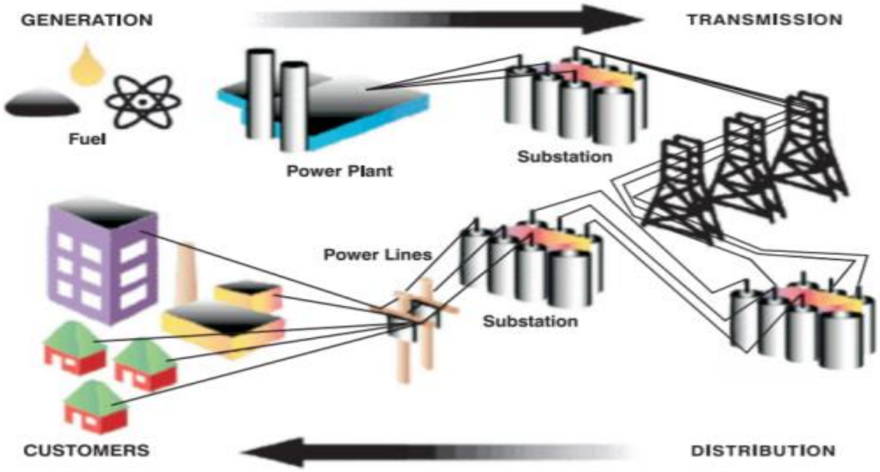


Figure 1: Typical Electric Power Supply Systems

Power Generation Plant

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 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.

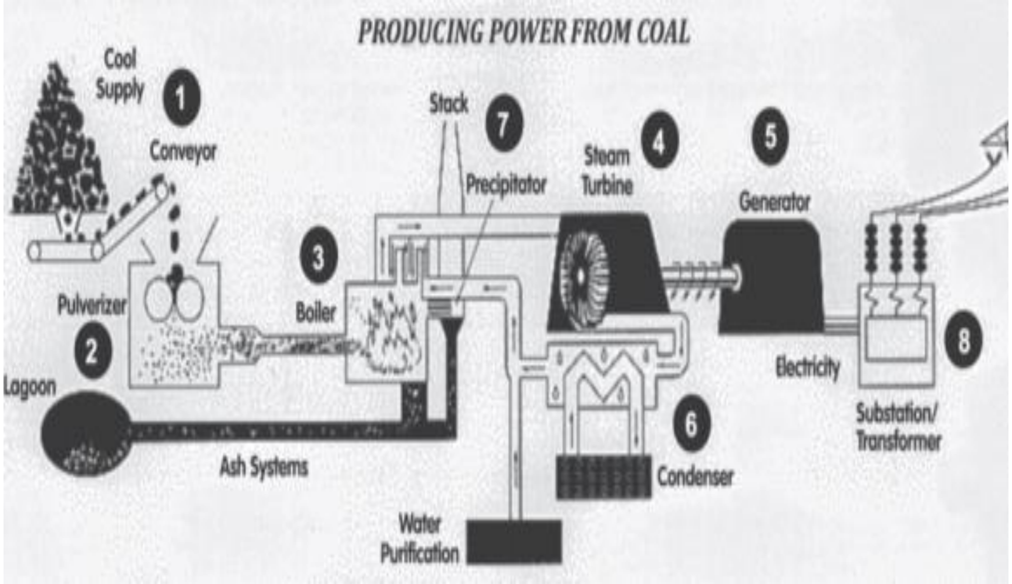


Figure 2 Principle of Thermal Power Generation

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.

Transmission and Distribution Lines

The power plants typically produce 50 cycle/second (Hertz), alternating-current (AC) electricity with voltages between 11kV and 33kV. At the power plant site, the 3-phase voltage is stepped up to a higher voltage for transmission on cables strung on cross-country towers.

Figure 3: High Voltage Transmission Line

High voltage (HV) and extra high voltage (EHV) transmission is the next stage from power plant to transport A.C. power over long distances at voltages like; 220 kV & 400 kV (Shown in fig 3). Where transmission is over 1000 km, high voltage direct current transmission is also favoured to minimize the losses. Sub-transmission network at 132 kV, 110 kV, 66 kV or 33 kV constitutes the next link towards the end user. Distribution at 11 kV / 6.6 kV / 3.3 kV constitutes the last link to the consumer, who is connected directly or through transformers depending upon the drawl level of service. The transmission and distribution network include sub-stations, lines and distribution transformers. High voltage transmission is used so that smaller, more economical wire sizes can be employed to carry the lower current and to reduce losses. Sub-stations, containing step-down transformers, reduce the voltage for distribution to industrial users. The voltage is further reduced for commercial facilities. Electricity must be generated, as and when it is needed since electricity cannot be stored virtually in the system. Typical voltage levels in a power system are given in figure 4.

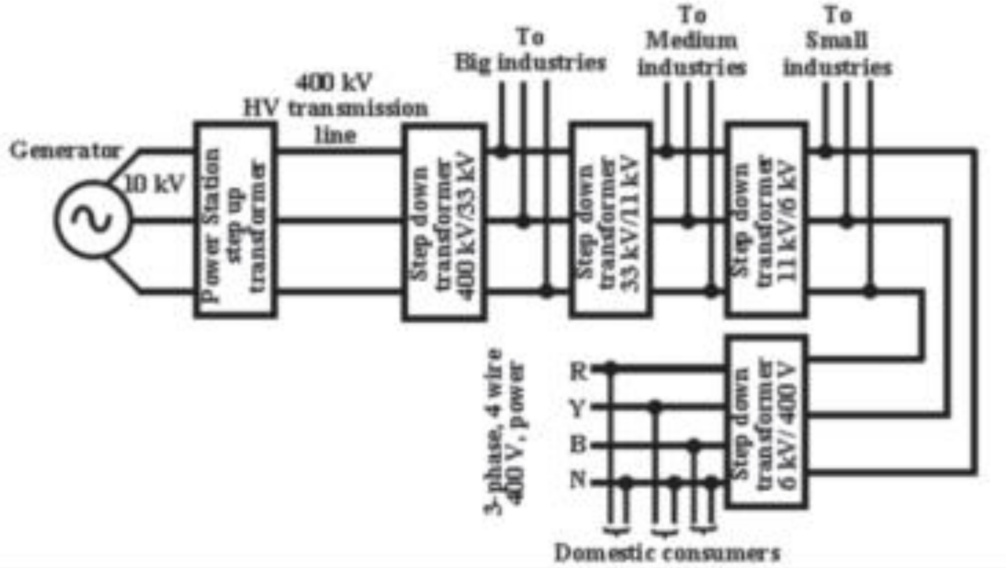


Figure 4: Typical Voltage Levels in a Power System

There is no difference between a transmission line and a distribution line except for the voltage level and power handling capability. Transmission lines are usually capable of transmitting large quantities of electric energy over great distances. They operate at high voltages. Distribution lines carry limited quantities of power over shorter distances. Voltage drops in line are in relation to the resistance and reactance of line, length and the current drawn. For the same quantity of power handled, lower the voltage, higher the current drawn and higher the voltage drop. The current drawn is inversely proportional to the voltage level for the same quantity of power handled. The power loss in line is proportional to resistance and square of current. (i.e. $P_{loss}=I^2R$). Higher voltage transmission and distribution thus would help to minimize line voltage drop in the ratio of voltages, and the line power loss in the ratio of square of voltages. For instance, if distribution of power is raised from 11 kV to 33 kV, the voltage drop would be lower by a factor $\frac{1}{3}$ and the line loss would be lower by a factor $\left(\frac{1}{3}\right)^2$ i.e., 1/9. Lower voltage transmission and distribution also calls for bigger size conductor on account of current handling capacity needed.

Industrial End User

At the industrial end user premises, again the plant network elements like transformers at receiving sub-station, switchgear, lines and cables, load-break switches, capacitors cause losses, which affect the input-received energy. However the losses in such systems are meager and unavoidable.

A typical plant single line diagram of electrical distribution system is shown in Figure 5.

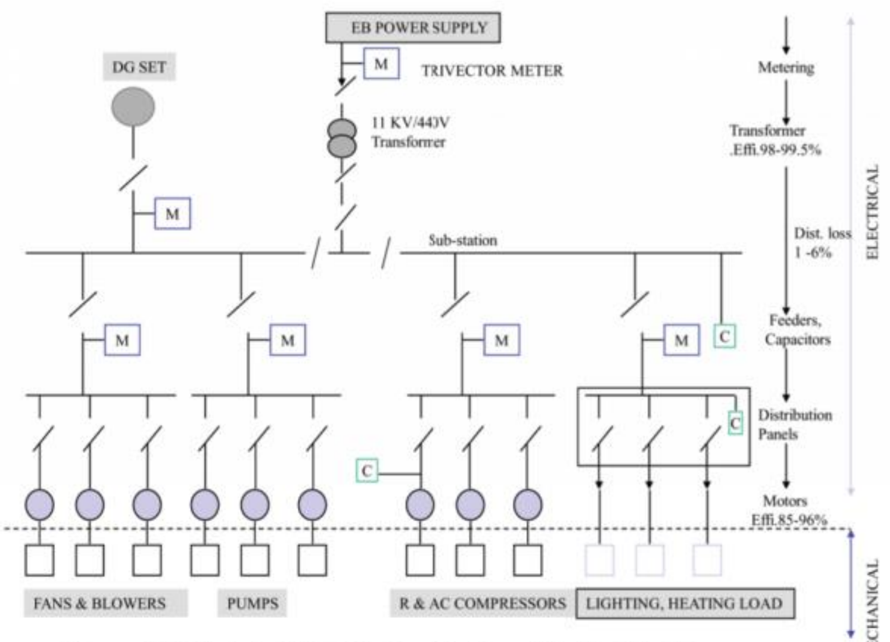


Figure 1.5 Electrical Distribution System –Single Line Diagram

After power generation at the plant it is transmitted and distributed over a wide network. The standard technical losses are around 17 % in India (Efficiency = 83%). But the figures for many of the states show T & D losses ranging from 17 – 50 %. All these may not constitute technical losses, since un-metered and pilferage are also accounted in this loss. When the power reaches the industry, it meets the transformer. The energy efficiency of the transformer is generally very high. Next, it goes to the motor through internal plant distribution network. A typical distribution network efficiency including transformer is 95% and motor efficiency is about 90%. Another 30 % (Efficiency =70%)is lost in the mechanical system which includes coupling/ drive train, a driven equipment such as pump and flow control valves/throttling etc. Thus the overall energy efficiency becomes 50%. (0.83 x 0.95x 0.9 x 0.70 = 0.50, i.e. 50% efficiency) Hence one unit saved in the end user is equivalent to two units generated in the power plant. (1Unit / 0.5Eff = 2 Units).

Effect of Plant Type on Rates

(Tariffs or Energy Element):

Rates are the different methods of charging the consumers for the consumption of electricity. It is desirable to charge the consumer according to his maximum demand (kW) and the energy consumed (kWh). The tariff chosen should recover the fixed cost, operating cost and profit etc. incurred in generating the electrical energy.

Requirements of a Tariff:

Tariff should satisfy the following requirements:

(1) It should be easier to understand.
(2) It should provide low rates for high consumption.
(3) It should encourage the consumers having high load factors.
(4) It should take into account maximum demand charges and energy charges.
(5) It should provide fewer charges for power connections than for lighting.
(6) It should avoid the complication of separate wiring and metering connections.

Types of Tariffs

The various types of tariffs are as follows,

(1) Flat demand rate
(2) Straight line meter rate
(3) Step meter rate
(4) Block rate tariff
(5) Two part tariff
(6) Three part tariff.

The various types of tariffs can be derived from the following general equation:

$Y = DX + EZ + C$

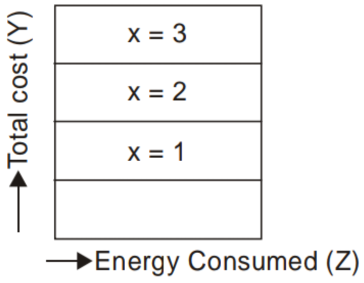
Where

Y = Total amount of bill for the period considered.
D = Rate per kW of maximum demand.
X = Maximum demand in kW.
E = Energy rate per kW.
Z = Energy consumed in kWh during the given period.

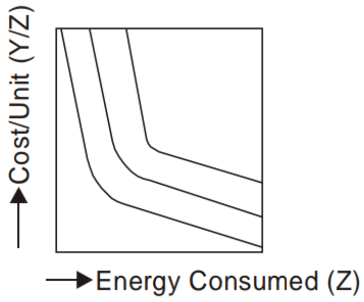
C = Constant amount to be charged from the consumer during each billing period.

Various types of tariffs are as follows:

(1) Flat Demand Rate. It is based on the number of lamps installed and a fixed number of hours of use per month or per year. The rate is expressed as a certain price per lamp or per unit of demand (kW) of the consumer. This energy rate eliminates the use of metering equipment. It is expressed by the expression.



(a)



(b)

(2) Straight Line Meter Rate. According to this energy rate the amount to be charged from the consumer depends upon the energy consumed in kWh which is recorded by a means of a kilowatt hour meter. It is expressed in the form

$Y = EZ$

This rate suffers from a drawback that a consumer using no energy will not pay any amount although he has incurred some expense to the power station due to its readiness to serve him. Secondly since the rate per kWh is fixed, this tariff does not encourage the consumer to use more power.

(3) Step Meter Rate. According to this tariff the charge for energy consumption goes down as the energy consumption becomes more. This tariff is expressed as follows.

$Y = EZ$ If $0 \leq Z \leq A$

$Y = E_1Z_1$ If $A \leq Z_1 \leq B$

$Y = E_2Z_2$ If $B \leq Z_2 \leq C$

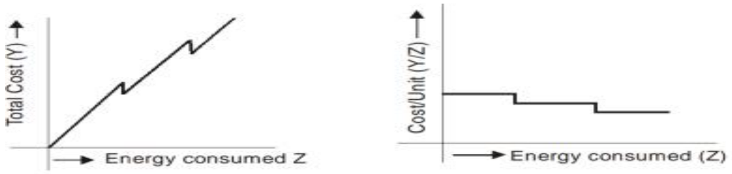
And so on. Where E, E_1, E_2 are the energy rate per kWh and A, B and C, are the limits of energy consumption.

(4) Block Rate Tariff. According to this tariff a certain price per units (kWh) is charged for all or any part of block of each unit and for succeeding blocks of energy the corresponding unit charges decrease.

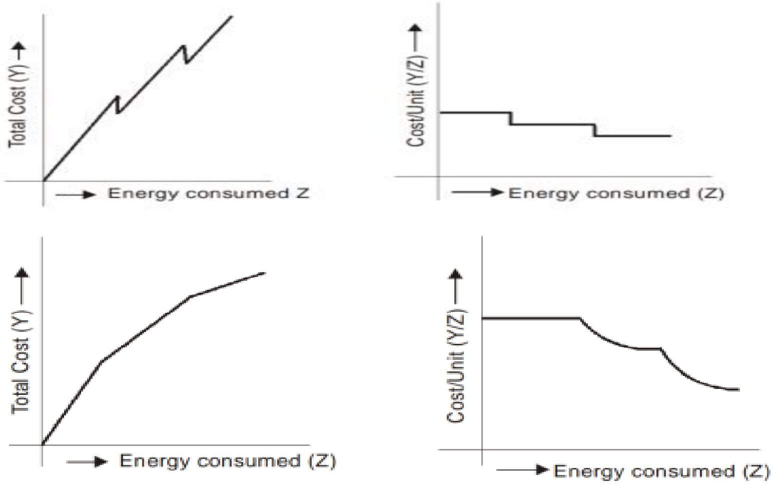
It is expressed by the expression

$$Y = E_1Z_1 + E_2Z_2 + E_3Z_3 + E_4Z_4 + \ldots..$$

Where E_1, E_2, E_3.... are unit energy charges for energy blocks of magnitude Z_1, Z_2, Z_3,.. respectively.



Step meter rate



(5) Two Part Tariff (Hopkinson Demand Rate). In this tariff the total charges are based on the maximum demand and energy consumed. It is expressed as

$$Y = D \times X + EZ$$

A separate meter is required to record the maximum demand. This tariff is used for industrial loads.

(6) Three-Part Tariff (Doherty Rate). According to this tariff the customer pays some fixed amount in addition to the charges for maximum demand and energy consumed. The fixed amount to be charged depends upon the occasional increase in fuel price, rise in wages of labour etc. It is expressed by the expression

$$Y = DX + EZ + C.$$

Electricity Billing

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.) kVA-hr drawn by the service is also recorded 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 (kVA-hr), which is a vector sum of kWh and kVA-hr.

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 kVA-hr 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.

As example, in an industry, if the drawl over a recording cycle of 30 minutes is:

2500 kVA for 4 minutes

3600 kVA for 12 minutes

4100 kVA for 6 minutes

3800 kVA for 8 minutes

The MD recorder will be computing MD as:

$$\frac{(\mathbf{2500\ x\ 4})\ +\ (\mathbf{3600\ x\ 12})\ +\ (\mathbf{4100\ x\ 6})\ +\ (\mathbf{3800\ x\ 8})}{\mathbf{30}} = \mathbf{3606.7}\ \boldsymbol{kVA}$$

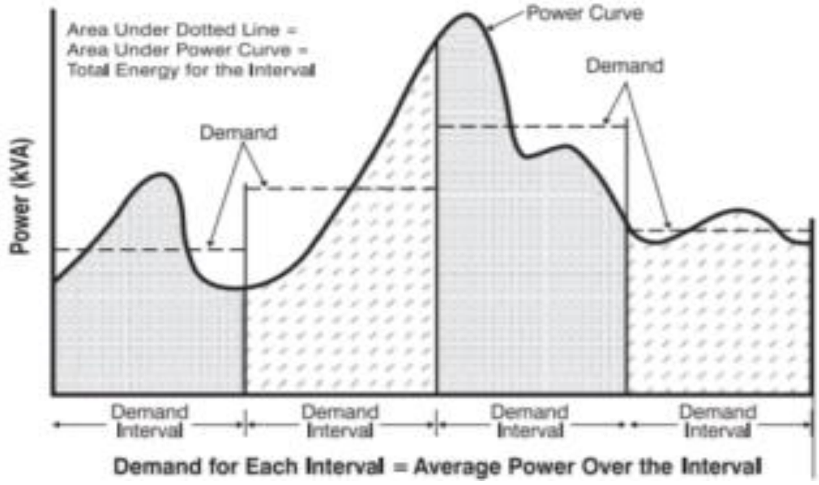


Figure 6: Demand Curve

The month’s maximum demand will be the highest among such demand values recorded over the month. The meter registers only if the value exceeds the previous maximum demand value and thus, even if, average maximum demand is low, the industry / facility has to pay for the maximum demand charges for the highest value registered during the month, even if it occurs for just one recording cycle duration i.e., 30 minutes during whole of the month. A typical demand curve is shown in Figure 6.

As can be seen from the Figure 6 above the demand varies from time to time. The demand is measured over predetermined time interval and averaged out for that interval as shown by the horizontal dotted line.

Of late most electricity boards have changed over from conventional electromechanical trivector meters to electronic meters, which have some excellent provisions that can help the utility as well as the industry. These provisions include:

- Substantial memory for logging and recording all relevant events
- High accuracy up to 0.2 class
- Amenability to time of day tariffs
- Tamper detection /recording
- Measurement of harmonics and Total Harmonic Distortion (THD)
- Long service life due to absence of moving parts
- Amenability for remote data access/downloads

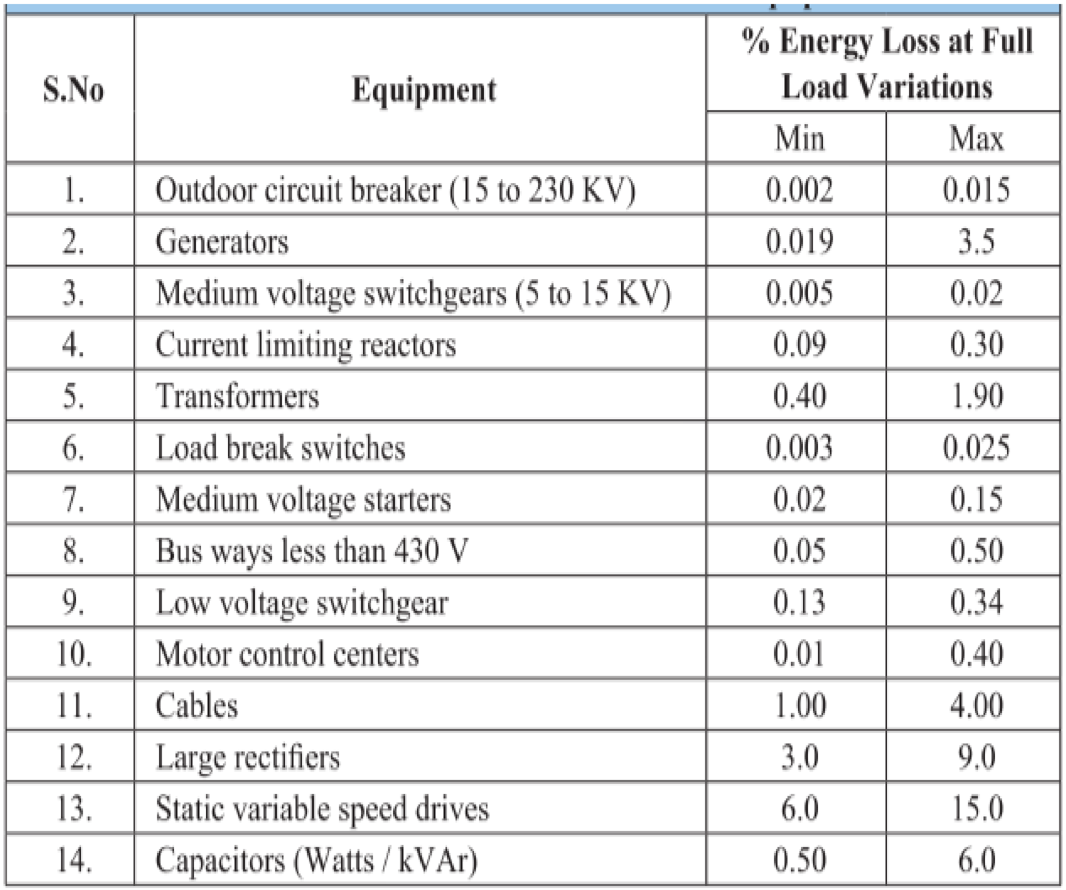
Trend analysis of purchased electricity and cost components can help the industry to identify key result areas for bill reduction within the utility tariff available framework along the following lines.

Distribution Losses in Industrial System:

In an electrical system often the constant no load losses and the variable load losses are to be assessed alongside, over long reference duration, towards energy loss estimation. Identifying and calculating the sum of the individual contributing loss components is a challenging one, requiring extensive experience and knowledge of all the factors impacting the operating efficiencies of each of these components.

For example the cable losses in any industrial plant will be up to 6 percent depending on the size and complexity of the distribution system. Note that all of these are current dependent, and can be readily mitigated by any technique that reduces facility current load. Various losses in distribution equipment are given in the **Table1.**

Table 1: Losses in Electrical Distribution Equipment



S.No	Equipment	% Energy Loss at Full Load Variations	
		Min	Max
1.	Outdoor circuit breaker (15 to 230 KV)	0.002	0.015
2.	Generators	0.019	3.5
3.	Medium voltage switchgears (5 to 15 KV)	0.005	0.02
4.	Current limiting reactors	0.09	0.30
5.	Transformers	0.40	1.90
6.	Load break switches	0.003	0.025
7.	Medium voltage starters	0.02	0.15
8.	Bus ways less than 430 V	0.05	0.50
9.	Low voltage switchgear	0.13	0.34
10.	Motor control centers	0.01	0.40
11.	Cables	1.00	4.00
12.	Large rectifiers	3.0	9.0
13.	Static variable speed drives	6.0	15.0
14.	Capacitors (Watts / kVAr)	0.50	6.0

In system distribution loss optimization, the various options available include:

- Relocating transformers and sub-stations near to load centers.
- Re-routing and re-conductoring such feeders and lines where the losses / voltage drops are higher.
- Power factor improvement by incorporating capacitors at load end.
- Optimum loading of transformers in the system.
- Opting for lower resistance All Aluminum Alloy Conductors (AAAC) in place of conventional Aluminum Cored Steel Reinforced (ACSR) lines.
- Minimizing losses due to weak links in distribution network such as jumpers, loose contacts, and old brittle conductors.

Lighting System:

All lighting systems generate heat that needs to be dissipated. By designing energy efficient lighting system that integrates day lighting and good controls, heat gains can be reduced significantly. This can reduce the size of the HVAC system resulting in first-cost savings.

Day lighting

Day lighting benefits go beyond energy savings and power reduction. Daylight spaces have been shown to improve people's ability to perform visual tasks, increase productivity and reduce illness. Building fenestration should be designed to optimize day lighting and reduce the need for electric lighting. Orient the building to minimize building exposure to the east and west and maximize glazing on the south and north exposures.

Daylight strategies do not save energy unless electric lights are turned off or dimmed appropriately. ECBC requires controls in day lit areas that are capable of reducing the light output from luminaires by at least half.

- Install dimmers to take advantage of day lighting and where cost-effective.
- Replace rheostat dimmers with efficient electronic dimmers.
- Combine time switching with day lighting using astronomical time clocks.
- Control exterior lighting with photo controls where lighting can be turned off after a fixed interval.

Switch off Lights When Not in Use

Provision of Separate Switches for Peripheral Lighting

A flexible lighting system, which made use of natural lighting for the peripherals of the room, should be considered so that these peripheral lights can be switched off when not needed.

Install High Efficiency Lighting System

Replace incandescent and other inefficient lamps with lamps with higher lighting efficacy. For example, replacing incandescent bulbs with compact fluorescent lamps can reduce electricity consumption by 75% without any reduction in illumination levels.

Fluorescent Tube Ballasts

The ballast losses of conventional ballast and electronic ballast are 12W and 2W respectively. Hence, consider the use of electronic ballast for substantial energy savings in the lighting system.

Lamp Fixtures or Luminaries

Optical lamp luminaries made of aluminum, silver or multiple dielectric coatings have better light distribution characteristics. Use them to reduce electricity consumption by as much as 50% without compromising on illumination levels.

Integration of Lighting System with Air-Conditioning System

In open plan offices, the air-conditioning and lighting systems can be combined in such a way that the return air is extracted through the lighting luminaires. This measure ensures that lesser heat will be directed from the lights into the room.

Cleaning of Lights and Fixtures

Clean the lights and fixtures regularly. For best results, dust at least four times a year.

Use Light Colors for Walls, Floors and Ceilings

The higher surface reflectance values of light colors will help to make the most of any existing lighting system. Consider light colored furniture and room partitions to optimize light reflectance. Avoid furniture colors and placement that will interfere with light distribution. Keep ceilings and walls as bright as possible.

Deal with each activity area and each fixture individually

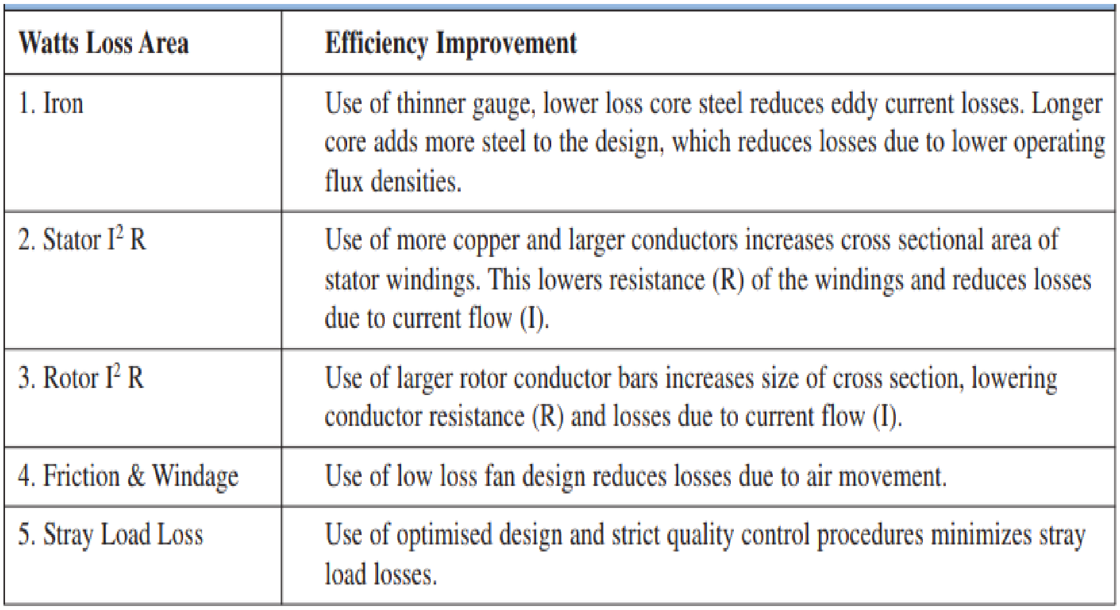
Eliminate excessive lighting by reducing the total lamp wattage in each activity area

Task Lighting

Lighting layout should use task lighting principle. Install focusing lamps or flexible extensions wherever needed.

Energy Efficient Motors

Minimizing Watts Loss in Motors: Improvements in motor efficiency can be achieved without compromising motor performance - at higher cost - within the limits of existing design and manufacturing technology. From the Table given below, it can be seen that any improvement in motor efficiency must result from reducing the Watts losses. In terms of the existing state of electric motor technology, a reduction in watts losses can be achieved in various ways.



Watts Loss Area	Efficiency Improvement
1. Iron	Use of thinner gauge, lower loss core steel reduces eddy current losses. Longer core adds more steel to the design, which reduces losses due to lower operating flux densities.
2. Stator I^2 R	Use of more copper and larger conductors increases cross sectional area of stator windings. This lowers resistance (R) of the windings and reduces losses due to current flow (I).
3. Rotor I^2 R	Use of larger rotor conductor bars increases size of cross section, lowering conductor resistance (R) and losses due to current flow (I).
4. Friction & Windage	Use of low loss fan design reduces losses due to air movement.
5. Stray Load Loss	Use of optimised design and strict quality control procedures minimizes stray load losses.

Table: Watt Loss Area and Efficiency Improvement

All of these changes to reduce motor losses are possible with existing motor design and manufacturing technology. They would, however, require additional materials and/or the use of higher quality materials and improved manufacturing processes resulting in increased motor cost.

Simply Stated: REDUCED LOSSES = IMPROVED EFFICIENCY

Thus 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.

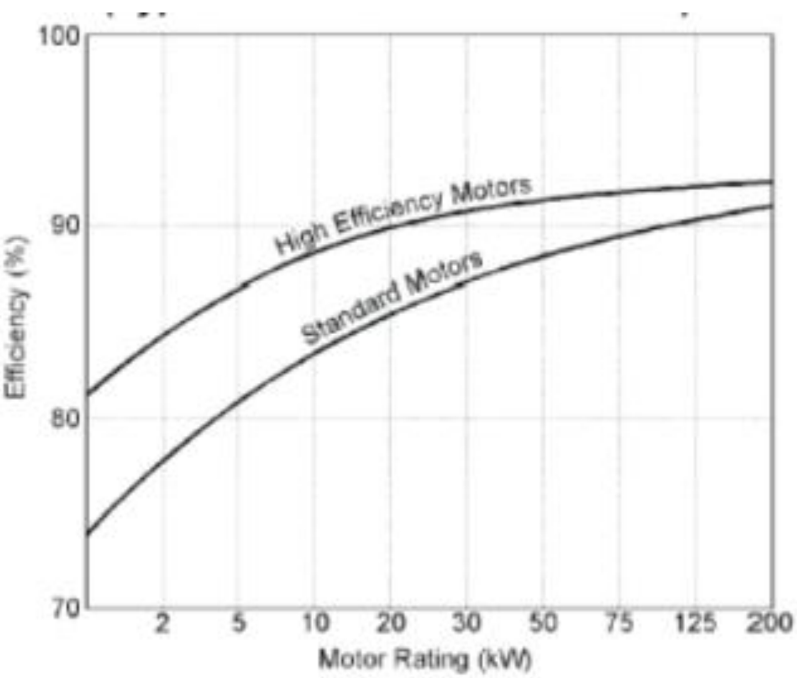


Fig: Efficiency Range for Standard and High Efficiency Motors

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.

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, and 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.

Variable Torque Vs. Constant Torque: Variable speed drives, and the loads that are applied to, can generally be divided into two groups: constant torque and variable torque. The energy savings potential of variable torque applications is much greater than that of constant torque applications. Constant torque loads include vibrating conveyors, punch presses, rock crushers, machine tools, and other applications where the drive follows a constant V/Hz ratio. Variable torque loads include centrifugal pumps and fans, which make up the majority of HVAC applications.

Why Variable Torque Loads Offer Greatest Energy Savings

In variable torque applications, the torque required varies with the square of the speed, and the horsepower required varies with the cube of the speed, resulting in a large reduction of horsepower for even a small reduction in speed. The motor will consume only 25% as much energy at 50% speed than it will at 100% speed. This is referred to as the Affinity Laws, which define the relationships between speed, flow, torque, and horsepower. The following laws illustrates these relationships:

- Flow is proportional to speed
- Head is proportional to $(\text{speed})^2$
- Torque is proportional to $(\text{speed})^2$
- Power is proportional to $(\text{speed})^3$.

Harmonics

a harmonic is a component frequency of the signal that is an integer multiple of the fundamental frequency. Harmonic voltages and currents is an electrical power system is a results of non-linear electric loads. **The harmonic current represents energy that cannot be used by any devices on the network. It will be therefore converted to heat and is wasted.** For instance, the fundamental frequency is 50 Hz, and then the 5th harmonic is five times that frequency, or 250 Hz (Fig.).

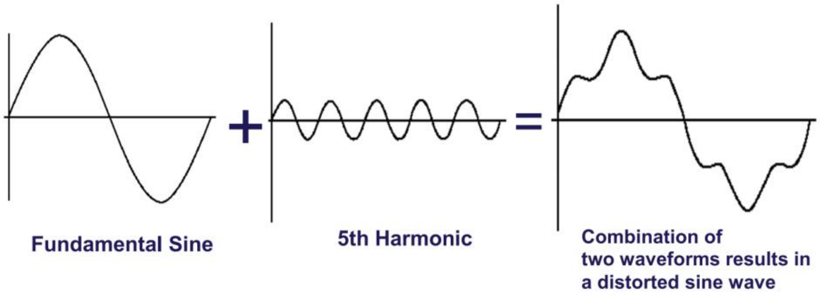


Fig: Harmonic Wave Pattern

Linear System:

In any alternating current network, flow of current depends upon the voltage applied and the impedance (resistance to AC) provided by elements like resistances, reactance of inductive and capacitive nature. As the value of impedance in above devices is constant, they are called linear whereby the voltage and current relation is of linear nature.

e.g. Incandescent lamps, Heater and to a great extent, motor are linear systems.

Non-Linear Systems:

Non-linear systems are one with varying impedance characteristics, these NON LINEAR devices cause distortion in voltage and current waveforms which is of increasing concern in recent times. e.g. variable frequency drives (VFDs), electronic ballasts, UPS and Computers, Induction and arc furnaces.

Current Distortion:

It could cause transformer heating or nuisance tripping by fuses, circuit breakers and other protective devices since they are typically not rated for harmonically rich waveforms.

$$THD_{current} = \sqrt{\sum_{n=2}^{n=n} \left(\frac{I_n}{I_1}\right)^2} \times 100$$

Harmonics can be discussed in terms of current or voltage. A 5th harmonic current is simply a current flowing at 250 Hz on a 50 Hz system. The 5th harmonic current flowing through the system impedance creates a 5th harmonic voltage. Total Harmonic Distortion (THD) expresses the amount of harmonics. The following is the formula for calculating the THD for current:

$$THD_{current} = \sqrt{\sum_{n=2}^{n=n} \left(\frac{I_n}{I_1}\right)^2} \times 100$$

Then,

$$THD_{current} = \sqrt{\left[\left(\frac{50}{250}\right)^2 + \left(\frac{35}{250}\right)^2\right]} \times 100 = 25\%$$

Current at fundamental frequency I_1 = Base Current = 250amps

Third Harmonic Current = 50 amps

Fifth Harmonic Current = 35 amps

When harmonic currents flow in a power system, they are known as “poor power quality” or “dirty power”. Other causes of poor power quality include transients such as voltage spikes, surges, sags, and ringing. Because they repeat every cycle, harmonics are regarded as a steady state cause of poor power quality. The distortion travels back into the power source and can affect other equipment connected to the same source.

Voltage Distortion:

A distortion current has higher peak values that cause non-sinusoidal voltage drops across the distortion system. The resulting voltage drops add or subtract from the sinusoidal voltage supplied by the utility. Other utility consumers could get distorted voltage on the downstream side of the power distribution circuit.

When expressed as a percentage of fundamental voltage THD is given by,

$$THD_{Voltage} = \sqrt{\sum_{n=2}^{n=n} \left(\frac{V_n}{V_1}\right)^2} \times 100$$

Where V_1 is the fundamental frequency voltage and V_n is n^{th} harmonic voltage component.

Major Causes of Harmonics

Devices that draw non-sinusoidal currents when a sinusoidal voltage is applied create harmonics. Frequently these are devices that convert AC to DC. Some of these devices are listed below:

Electronic Switching Power Converters

- Computers, Uninterruptible power supplies (UPS), Solid-state rectifiers
- Electronic process control equipment, PLC’s, etc
- Electronic lighting ballasts, including light dimmer
- Reduced voltage motor controllers

Arcing Devices

- Discharge lighting, e.g. Fluorescent, Sodium and Mercury vapor
- Arc furnaces, Welding equipment, Electrical traction system

Ferromagnetic Devices

- Transformers operating near saturation level
- Magnetic ballasts (Saturated Iron core)
- Induction heating equipment, Chokes, Motors

Appliances

- TV sets, air conditioners, washing machines, microwave ovens
- Fax machines, photocopiers, printers

These devices use power electronics like SCRs, diodes, and thyristors, which are a growing percentage of the load in industrial power systems. The majority use a 6-pulse converter. Most loads which produce harmonics do so as a steady-state phenomenon. A snapshot reading of an operating load that is suspected to be non-linear can determine if it is producing harmonics. Normally each load would manifest a specific harmonic spectrum.

Many problems can arise from harmonic currents in a power system. Some problems are easy to detect; others exist and persist because harmonics are not suspected. Higher RMS current and voltage in the system are caused by harmonic currents, which can result in any of the problems listed below:

1. Blinking of Incandescent Lights - Transformer Saturation
2. Capacitor Failure - Harmonic Resonance
3. Circuit Breakers Tripping - Inductive Heating and Overload
4. Conductor Failure - Inductive Heating
5. Electronic Equipment Shutting down - Voltage Distortion
6. Flickering of Fluorescent Lights - Transformer Saturation
7. Fuses Blowing for No Apparent Reason - Inductive Heating and Overload
8. Motor Failures (overheating) - Voltage Drop
9. Neutral Conductor and Terminal Failures - Additive Triplen Currents
10. Electromagnetic Load Failures - Inductive Heating
11. Overheating of Metal Enclosures - Inductive Heating
12. Power Interference on Voice Communication - Harmonic Noise
13. Transformer Failures - Inductive Heating

Overcoming Harmonics

Tuned Harmonic filters consisting of a capacitor bank and reactor in series are designed and adopted for suppressing harmonics, by providing low impedance path for harmonic component.

The Harmonic filters connected suitably near the equipment generating harmonics help to reduce THD to acceptable limits. In present Indian context where no Electro Magnetic Compatibility regulations exist as an application of Harmonic filters is very relevant for industries having diesel power generation sets and co-generation units.

Note:

High tension (HT) power distribution, High Voltage Direct current (HVDC) and High Voltage Alternating current (HVAC) is the part of assignment ques. and will be provided later.