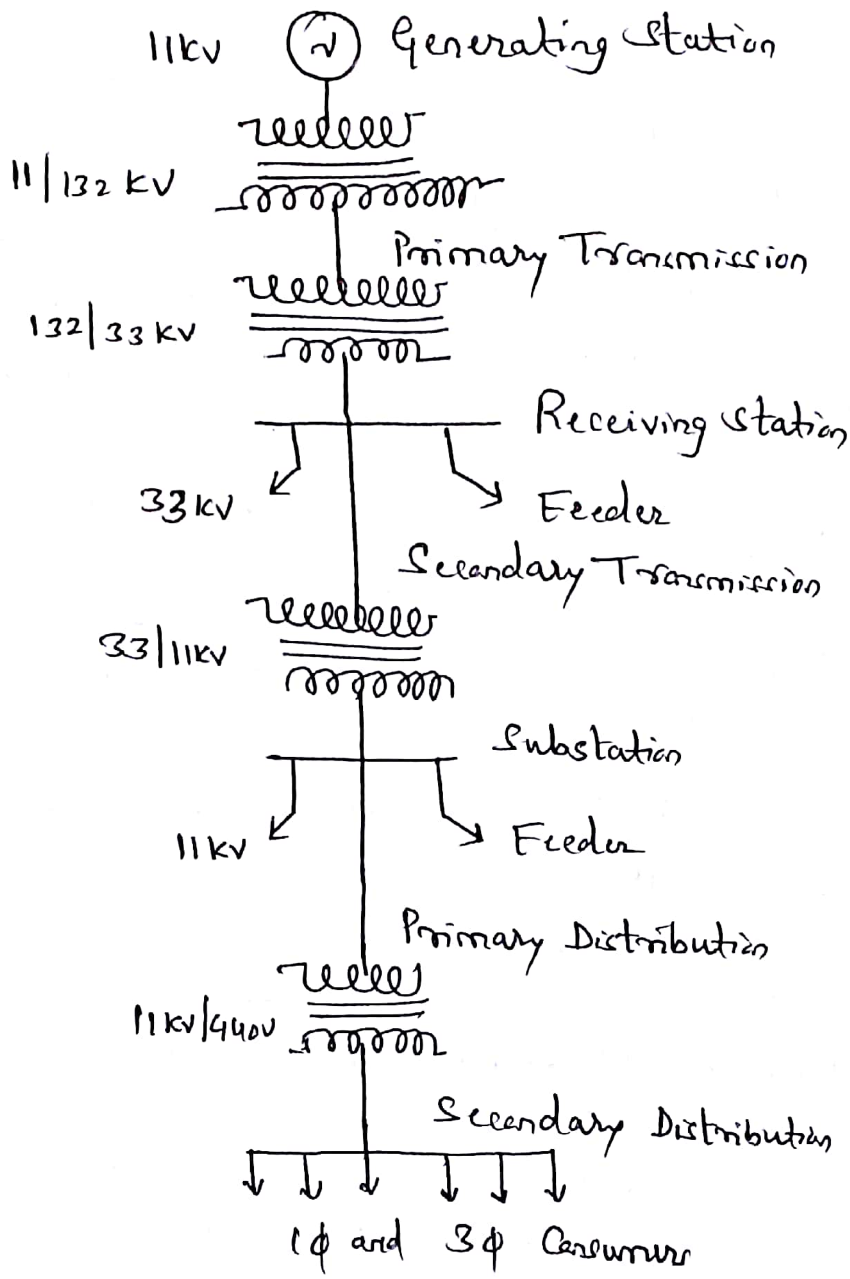
Unit - IV

Electrical System Optimization

Electrical Power System:

Single line diagram of typical AC Power supply Scheme



1) **Generating Station**: Generating station where electric power is produced by 3φ alternators operating in parallel. The usual generation voltage is 11KV. For economy in the transmission of electric power, the generation voltage (11kV) is stepped up to 132 kV (or more) at the generating station with the help of 3φ transformers. The transmission of electric power at high voltage has several advantages including the saving of conductor material and high transmission efficiency

It may appear advisable to use the highest possible voltage for transmission of electric power to save conductor material and have other advantages. But there is a limit to which this voltage can be increased. It is because increase in transmission voltage introduces insulation problems as well as the cost of switchgear and transformer equipment is increased.

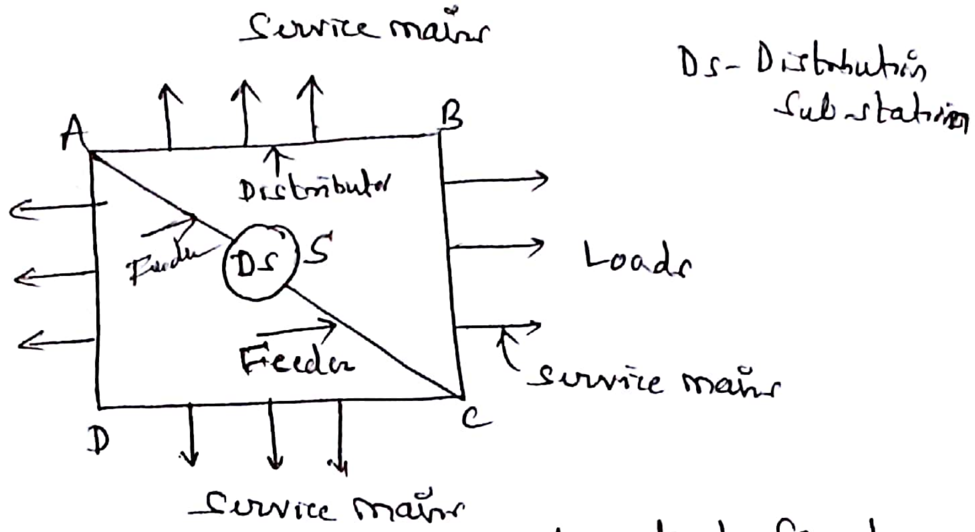
2) Primary transmission: The electric power at 132 kV is transmitted by 3φ, 3 wire overhead systems to the outskirts of the city. This forms the primary transmission.

3) Secondary transmission: The primary transmission line terminates at the receiving station which usually lies at the outskirts of the city. At the receiving station, the voltage is reduced to 33 kV by stepdown transformer, from this station electric power is transmitted at 33 kV by 3φ, 3 wires overhead system to various substations located at the strategic points in the city. This forms the secondary transmission.

4) Primary Distribution: The secondary transmission line terminates at the substation where voltage is reduced from 33 kV to 11 kV, 3φ 3 wire the 11 kV lines run along the important road sides of the city. This forms the primary distribution. It may be noted that big consumers, having demand more than 50 kW are generally supplied power at 11 kV for further handling with their own substation equipment.

5) Secondary Distribution: The electric power from primary distribution line (11 kV) is delivered to distribution substations. Thus substations are located near the consumer's localities and stepdown the voltage to 400V, 3φ, 4 wire for secondary distribution. The voltage between 2 phase is 400V and between any phase and neutral is 230V. The 1φ residential lighting load is connected between any one phase and the neutral, whereas 3φ, 400V motor load is connected across 3φ lines directly.

Feeders, Distributors and service mains



It may be worth while to mention here that Secondary distribution system consists of feeders, distributors and service mains. Fig shows the elements of low voltage distribution system. Feeders (SC/SA) radiating from the distribution substation (DS) supply power to the distributors (AB, BC, CD & AD). No consumer is given direct connection from the feeders instead the consumers connected to the distributors through their service mains. Feeder feeds the power from one place to another place through 3φ, 3wire system as there is no neutral point, not possible to connect load directly to the feeder, whereas distributor distributes power from three phase 4 wire system 1φ aswell as 3φ loads can be connected to the distributor connection is in delta-star. Loads are connected to the distributor through service mains. Service mains are nothing but current carrying conductors connected between the meter board of the customer and the distributor taping point.

The Power Triangle

The total power requirement of a load is madeup of two components: namely, the resistive part and reactive part. The Resistive portion of a load cannot be added directly to the Reactive component since it is essentially 90° out of phase with the other. The pure resistive power is known as the watt, while the reactive power is referred to as the reactive volt amperes.

To compute the total volt ampere load it is necessary to analyze the Power triangle indicated below.

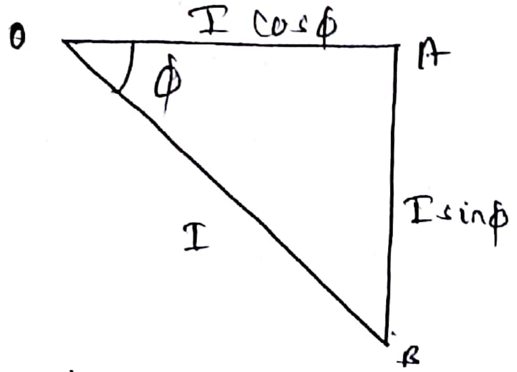


Fig ① Current triangle

I cosφ :- Active Component of current i.e. Current flowing through resistance

I sinφ :- Reactive Component of Current i.e current flowing through reactance of the ckt

I → Total current flowing through resistance & inductance of the circuit

φ → is the angle between active component of current and total current.

The analysis of power factor can also be made in terms of power drawn by the A.C. circuit. If each side of the current triangle OAB of fig ① is multiplied by voltage 'V' then we get the power triangle OAB shown in fig ②, where

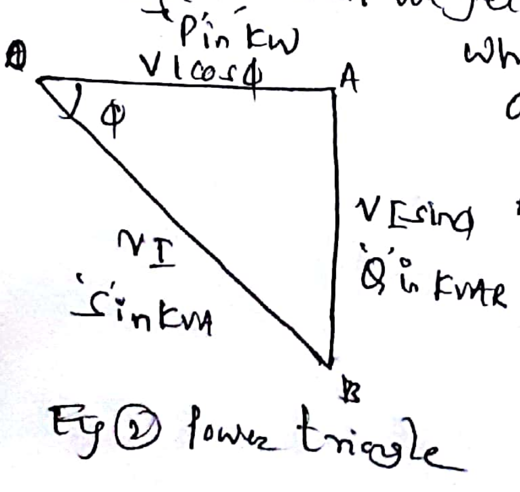


Fig ② Power triangle

OA = VI cosφ and represents the active power in watts or kW

AB = VI sinφ and represents the reactive power in VAR or kVAR

OB = VI and represents the apparent power in VA or kVA.

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The following points may be noted from the power triangle

i) The apparent power in an A.C circuit has two components viz, active and reactive power at right angles to each other. $OB^2 = OA^2 + AB^2$

$$(\text{Apparent Power})^2 = (\text{Active power})^2 + (\text{Reactive power})^2$$

$$(KVA)^2 = (KW)^2 + (KVAR)^2$$

ii) Power factor $\cos\phi = \frac{OA}{OB} = \frac{\text{Active Power}}{\text{Apparent Power}} = \frac{KW}{KVA}$

Thus the power factor of circuit may also be defined as the ratio of active power to the apparent power.

iii) The lagging reactive power is responsible for the low power factor. It is clear from the power triangle that smaller the reactive power component, the higher is the power factor of the circuit.

$$KVAR = KVA \sin\phi = \frac{KW}{\cos\phi} \sin\phi = KW \tan\phi$$

In an AC circuit, if the current drawn lags behind the voltage, the reactive power drawn is known as lagging reactive power. However, if the circuit's current leads the voltage, the reactive power is known as leading reactive power.

iv) For leading currents, the power triangle becomes reversed. If a device taking leading reactive power (e.g Capacitor) is connected in parallel with the load, then the lagging reactive power of the load will be partly neutralized, thus improving the power factor of the load.

v) The power factor of a circuit can be defined in one of the following three ways

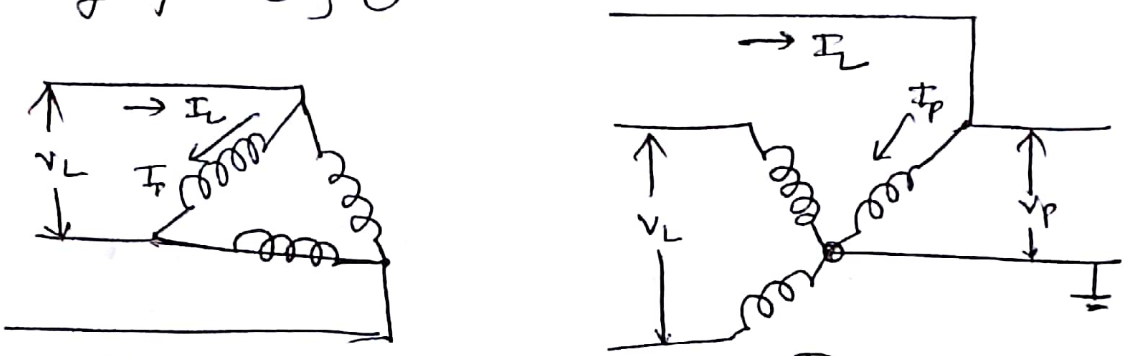
i) Power factor = $\cos\phi$ = Cosine of the angle b/w V & I

ii) P.f = R/Z = Resistance/Impedance

iii) P.f = $\frac{VI\cos\phi}{VI}$ = Active Power / Apparent Power.

The reactive power is neither consumed in the ckt nor does it any useful work. It merely flows back and forth in both direction in the ckt. A wattmeter does not measure reactive power.

The windings of transformers and motors are usually connected in a star or delta configuration. The relationship for line and phase voltages and currents are illustrated by fig 3 (a) & (b)



$I_L = \sqrt{3} I_P$

$V_L = V_P$

$I_L = I_P$ $\quad V_L = \sqrt{3} V_P$

Fig 3 (a) Delta connected wdg (b) star connected wdg.

For a Balanced 3ϕ load.

Power $P = \sqrt{3} V_L I_L \cos\phi$

Watts = Voltamperes × Power factor.

For a balanced 1ϕ load.

$P = VI\cos\phi$.

The primary wdg of 11KV/400V Secondary distribution transformer is usually Delta connected with the Secondary Star connected.

Motor Horse Power

The standard power rating of a motor is referred to as Horse power. In order to relate the motor horsepower to kilowatt (kW) multiply the horse power by 0.746 (conversion factor) and divide by the motor efficiency and power factor.

$$kW = \frac{HP \times 0.746}{\eta \times \cos\phi}$$

where HP = Motor Horse power

η = Efficiency &

$\cos\phi$ = Power factor.

Motor efficiency and power factors vary with load. Typical values are shown in table below. Values are based on totally enclosed fan cooled motors (TEFC) running at 1800rpm 'T' frame.

H.P Range	3-30	40-100
Efficiency at		
1/2 load	82.3	89.2
3/4th load	85.8	90.7
Full load	86.2	90.9
Power factor at		
1/2 load	70.1	79.2
3/4th load	79.2	85.4
Full load	83.8	87.4

Power flow Concept

Power flowing is analogous to water flowing in a pipe. To supply several small water users a large pipe services the plant at a high pressure, several branches from the the main pipe service, various loads pressure reducing the pressure reducing station reduce the main pressure to meet the requirements of each user similarly large feeder at a high voltage services a plant through switchgear, breaker the main feeder is distributed into smaller feeders. Transformers are used to lower the voltage to the nominal value needed by the user.

Plant Energy performance (PEP)

* Amount of output per unit of Energy

Plant Energy performance is the measure of whether a plant is now using more or less energy to manufacture its products than it did in the past, a measure of how well the Energy management programme is doing. It compares the Change in Energy Consumption from one year to the other considering production output. PEP monitoring compares plant Energy use at a reference year with the subsequent years to determine the improvement that has been made. However, a plant production output may vary from year to year and the output has a significant bearing on plant Energy use. For a meaningful comparison, it is necessary to determine the energy that would have been required to produce three year production output if the plant had operated in the same way as it did during the reference year. This collected value can then be compared with the actual value to determine the improve or deterioration that has taken place since the reference year.

Production factor

Production factor is used to determine the energy that would have been required to produce this year's production output if the plant had operated in the same way as it did in the reference year. It is defined as

$$\text{Production factor} = \frac{\text{Current Years production}}{\text{Reference year Production}}$$

The reference year's energy use that would have been used to produce the current year's production output may be called the "reference year energy use equivalent" or "Reference year equivalent" for short.

Reference year equivalent = Reference years energy use X production factor

The improvement or deterioration from the reference year is called "Energy performance" and is a measure of the plants energy management progress. It is the reduction or increase in the current years energy use over the reference and is calculated by subtracting the current years energy use from the reference year's equivalent. the result is divided by the reference year equivalent and multiplied by the 100 to obtain a percentage.

$$\text{Plant Energy performance} = \frac{\text{Reference year equivalent} - \text{Current years energy}}{\text{Reference year equivalent}} \times 100$$

The Energy performance is the percentage of Energy saved at the current rate of use compared to the reference year rate of use. the greater the improvement, the higher the number will be

Matching Energy usage to requirement

Mismatch between equipment capacity and user requirement often leads to inefficiencies due to part load operations, wastages etc. Following are some examples for matching of energy equipment capacity to end use needs based on energy managers mandate for optimization

1) Eliminate throughtling of a pump by impeller trimming, resizing pump, installing variable speed drives.
2) Pulley diameter modification for belt drive, fan resizing for better efficiency.
3) Moderation of chilled water temperature for process chilling needs
4) Recovery of energy lost in control valve pressure drops
5) Adoptation of task lighting in place of less effective area lighting

Maximizing system efficiency:

Once the energy usage and sources are matched properly, the next step is to operate the equipment efficiently through best practices in operation and maintenance. Some examples in the context are

1) Eliminate steam leakages by trap improvements
2) Replace pumps, fans, air compressor refrigeration compressors, boilers, furnaces and heaters and other energy conservation equipment wherever significant energy efficiency margins exist.
3) Adopt combustion controls for maximizing combustion efficiency.

Optimizing input energy requirement:

1) Optimization of transformer operation with respect to load
2) Periodic review of insulation thickness
3) Identify potential for heat exchanger networking and process integration

Fuel and Energy Substitution :

Energy is an important input in the production. There are two ways to reduce energy dependency; Energy Conservation and Substitution. Substituting existing fossil fuel with more efficient and less cost, less polluting fuel such as natural gas, biogas and locally available agro residues. Natural gas is used as fuel in the fertilizer, petrochemicals, power and iron industries. In some of the industries coal is replaced by coconut shells and rice husk.

Few examples of Energy substitution are

i) Replacement of electric heaters by steam heaters

ii) Replacement of steam based hot water by solar systems

Unit 5 & 6

Electrical Equipment and Power factor

Power factor:

The cosine of angle between voltage and current in an a.c circuit is known as power factor. If the circuit is inductive, the current lags behind the voltage and the power factor is referred to as lagging. However in a capacitive circuit, current leads the voltage and power factor is said to be leading. In case of resistive circuit current is in phase with applied voltage and hence power factor is unity.

Causes of low power factor

Low P.f is undesirable from economic point of view. Normally, the P.f of the whole load on the supply system is less than 0.8. The followings are the causes of low P.f.

i) Most of the A.C Motors are of inductive type (1ϕ or 3ϕ I.M) which have low lagging P.f. The 3ϕ I.M work at a P.f which is extremely small on light load (0.2 to 0.3) and rises to around 0.8 lagging at full load and P.f of 1ϕ I.M are about 0.6 lag at full lo.

ii) Transformers draw a magnetizing current from the line. This current lags the voltage at an angle 90°

iii) Arc lamps, electric discharge lamps and industrial heating furnaces, welding equipment operate at low lagging P.f

iv) The load on the power system is varying, being high during morning and evening and low at other times. During low load period, supply voltages are increased which increases the magnetizing current. This results in the decreased power factor

v) The power factor at which motors operate falls due to improper maintenance and repairs of motors. In repaired motors, less wire is sometimes used than originally wound motors, therefore, in such motors leakage of magnetic flux increases and power factor of the motor decreases

Dis-advantages of Low Power factor

A power factor less than unity result in the following dis-advantages

i) **Large KVA rating of equipment:**

The electrical machinery (e.g. Alternators, transformers & Switchgear) is always rated in KVA. Now KVA = KW/cos φ

It is clear that KVA rating of the equipment is inversely proportional to P.f the smaller the P.f, the larger is the KVA rating. Therefore, at low P.f, the KVA rating of the equipment (size of the equipment) has to be made large, making the equipment larger and expensive

ii) **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 P.f. This necessitates large conductor size. Cost of conductor required for transmission and distribution will increases

iii) **Large Copper losses:** the large current at low lagging P.f. causes more I^2R losses in all the elements of the supply system. This results in poor efficiency

iv) **Poor Voltage regulation:** the large current at low lagging P.f causes greater voltage drops in alternators, transformers and transmission line and distributors. this results in decreased voltage available at the receiving end thus voltage regulation is more, poor voltage at the receiving end impairing the performance of utilization devices. According to BIS the voltage regulation should not vary + or − 5%.

v) **Reduced handling capacity of system:** the low lagging P.f. reduces the Power handling capacity of all the elements of the power system. It is because the reactive component of current prevents the full utilization of installed capacity. Therefore active power supplied by alternator and transformer reduces.

The average power factors of some of the common appliances are given below

Type of load	Power factor
Incandescent lamp	0.98 - 1.0
Flourescent lamps	0.6 - 0.8
Neon lamps used for advertisements	0.4 - 0.5
Arc lamps used in cinemas	0.3 - 0.7
Fans	0.5 - 0.8
Induction motors	0.5 - 0.85
Fractional KW motors	0.4 - 0.75
Induction heaters	0.85
Resistance furnaces	0.6 - 0.9
Arc "	0.85
Induction "	0.6
Arc welders	0.3 - 0.4
Resistance welders	0.4 - 0.75

vi) In case of heavily worn-out bearings, the rotor may catch at the stator.
Some metal is sometimes removed from the rotor by turning instead of replacing the defective bearing. In doing so, the length of airgap between stator and rotor increase due to which greater magnetizing current is required and, therefore, power factor drops.

Power factor Improvement Equipment

Normally, the power factor of the whole load on a large generating station is in the region of 0.8 to 0.9. However, Sometimes it is lower and in such cases it is generally desirable to take special steps to improve the power factor. This can be achieved by the following equipment

1) Static capacitors

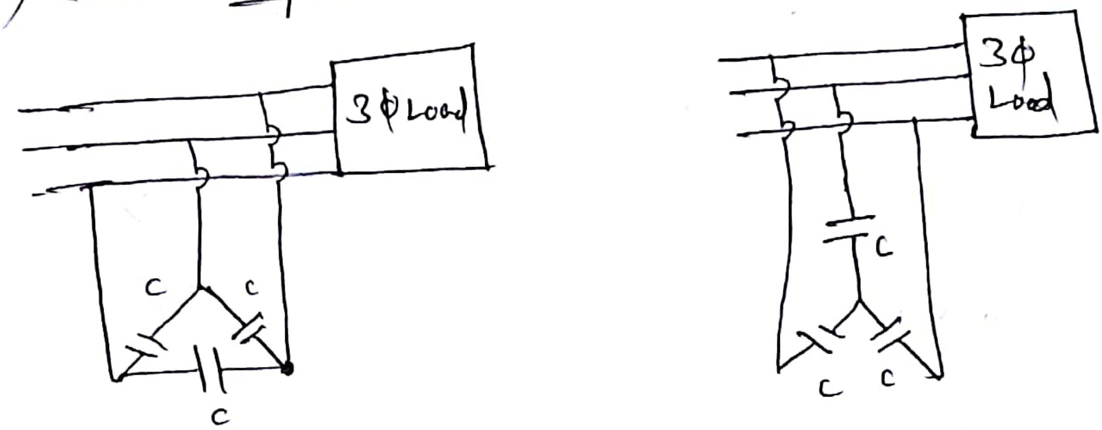


Fig ① Delta and star connected capacitor.

The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor. The capacitor (generally known as static capacitor) draws a leading current and partly or completely neutralises the lagging reactive component of load current. This raises the power factor of the load. For 3 φ loads, Capacitors can be connected in delta or star as shown in fig ①. Static capacitors are invariably used for power factor improvement in factories.

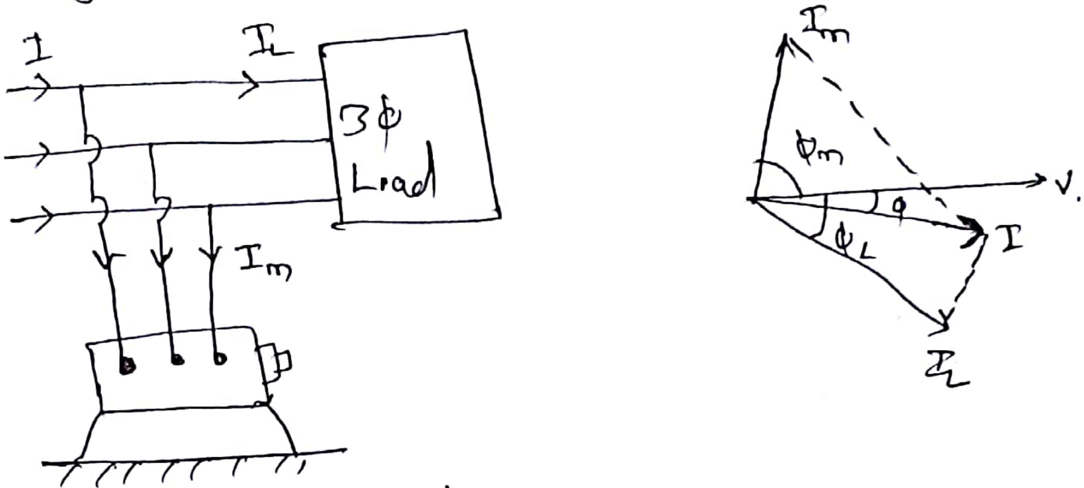
Advantages:

1) They have low losses
2) They require little maintenance as there are no rotating parts
3) They can be easily installed as they are light & require no foundation

Dis-advantages:

1) They have short service life ranging from 8 to 10yrs.
2) They are easily damaged if the voltage exceeds the rated value
3) Once the capacitors are damaged, their repair is uneconomical.

2) Synchronous Condenser



3φ synchronous motor

Fig ②

A synchronous motor takes a leading current when over-excited and therefore behaves as a capacitor. An over-excited synchronous motor running on no load is known as synchronous condenser. When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralises the lagging reactive component of the load. Thus the power factor is improved.

Fig ② shows the power factor improvement by synchronous condenser method. The 3φ load takes current I_L at low lagging power factor $\cos\phi_L$. The synchronous condenser takes a current I_m which leads the voltage by an angle ϕ_m. The resultant current I is the phasor sum of I_m & I_L and lags behind the voltage by an angle ϕ. It is clear that ϕ is less than ϕ_L so that $\cos\phi$ is greater than $\cos\phi_L$. Thus the power factor is increased from $\cos\phi_L$ to $\cos\phi$. Synchronous condensers are generally used at major bulk supply substations for power factor improvement.

Advantages :

1) By varying the field excitation the magnitude of current drawn by the motor can be changed by an amount. This helps in achieving stepless control of power factor
2) The motor windings have high thermal stability to short circuit currents
3) The faults can be removed easily

Disadvantages

1) There are considerable losses in the motor
2) The maintenance cost is high
3) It produces noise
4) Except in sizes above 500 kVA, the cost is greater than that of static capacitors of the same rating
5) As a synchronous motor has no self starting torque, therefore, an auxiliary equipment has to be provided for this purpose.

Note :

The reactive power taken by a synchronous motor depends upon two factors, the d.c field excitation and the mechanical load delivered by the motor. Maximum leading power is taken by a synchronous motor with maximum excitation and zero load.

3) Phase Advancers :

Phase advancers are used to improve the power factor of induction motors. The low power factor of an induction motor is due to the fact that its stator winding draws exciting current which lags behind the supply voltage by 90°. If the exciting ampere turns can be provided from some other a.c source, then the stator winding will be relieved of exciting current and the power factor of the motor can be improved. This job is accomplished by the phase advancer which is simply an a.c exciter. The phase advancer is mounted on the same shaft as the main motor and is connected in the rotor circuit of the motor. It provides exciting ampere turns to the rotor circuit at slip frequency. By providing more ampere turns than required, the induction motor can be made to operate on leading power factor like an over-excited synchronous motor.

Phase advancers have two principal advantages. Firstly, as the exciting ampere turns are supplied at slip frequency, therefore, lagging KVAR drawn by the motor are considerably reduced.

Secondly, phase advancer can be conveniently used where the use of synchronous motors is unadmissible.

However, the major disadvantage of phase advancers is that they are not economical for motors below 200 H.P.

Calculations of Power Factor Correction

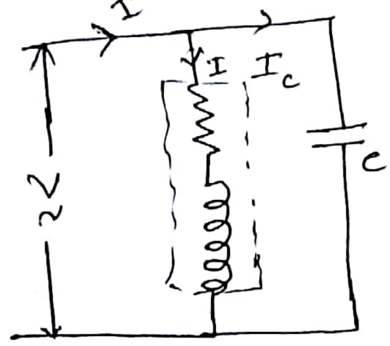


Fig (a)

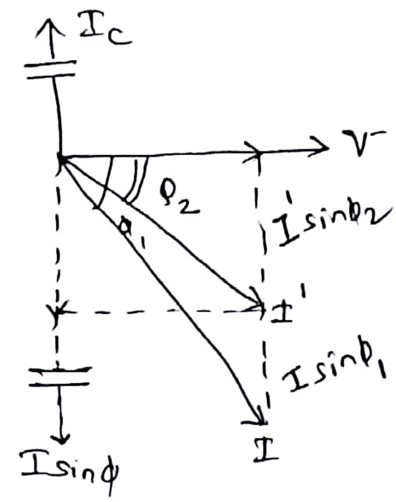


Fig (b)

Consider an inductive load taking a lagging current I at a power factor $\cos\phi_1$. In order to improve the P.f of this circuit, the remedy is to connect such an equipment in parallel with the load which takes a leading reactive component and partly cancels the lagging reactive component of the load. Fig (a) shows a capacitor connected across the load. The capacitor takes a current I_c which leads the supply voltage V by $90°$. The current I_c partly cancels the lagging reactive component of the load current as shown in the phasor diagram in fig (b). The resultant circuit current becomes I' and its angle of lag is ϕ_2. It is clear that ϕ_2 is less than ϕ_1 so that new P.f $\cos\phi_2$ is more than the previous P.f $\cos\phi_1$.

From the phasor diagram, it is clear that after P.f. correction, the lagging reactive component of the load is reduced to $I'\sin\phi_2$

Obviously $I'\sin\phi_2 = I\sin\phi_1 - I_c$

$$I_c = I\sin\phi_1 - I'\sin\phi_2$$

$\therefore$ Capacitance of Capacitor to improve P.f from $\cos\phi_1$ to $\cos\phi_2$ $= \frac{I_c}{\omega V}$ $\left(\because X_c = \frac{V}{I_c} = \frac{1}{\omega C}\right)$

$I_c = V\omega C$

$\therefore C = \frac{I_c}{\omega V}$

Power Triangle

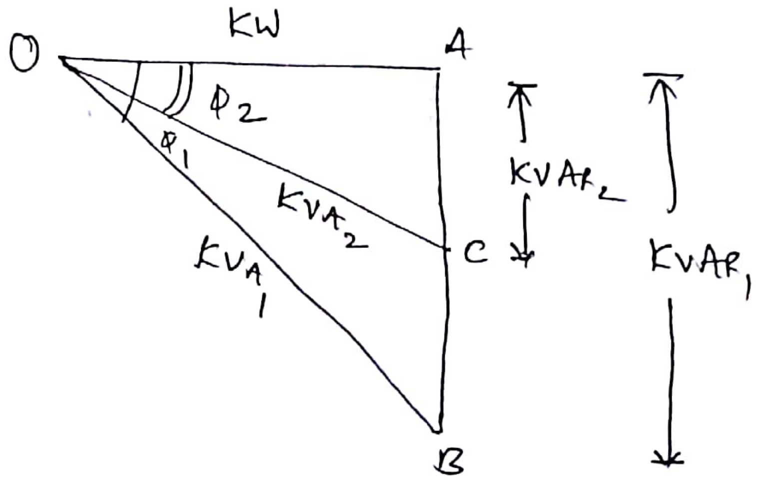


Fig ©

The power factor correction can also be illustrated from power triangle. Thus referring to fig ©, the power triangle OAB is for the power factor $\cos\phi_1$, whereas power triangle OAC is for the improved power factor $\cos\phi_2$. It may be seen that active power (OA) does not change with power factor improvement. However, the lagging KVAR of the load is reduced by the P.f correction equipment, thus improving the P.f to $\cos\phi_2$

Leading KVAR supplied by P.f. correction equipment

$= BC$

$= AB - AC$

$= KVAR_1 - KVAR_2$

$= OA(\tan\phi_1 - \tan\phi_2)$

$= KW(\tan\phi_1 - \tan\phi_2)$

$\sin\theta = \frac{KVAR}{KVA}$

$\cos\theta = \frac{KW}{KVA}$

$KVAR = KVA\sin\phi$

$= \frac{KW}{\cos\phi}\sin\phi$

$= KW\tan\phi$

Knowing the leading KVAR supplied by the P.f. correction equipment, the desired results can be obtained.

Ex: 1) An alternator is supplying a load of 300 kW at a p.f of 0.6 lagging. If the p.f is raised to unity, how many more kilowatts can alternator supply for the same kVA loading? Comment on the result obtained

Soln

$$KVA = \frac{KW}{\cos\phi} = \frac{300}{0.6} = 500\ KVA$$

KW at 0.6 p.f = 300 kW

∴ Increased power supplied by the alternator

= 500 − 300 = 200 kW

Note the importance of p.f improvement. When the p.f of the alternator is unity, the 500 kVA are also 500 kW and the engine driving the alternator has to be capable of developing this power together with the losses in the alternator. But when the p.f of the load is 0.6, the power is only 300 kW. Therefore, the engine is developing only 300 kW, though the alternator is supplying its rated output of 500 kVA.

2) A single phase motor connected to 400V, 50 Hz supply takes 31.7A at a p.f of 0.7 lagging. Calculate the capacitance required in parallel with the motor to raise the p.f to 0.9 lagging.

Soln

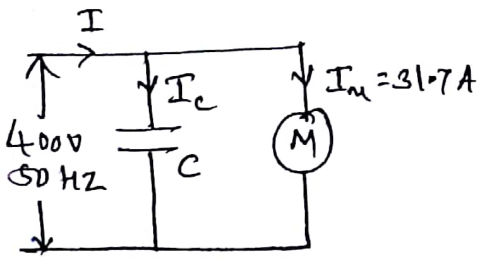


Fig ①

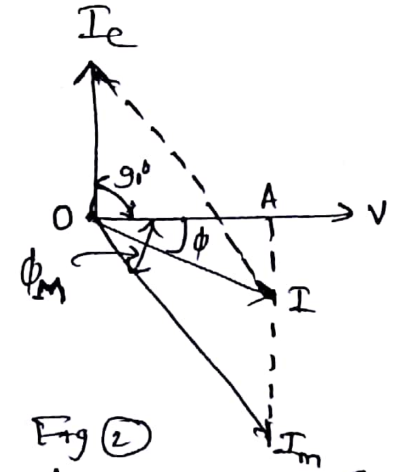


Fig ②

The circuit and phasor diagrams are shown in fig ① & ② respectively. Here motor 'M' is taking a current I_M of 31.7A. The current I_c taken by the capacitor must be such that

When combined with I_M, the resultant current, I lags the voltage by an angle ϕ where $\cos\phi = 0.9$.

Referring to the phasor diagram in fig ②

Active component of $I_M = I_M \cos\phi_M = 31.7 \times 0.7$
$= 22.19\,A$

Active component of $I = I\cos\phi$
$= I \times 0.9$

These components are represented by OA in fig ②

$$I = \frac{22.19}{0.9} = 24.65\,A \qquad (\because I = I_M)$$

Reactive component of $I_M = I_M \sin\phi_M$
$= 31.7 \times 0.714 \quad \left(\because \sin\phi_M = \sqrt{1-\cos^2\phi_M} = \sqrt{1-0.7^2} = 0.714\right)$
$= 22.6\,A$

Reactive component of $I = I\sin\phi$
$= 24.65\sqrt{1-(0.9)^2}$
$= 24.65 \times 0.436$
$= 10.75\,A$

It is clear from fig ② that,

I_C = Reactive component of I_M − Reactive component of I

$= 22.6 - 10.75 = 11.85\,A$

But $I_C = \frac{V}{X_C} = V \times 2\pi f C$

$11.85 = 400 \times 2\pi \times 50 \times C$

$\therefore C = 94.3 \times 10^{-6}\,F$

$\therefore$ $\boxed{C = 94.3\,\mu F}$

Note the effect of connecting a $94.3\,\mu F$ capacitor in parallel with the motor. The current taken from the supply is reduced from 31.7A to 24.65A without altering the current or power taken by the motor, This enables an economy to be affected in the size of* generating plant & in the X-sectional area of the conductors.

Ex: 3) A 3ϕ, 50 Hz 400V motor develops 200 H.P (149.2 kW) the power factor being 0.75 lagging and efficiency 90%. A bank of capacitors is connected in delta across the supply terminals and power factor raised to 0.95 lagging. Each of the capacitance units is built of 4 similar 100V capacitors. Determine the capacitance of each capacitor.

Soln

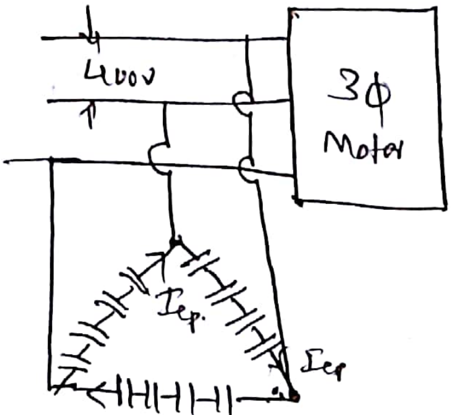


Fig ①

Original P.f $\cos\phi_1 = 0.75$ lagging

Final P.f $\cos\phi_2 = 0.95$ lag

Motor input $P = \frac{O/P}{\eta} = \frac{149.2 \times 10^3}{0.9} = 165.77\,kW$

$\phi_1 = \cos^{-1}(0.75) = 41.41°$

$\tan\phi_1 = \tan 41.41° = 0.8819$

$\phi_2 = \cos^{-1}(0.95) = 18.19°$

$\tan\phi_2 = \tan 18.19° = 0.3286$

Leading KVAR taken by the condenser bank $= P(\tan\phi_1 - \tan\phi_2)$

$= 165.77(0.8819 - 0.3286) = 91.72$ KVAR

Leading KVAR taken by each of three sets $= \frac{91.72}{3} = 30.57$ KVAR — ①

Fig ① shows the delta connected condenser bank. Let C farad be the capacitance of 4 capacitors in each phase

phase current of capacitor is

$I_{cp} = V_{ph}/X_c = 2\pi f C V_{ph}$

$= 2\pi \times 50 \times C \times 400 = 125663.7C$ amper.

$KVAR/phase = \frac{V_{ph} I_{cp}}{1000} = \frac{400 \times 125663.7\,C}{1000}$

$= 50265.48\,C$ — ②

Equating expressions ① & ② we get

$30.57 = 50265.48C$

$\therefore C = 608.17 \times 10^{-6}$ farad

$= 608.17 \mu F$

Since it is combined capacitance of four equal capacitors joined in series.

$\therefore$ Capacitance of each capacitor $= 4 \times 608.17 \mu F$

$= 2432.68 \mu F$

Ex: A 3ϕ, 5 kW induction motor has a p.f. of 0.75 lagging. A bank of capacitors is connected in delta across the supply terminals and p.f raised to 0.9 lagging. Determine the KVAR rating of the capacitors connected in each phase.

Sol: Original p.f $\cos\phi_1 = 0.75$ lag Final p.f $\cos\phi_2 = 0.9$ lag

Motor input = 5 kW, Efficiency $\eta = 100\%$ (assumed)

$\phi_1 = \cos^{-1}(0.75) = 41.41^\circ$ $\phi_2 = \cos^{-1}(0.9) = 25.84^\circ$

Leading KVAR taken by the condenser bank

$= P(\tan\phi_1 - \tan\phi_2)$

$\therefore \tan\phi_1 = \tan(41.41^\circ) = 0.8819$

$\tan\phi_2 = \tan(25.84^\circ) = 0.4843$

$\therefore = 5(0.8819 - 0.4843)$

$= 1.99$ KVAR

$\therefore$ Rating of capacitors connected in each phase

$= 1.99/3 = 0.663$ KVAR

Ex 4) A single phase a-c generator supplies the following loads

i) Lighting load of 20 kW at unity power factor

ii) Induction motor load of 100 kW at p.f 0.707 lagging

iii) Synchronous motor load of 50 kW at p.f 0.9 leading

Calculate the total kW and kVA delivered by the generator and the power factor at which it works.

Sol: Using the suffixes 1, 2, and 3 to indicate the different loads, we have

$$kVA_1 = \frac{kW_1}{\cos\phi_1} = \frac{20}{1} = 20\ kVA$$

$$kVA_2 = \frac{kW_2}{\cos\phi_2} = \frac{100}{0.707} = 141.4\ kVA$$

$$kVA_3 = \frac{kW_3}{\cos\phi_3} = \frac{50}{0.9} = 55.6\ kVA$$

These loads are represented in fig ①. The three kVA's are not in phase. In order to find the total kVA, we resolve each kVA into rectangular components – kW and kVAR as shown in fig ①. The total kW and kVAR may then be combined to obtain total kVA

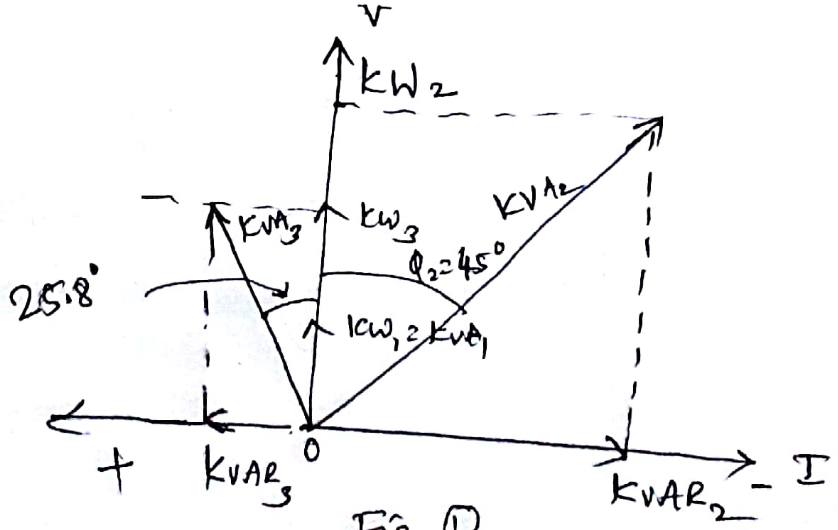


Fig ①

$KVAR_1 = KVA_1 \sin\phi_1 = 20 \times 0 = 0$

$KVAR_2 = KVA_2 \sin\phi_2 = -141.4 \times 0.707 = -100$ KVAR

$KVAR_3 = KVA_3 \sin\phi_3 = +55.6 \times 0.436 = +24.3$ KVAR

Note that $KVAR_2$ and $KVAR_3$ are in opposite directions. $KVAR_2$ being a lagging while $KVAR_3$ being a leading KVAR.

Total KW = 20 + 100 + 50 = 170 KW

Total KVAR = 0 − 100 + 24.3

= −75.7 KVAR

$$\text{Total KVA} = \sqrt{(KW)^2 + (KVAR)^2}$$

$$= \sqrt{(170)^2 + (75.7)^2}$$

= 186 KVA

$$\text{Power factor} = \frac{\text{Total KW}}{\text{Total KVA}}$$

$$= \frac{170}{186}$$

= 0.914 lagging

The power factor must be lagging since the resultant KVAR is lagging

Advantages of High Power factor

Installation of P.f improvement device to raise the P.f results in the following advantages

1) Reduces the transmission and distribution line losses
2) Improves the voltage regulation of the line
3) Reduction in circuit current
4) Increases the voltage level at load
5) Reduction in KVA demand charges for large consumers
6) Avoids the L.P.f penalty to the HT consumer.
7) Performance of devices connected to the supply will increase.

Power factor Improvement (Importance)

The improvement of powerfactor is very important for both consumers and generating stations as discussed below

i) For consumers: A consumer has to pay electricity charges for his maximum demand in KVA plus the units consumed. If the consumer improves the powerfactor, then there is a reduction in his maximum KVA demand and consequently there will be annual saving due to maximum demand charges. Although P.f improvement involves extra annual expenditure on account of P.f correction equipment, yet improvement of P.f to a proper value results in the net annual saving for the consumer.

ii) For generating stations: A generating station is as much concerned with P.f. improvement as the consumer. The generators in a power station are rated in KVA but the useful output depends upon KW output. As station output is $KW = KVA \times \cos\phi$, therefore, number of units supplied by it depends upon the power factor. The greater the P.f. of the generating station, the higher is the KWh it delivers to the system. This leads to the conclusion that improved P.f increases the earning capacity of the power station.

Most Economical Power Factor

If a consumer improves the power factor, there is reduction in his maximum KVA demand and hence there will be annual saving over the maximum demand charges. However, when power factor is improved, it involves capital investment on the power factor correction equipment. The consumer will incur expenditure every year in the shape of annual interest and depreciation on the investment made over the P.f correction equipment. Therefore the net annual saving will be equal to the annual saving in maximum demand charges minus annual expenditure incurred on P.f. correction equipment.

The value to which the power factor should be improved so as to have maximum net annual saving is known as the most economical power factor.

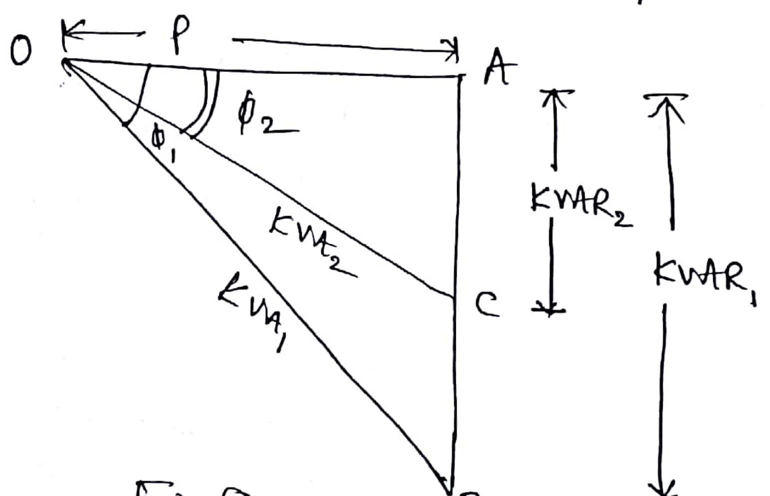


Fig ①

Consider a consumer taking a peak load of 'P' KW at a p.f of $\cos\phi_1$ and charged at a rate of Rs 'x' per kVA of maximum demand per annum. Suppose the consumer improves the P.f to $\cos\phi_2$ by installing P.f correction equipment. Let expenditure incurred on the P.f. correction equipment be Rs 'y' per KVAR per annum. The power triangle at the original P.f. $\cos\phi_1$ is OAB and for the improved P.f. $\cos\phi_2$, it is OAC (Ref fig ①)

KVA max. demand at $\cos\phi_1$, $KVA_1 = P/\cos\phi_1 = P\sec\phi_1$

KVA max. demand at $\cos\phi_2$, $KVA_2 = P/\cos\phi_2 = P\sec\phi_2$

Annual saving in maximum demand charges

$$= Rs\ x\,(KVA_1 - KVA_2)$$

$$= Rs\ x\,(P\sec\phi_1 - P\sec\phi_2)$$

$$= Rs\ xP\,(\sec\phi_1 - \sec\phi_2) \quad \text{---} \ (1)$$

Reactive power at $\cos\phi_1$, $KVAR_1 = P\tan\phi_1$

Reactive power at $\cos\phi_2$, $KVAR_2 = P\tan\phi_2$

Leading KVAR taken by P.f correction equipment

$$= P\,(\tan\phi_1 - \tan\phi_2)$$

Annual cost of P.f. correction equipment

$$= Rs\ Py\,(\tan\phi_1 - \tan\phi_2) \quad \text{---} \ (2)$$

Net annual saving $S = \exp(1) - \exp(2)$

$$= xP(\sec\phi_1 - \sec\phi_2) - yP(\tan\phi_1 - \tan\phi_2)$$

In this expression, only ϕ_2 is variable while all other quantities are fixed. Therefore, the net annual saving will be maximum if differentiation of above expression w.r.t ϕ_2 is zero. i.e. $\frac{d}{d\phi_2}(S) = 0$

or $$\frac{d}{d\phi_2}\left[xP(\sec\phi_1 - \sec\phi_2) - yP(\tan\phi_1 - \tan\phi_2)\right] = 0$$

or $$\frac{d}{d\phi_2}(xP\sec\phi_1) - \frac{d}{d\phi_2}(xP\sec\phi_2) - \frac{d}{d\phi_2}(yP\tan\phi_1) + yP\frac{d}{d\phi_2}(\tan\phi_2) = 0$$

or $$0 - xP\sec\phi_2\tan\phi_2 - 0 + yP\sec^2\phi_2 = 0 \qquad \div \sec\phi_2$$

$$-x\tan\phi_2 + y\sec\phi_2 = 0$$

$$\tan\phi_2 = y/x\ \sec\phi_2$$

$$\sin\phi_2 = y/x$$

Most economical P.f. $\cos\phi_2 = \sqrt{1 - \sin^2\phi_2} = \sqrt{1 - (y/x)^2}$

It may be noted that the most economical P.f ($\cos\phi_2$) depends upon the relative costs of supply & P.f correction equipment but is independent of the original P.f $\cos\phi_1$.

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Ex : 5) The monthly readings of a consumer's meter are as follows
July 2014 Maximum demand = 50 kW, Energy consumed = 36,000 kWh
Reactive energy = 23 400 KVAR. If the tariff is Rs 100 per
June 2014 kW of maximum demand plus 6 paise per unit plus 0.5 paise per units for each 1% of power factor below 86%, calculate the monthly bill of the consumer.

Sol

Monthly bill = M.D charges + Energy charges + P.f surcharge

$$\text{Average load} = \frac{36000}{24 \times 30} = 50 \text{ kW}$$

$$\text{Average reactive power} = \frac{23400}{24 \times 30} = 32.5 \text{ KVAR}$$

Suppose ϕ is the Power factor angle

$$\therefore \tan\phi = \frac{\text{KVAR}}{\text{Active power}} = \frac{32.5}{50} = 0.65$$

$$\therefore \phi = \tan^{-1}(0.65) = 33.02^\circ$$

$$\therefore \text{Power factor } \cos\phi = \cos(33.02^\circ) = 0.8384$$

Power factor surcharge =

$$Rs \frac{36000 \times 0.5}{100}(86 - 83.84)$$

$$= Rs\ 388.8$$

$$\therefore \text{Monthly bill} = Rs(100 \times 50 + 0.06 \times 36000 + 388.8)$$

$$= Rs\ 7548.8$$

Ex: 6) A factory has a maximum Load of 240 kW at 0.7 pf lagging with an annual consumption of 50,000 Units. the tariff is Rs 50 per kVA of maximum demand plus 10 paise per unit. calculate the flat rate of energy consumption. What will be the annual saving if P.f is raised to unity?

June 2015

Sol: Maximum demand in kVA at a P.F of 0.7

$$= \frac{240}{0.7} = 342.857 \text{ kVA}$$

∴ Annual bill = Demand charges + Energy charges

= Rs (50 × 342.857) + (0.1 × 50,000)

= Rs 22142.85

∴ Flat rate/unit = Rs $\frac{22142.85}{50,000}$

= Rs 0.4428

= 44.28 paise

When P.F raised to unity the Maximum demand in kVA

$$= \frac{240}{1} = 240 \text{ kVA}$$

Annual bill = Rs (50 × 240) + (0.1 × 50,000)

= Rs 17,000

Annual Saving = Rs (22142.85 − 17000)

= Rs 5142.85

Ex: 7) An industrial load takes 80,000 units in a year, the average power factor being 0.707 lagging. The recorded maximum demand is 500 kVA. The tariff is Rs 120 per kVA of maximum demand plus 2.5 paise per kWh. Calculate the annual cost of supply and find out the annual saving in cost by installing phase advancing plant costing Rs 50 per kVAR which raises the p.f from 0.707 to 0.9 lagging. Allow 10% per year on the cost of phase advancing plant to cover all additional costs.

Soln Energy consumed / year = 80,000 kWh

Maximum kVA demand = 500

Annual cost of supply = MD charges + Energy charges

= Rs (120 × 500 + 0.025 × 80,000)

= Rs (60,000 + 2000)

= Rs 62,000

$\cos\phi_1 = 0.707$ lag, $\cos\phi_2 = 0.9$ lag

Maximum kW demand at 0.707 p.f, $P = 500 \times 0.707 = 353.5$ kW

Leading kVAR taken by phase advancing equipment

$= P[\tan\phi_1 - \tan\phi_2]$

$= 353.5 [\tan(\cos^{-1} 0.707) - \tan(\cos^{-1} 0.9)]$

$= 353.3 [1 - 0.484] = 182.3$ kVAR

Annual cost of phase advancing equipment

= Rs 182.3 × 50 × 0.1 = Rs 912

When p.f is raised from 0.707 lag to 0.9 lag, new maximum kVA demand is $= \frac{353.3}{0.9} = 392.6$ kVA

Reduction in kVA demand = 500 − 392.6 = 107.4

Annual saving in kVA charges = Rs 120 × 107.4 = Rs 12,888

As the units consumed remain the same, therefore saving will be equal to saving in MD charges minus annual cost of phase advancing plant.

∴ Annual saving = Rs (12882 − 912) = Rs 11976

Ex: 8) A factory which has a maximum demand of 175 kW at a power factor of 0.75 lagging is charged at Rs 72 per KVA per annum. If the phase advancing equipment costs Rs 120 per KVAR, find the most economical power factor at which the factory should operate. Interest and depreciation total 10% of the capital investment on the phase advancing equipment.

Sol: Power factor of the factory $\cos\phi_1 = 0.75$ lag

Maximum demand charges $x =$ Rs 72 per kVA per annum

Expenditure on phase advancing equipment

$y =$ Rs 120×0.1

$=$ Rs 12^* / KVAR / annum

$\therefore$ Most economical p.f at which factory should operate is

$$\cos\phi_2 = \sqrt{1-(y/x)^2} = \sqrt{1-\left(\frac{12}{72}\right)^2} = 0.986 \text{ lag.}$$

* The total investment for producing 1 KVAR is Rs 120.
The annual interest and depreciation is 10%.
It means that an expenditure of Rs $120 \times \frac{10}{100} =$ Rs 12 is incurred on 1 KVAR per annum.

Ex 9) A consumer has an average demand of 400 kW at a p.f of 0.8 lagging and annual load factor of 50%. The tariff is Rs 50 per kVA of maximum demand per annum plus 5 paise per kWh. If the power factor is improved to 0.95 lagging by installing phase advancing equipment, calculate
i) the capacity of the phase advancing equipment
ii) The annual saving effected.
The phase advancing equipment costs Rs 100 per kVAR and the annual interest and depreciation together amount to 10%.

Sol:
Max. kW demand $P = 400/0.5 = 800$ kW

Original p.f $\cos\phi_1 = 0.8$ lag   Final p.f $\cos\phi_2 = 0.95$ lag

$\phi_1 = \cos^{-1}(0.8) = 36.9^\circ$ $\tan\phi_1 = \tan 36.9^\circ = 0.75$

$\phi_2 = \cos^{-1}(0.95) = 18.2^\circ$ $\tan\phi_2 = \tan 18.2^\circ = 0.328$

i) Leading kVAR taken by phase advancing equipment
$= P(\tan\phi_1 - \tan\phi_2) = 800(0.75 - 0.328) = 337$ kVAR

∴ Capacity of phase advancing equipment should be 337 kVAR

ii) Max. demand charges, $x =$ Rs 50/kVA/annum
Expenditure on phase advancing equipment
$y =$ Rs $0.1 \times 100 =$ Rs 10/kVAR/annum

Max. kVA demand at 0.8 pf $= 800/0.8 = 1000$ kVA

Max. kVA demand at 0.95 pf $= 800/0.95 = 842$ kVA

Annual saving in maximum demand charges
$=$ Rs $50(1000 - 842) =$ Rs 7900

Annual expenditure on phase advancing equipment
$=$ Rs ($y \times$ capacity of equipment)

$=$ Rs $10 \times 337 = 3370$

∴ Net annual saving $=$ Rs $(7900 - 3370)$
$=$ Rs 4530.

Location of Capacitors

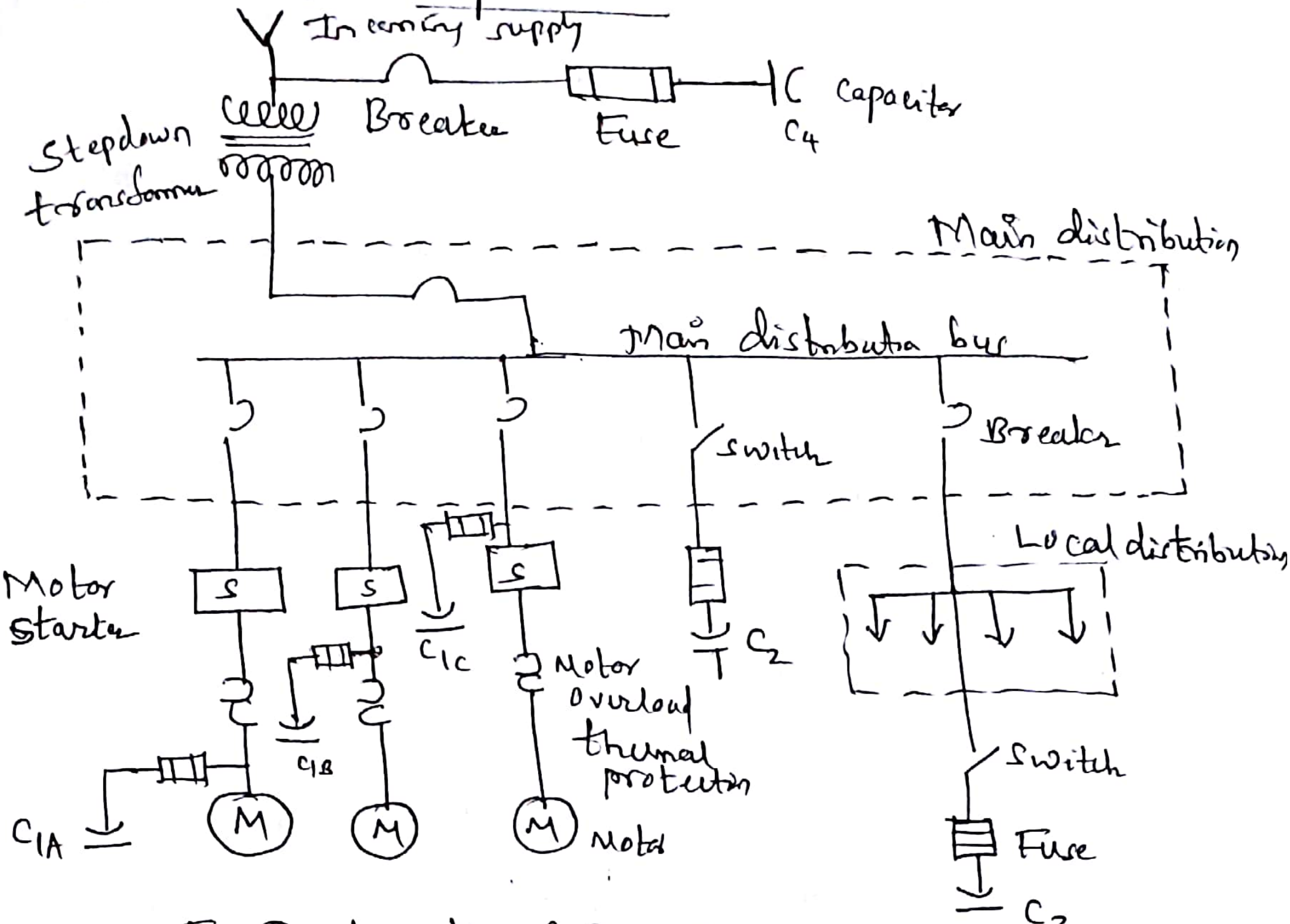

Fig ① Location of Capacitors

The primary purpose of capacitors is to reduce the power consumption, additional benefits are derived by capacitor location. Fig ① 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 C_{1A}, C_{1B} & C_{1C} of fig ① 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 4. C_{1A} is recommended for new installation, since the maximum benefit is derived and the size of the motor thermal protector is reduced. In case of C_{1B} as in case C_{1A}, the capacitor is energized only when the motor is in operation, Case C_{1B} is recommended in cases where the installation is existing and the thermal protector does not need to be resized. In position C_{1C}, the capacitor is permanently connected to the circuit but does not require a separate switch, since it can be disconnected by the breaker before the starter.

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. That is why most motor manufacturers specify maximum capacitor ratings to be applied to specific motors.

The next preference for capacitor locations as indicated in fig (1) is at locations C_2 and C_3. In these locations, a breaker or switch will be required. Location C_4 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.

Capacitors for other Loads

The other types of load requiring capacitor application include induction furnaces, induction heaters and arc welding transformer etc. The capacitors are normally supplied with control gear for the application of induction furnaces and induction heating furnaces. The P.F 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 transformer is corrected by connecting capacitors across the primary winding of the transformer, as the normal PF would be in the range of 0.35.

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Energy Efficient Motors

Standard Motors remain popular because they generally cost less than energy efficient motors. Losses in I.M consist of losses which vary with load and those that are constant whatever the load. The split is about 70% & 30% respectively of full load losses i.e. when a motor is running at full load. The load losses include the rotor resistance loss, the stator resistance losses and stray losses usually regarded as losses in or near rotor conductor slots. When the motor is running with no load these losses are nill. However once a load is applied, these losses will increase as the square of the motor output being I^2R losses and therefore function of current. The constant losses consists of the components - the mechanical & electrical. The mechanical component is that of friction in bearing, turbulence around the rotor as it rotates and the windings of the cooling fan motors designed to minimize these losses are termed as energy efficient motors.

Modern technology and research in material science have helped a great deal in designing and manufacturing energy efficient motors. Energy efficient motors are generally made to higher manufacturing standards and tighter quality controls than the standard efficiency motors. The new motors run cooler because they generate less I^2R heat producing less stress on windings. This is generally taken to be an indication that, life of energy efficient motors is more than standard motor and operating or repair cost is less than standard motors. Its installation is justified based on its operating hours, whenever its operating hours is more than 2000 hrs/year it is economical. Power factor of energy efficient motor is better than std motor for different load conditions.

Constructional
Features of Energy Efficient Motors

1) Use of superior steel laminations with higher densities results in reduction in core length and consequently length of the copper wire. Thus iron and copper losses are optimised.

2) Use of thinner but better quality insulation in slots and increased cross section of copper results in decreased copper losses in stator.

3) Use of copper instead of aluminium enables the slot size to be reduced and improvement in magnetic flux with reduction in core losses.

4) Use of unidirectional fan consumes less power especially in pumps and compressors

5) Internal grinding and stator bore and better machining tolerances reduces the air gap b/w stator and rotor and improve the power factor of the motor.

Though there are several other innovative features of modern motors, only a few are mentioned above, the cost however is more but it pays back within reasonable time due to saving in consumption of power. Typical energy efficient motor and std motor efficiency curves showing the reduction in losses are shown in fig ①

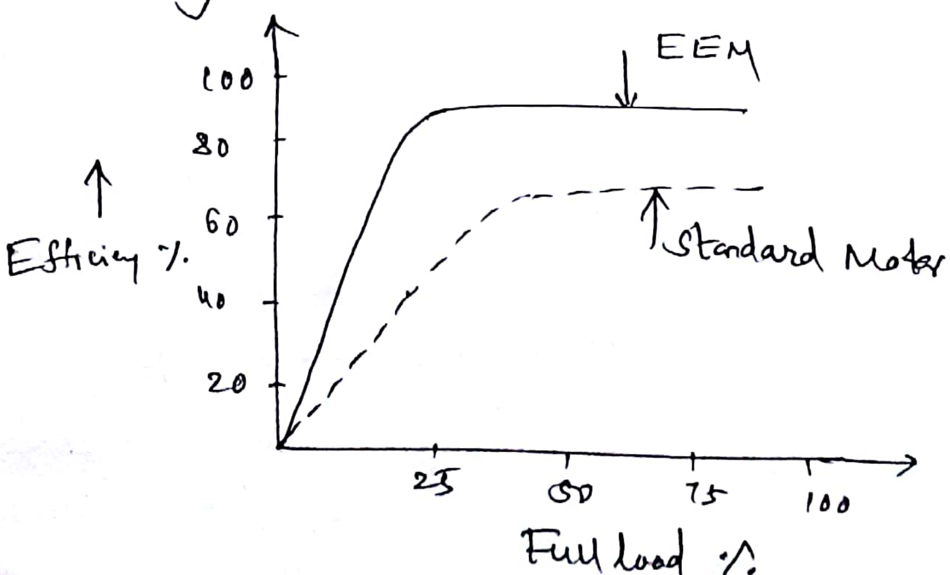

Fig ① Efficiency v/s % of full load.

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Typical EEM and Std Motor characteristic i.e. Efficiency v/s HP rating and Pf v/s HP rating are shown in fig ② & ③

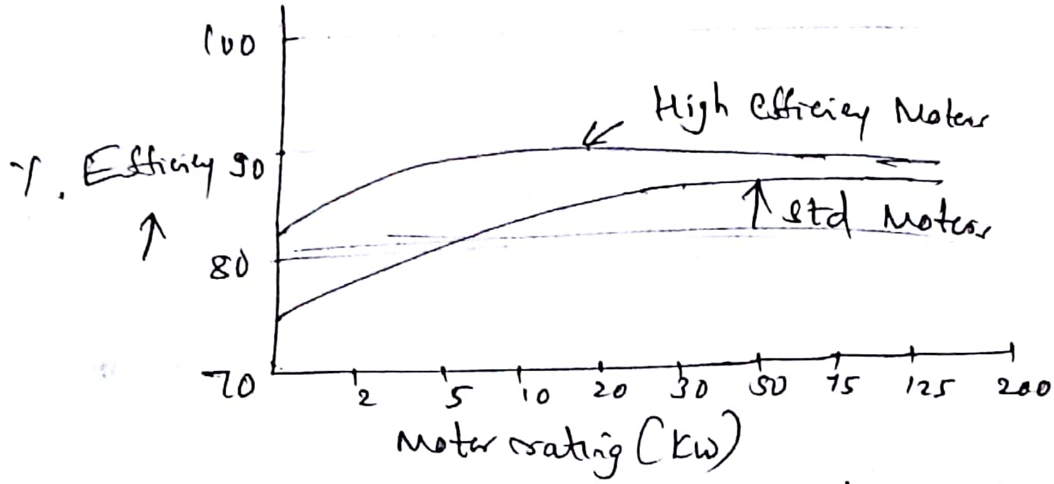

Fig ② Efficiency v/s HP rating

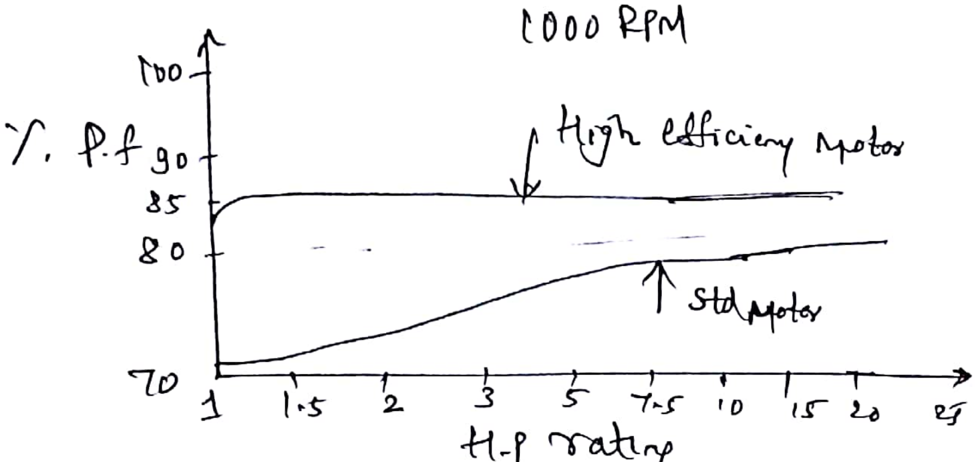

Fig ③ Power factor v/s H.P rating

Advantages of Energy efficient Motors :

1) Reducing Low power consumption
2) Lower temperature rise, increased service life
3) Broad band of constant efficiency
4) Enabling operation at lower loads without appreciable drop in efficiency
5) Improved power factor of operation even at light loads
6) Less noise level
7) Ability to accelerate higher inertia loads than standard Motors.

It will be seen that with the energy efficient motor loss reduction is particularly good at light loads. ∴ This obviously improves performance in such cases where long period of the operating time are on very light loads. For example an air compressor motor can be running off loaded for greater part of the day. Typical cases of motor replacement by EEM have shown payback period b/w 6 months to 2½ years depending on whether the motor is being run continuously over the year or in single shift.

<u>Factors to be taken into account when looking at the EEM</u>

Tariff

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

Objectives of Tariff :

Like other commodities, electrical energy is also 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.

i) Recovery of cost of producing electrical energy at the power station

ii) Recovery of cost on the capital investment in transmission and distribution systems.

iii) Recovery of cost of operation and maintenance of supply of electrical energy e.g. metering equipment, billing etc

iv) A suitable profit on the capital investment.

Desirable characteristics of a Tariff

A tariff must have the following desirable characteristics

i) Proper return : The tariff should be such that it ensures the proper return from each consumer. In other words the total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit. This will enable the electric supply company to ensure continuous and reliable service to the consumers.

ii) Fairness : The tariff must be fair so that different types of consumer are satisfied with the rate of charge of electrical energy. Thus a big consumer should be charged at a lower rate than a small consumer. A consumer whose load conditions do not deviate much from the ideal (i.e. non-variable) should be charged at a lower rate than the one whose load conditions change appreciably from the ideal

iii) Simplicity : The tariff should be simple so that an ordinary consumer can easily understand it. A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.

iv) Reasonable profit : The profit element in the tariff should be reasonable. An electric supply company is a public utility company and generally enjoys the benefits of monopoly. Therefore, the investment is relatively safe due to non-competition in the market. This calls for the profit to be restricted to 8% or so per annum.

v) Attractive : the tariff should be attractive so that a large number of consumers are encouraged to use electrical energy. Efforts should be made to fix the tariff in such a way so that consumer can pay easily

Types of Tariff :

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

1) Simple tariff OR Uniform rate tariff

When there is a fixed rate per unit of energy consumed, it is called a simple tariff or uniform rate tariff.

In this type of tariff, the price charged per unit is constant i.e. it doesnot vary with increase or decrease in number of units consumed. The consumption of electrical energy at the consumer's terminals is recorded by means of an energy meter. This is the simplest of all tariffs and is readily understood by the consumers.

Disadvantages :

i) There is no discrimination b/w different types of consumers since every consumer has to pay equitably for the fixed charges.

ii) The cost per unit delivered is high
iii) It does not encourage the use of electricity.

2) Flat rate tariff :

When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.

In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate. For instance, the flat rate per kWh for lighting load may be 60 paise, whereas it may be slightly less (say 55 paise per kwh) for power load. The different classes of consumers are made taking into account their diversity and load factors. The advantage of such a tariff is that it is more fair to different types of consumers and is quite simple in calculations.

Disadvantages

i) Since the flat rate tariff varies according to the way the supply is used, separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.
2) A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

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 block rate 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. For example the first 30 units may be charged at the rate of 60 paise per unit; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.

The advantage of such a tariff is that the consumer gets an incentive to consume more electrical energy. This increases the load factor of the system and hence the cost of generation is reduced. However, its principal defects is that it lacks a measure of the consumer's demand. This type of tariff is being used for majority of residential and small commercial consumers.

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.

In two-part tariff, the total charge to be made from the consumer is split two components 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. Thus, the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kwh of energy consumed i.e.

Total charges = Rs (b x kW + c x kWh)

Where b = charge per kW of maximum demand

c = charge per kWh of energy consumed

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

Advantages

i) It is easily understood by consumers

ii) It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

Dis-advantages

i) The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.

ii) there is always error in assessing the maximum demand of the consumer.

3) 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. This removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the rateable value

This type of tariff is mostly applied to big consumers. However, it is not suitable for a small consumer (e.g. residential consumer) as a separate maximum demand meter is required.

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.

In an AC system, P.f plays an important role. A low P.f increases the rating of station equipment and line losses. Therefore, a consumer having low P.f must be penalised. The following are the important types of power factor tariff.

i) KVA maximum demand tariff :

It is a modified form of two part tariff. In this case, the fixed charges are made on the basis of maximum demand in KVA and not in KW. As KVA is inversely proportional to P.f, therefore, a consumer having low P.f has to contribute more towards the fixed charges. This type of tariff has the advantage that it encourages the consumers to operate their appliances and machinery at improved P.f

ii) Sliding scale tariff or Average Power factor tariff

This is also known as average power factor tariff. In this case, an average P.f say 0.8 lagging, is taken as the reference. If the P.f of the consumer falls below this factor, suitable additional charges are ~~[illegible]~~ made. On the other hand, if the power factor is above the reference, a discount is allowed to the consumer.

iii) KW & KVAR tariff:

In this type, both active power (KW) and reactive power (KVAR) supplied are charged separately. A consumer having low P.f will draw more reactive power and hence shall have to pay more charges.

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 three-part tariff i.e.

$$\text{Total Charge} = Rs\left(a + b \times kW + c \times kWh\right)$$

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.

Concept of Availability Based Tariff (ABT)

Introduced form 1 July 2002.

It is a performance based tariff for the supply of electricity by generators owned and controlled by the central government. It is a frequency based and also reactive power based tariff. It is also a new system of scheduling and dispatching, which requires both generators and beneficiaries to commit to day ahead schedules. It is a system of rewards and penalties seeking to enforce day ahead pre-committed schedules, though variations are permitted if notified one to one and half hours in advance.

IEGC — Indian Electricity Grid Code

Objective
1) To improve quality of power
2) To encourage grid discipline
3) Encourage higher generation availability

Component of ABT

Capacity charge

1. A fixed charge (FC) payable every month by each beneficiary to the generator for making capacity available for use. The F.C is not same for each beneficiary. It varies with share of beneficiary in a generator capacity. The F.C payable from each beneficiary will also vary with level of availability, achieved by a generator. It will comprise interest on loan, depreciation, O&M expenses, return on equity (RoE), income tax and interest on working capital.

Schedule charge

2. An energy charge per kwh of energy supplied as per the pre-committed schedule of supply drawn up on a daily basis.
3. A charge for unscheduled interchange (UI charge) for the supply and consumption of energy in variation from the pre-committed daily schedule. This charge varies inversely with the system frequency prevailing at the time of supply / consumption. Hence it reflects the marginal value of energy at the time of supply.

Broad features of ABT design

1) It implements the long held view that electricity tariffs should be two parts comprising of a fixed charge and a separate energy charge.

2) It increases the target availability level at which generators will be able to recover their fixed costs and RoE from 62.79% deemed PLF at present to 80% (85% after one year) for all thermal stations, 85% for hydro in the first year and 77% (82% after one year) for NLC.

3. Misdeclaration of availability entails severe penalties.

4. It rationalizes the relationship b/w availability level and recovery of fixed cost. The draft notification provided for recovery of (annual fixed cost minus RoE) at 30% availability and recovery of RoE on prorata b/w 30% & 70% availability.

5. It delinks the earning of incentive from availability and links it instead to the actual achievement of generation. Hence incentives will be earned by generators only.

6. Draft notification linked incentives to equity. This order preserves the status quo of one paise/kwh per each 1% increase in PLF above availability

7. It increases the minimum performance criterion for earning of an incentive from 68.5% deemed PLF at present to 80% for all thermal stations, 85% for hydro & 77% (82% after one year) for NLC

8. It introduces severe financial penalties for grid indiscipline along with significant rewards for behavior, which enforces grid discipline for both generators as well as beneficiaries.

9. The order permits market pricing for the trading of surplus energy for beneficiaries and generators.

10. The order urges the GOI to allocate the unallocated capacity a month in advance so that beneficiaries know their exact share in capacity in advance and can take steps to trade

Unscheduled Interchange (UI) rate v/s frequency graph of ABT

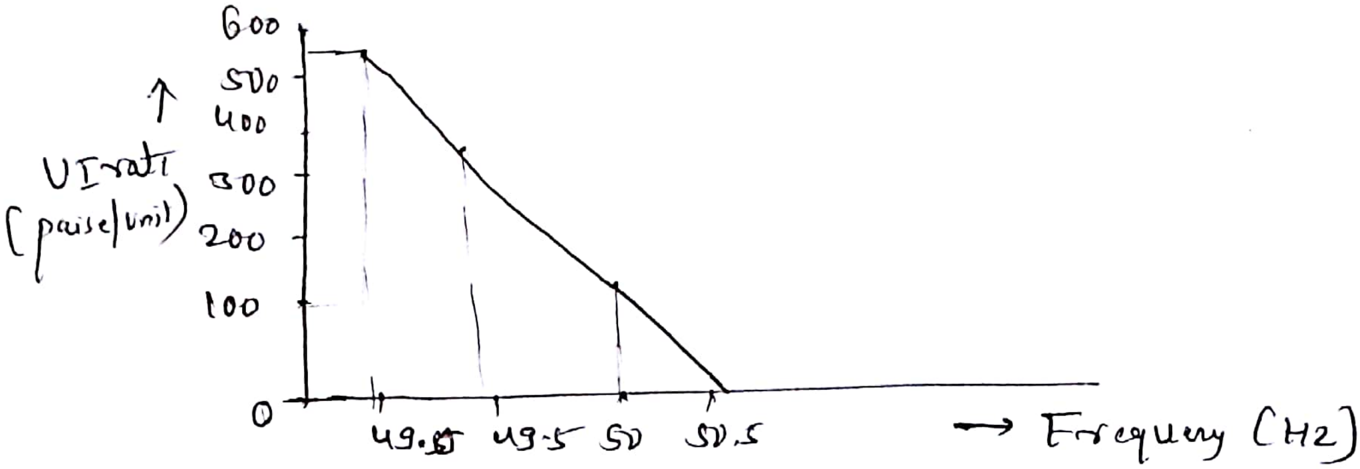

Fig ① UI v/s Frequency graph of ABT

The graph ① illustrates the variation of energy cost (UI rate) with respect to frequency of supply. Cost per unit of energy consumption increases whenever the frequency of grid is less than 50 HZ, but cost per unit of energy consumption decreases whenever grid frequency is more than 50 HZ.

Adverse conditions prior to introduction of ABT

1) Low frequency during peak load hours with frequency going down to 48 to 48.5 HZ for many hours everyday

2) High frequency during off peak hours with frequency going upto 50.3 to 51 HZ for many hours everyday

3) Rapid and wide changes in frequency - 1 HZ change in 5 to 10 minutes. Frequent grid disturbance causing tripping of generating stations interruption of supply to large blocks of consumers and disintegration of regional grid.

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LIGHTING BASICS

Lighting is an essential service in all the industries. The power consumption by the industrial lighting varies between 2 to 10% of the total power depending on the type of industry. Innovation and continuous improvement in the field of lighting, has given rise to tremendous energy saving opportunities in this area. Lighting is an area which provides a major scope to achieve energy efficiency at the design stage. By using modern energy efficient lamps, luminaries and gears, apart from good operational practices.

Lamp types and their features

→ C.R.I: Is a measure of the degree to which the colours of surfaces illuminated by a given light source conform to those of the same surfaces under a reference illuminant.

Type of Lamp	Lumens/Watt Range	Lumens/Watt Av.	C.R.I	Life (hours)	Application
1) Incandescent	8-18	14	Excellent	1000	Homes, Restaurant, general lighting.
2) Flourescent	46-60	50	Good	5000	Offices, Shops, hospitals, homes.
3) C.F.L	40-70	60	Very good	8000-10,000	Hostels, Shops, homes, offices
4) H.P.M.V	44-57	50	Fair	5000	General lighting in factories, flood lighting, parking
5) Halogen	18-24	20	Excellent	2000-4000	Display, flood light, Stadium, grounds
6) H.P.S.V	67-121	90	Fair	6000-12000	G.L in factories, Ware house, Street lighting
7) L.P.S.V	100-175	150	Poor	6000-12000 →	Roadways, tunnels, Street lighting
8) High Power LED	100		Excellent	50,000	G.L, street lighting

★ Luminous Efficacy (lm/w)

It is the ratio of luminous flux emitted by a lamp to the power consumed by lamp. It is a reflection of efficacy of energy conversion from electricity to light form.

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Some Good Practices in Lighting

1) Installation of Compact fluorescent lamps (CFL's) in place of Incandescent lamps.

CFL's are generally considered best for replacement of lower wattage Incandescent lamps. These lamps have efficacy ranging from 55 to 65 lumens/watt. The average lamp life is 10,000 hours, which is 10 times longer than that of normal incandescent lamps. CFL's are highly suitable for places such as living room, Hotel, Restaurants, Pathways, Building entrances, Corridors etc.

2) Installation of metal halide lamps in place of mercury/ Sodium Vapor lamps.

Metal halide lamps provide high color rendering index when compared with MV & S.V lamps. These lamps offer efficient white light. Hence, MHL is the choice for colour critical applications where higher illumination levels are required. These lamps are highly suitable for applications such as assembly line, inspection areas, painting shops etc. It is recommended to install MHL where colour rendering is more critical.

3) Installation of High pressure Sodium Vapor (HPSV) lamps for applications where colour rendering is not critical.

HPSV lamps offer more efficacies. But the colour rendering property of HPSV is very low. Hence it is recommended to install HPSV lamps for applications such as street lighting, Yard lighting etc.

4) Installation of LED panel indicator lamps in place of filament lamps.

Panel indicator lamps are used widely in industries for monitoring, fault indication, signaling etc. Conventionally filament lamps are used for the purpose have got the following dis-advantages

a) High energy consumption (15W/lamp)
b) Failure of lamps is high (operating life < 1000 hours)
c) Very sensitive to voltage fluctuations.

Recently conventional filament lamps are being replaced with LEDs. The LEDs have the following merits over filament lamps

a) Lesser power consumption (< 1W/lamp)
b) Withstand high voltage fluctuations in the power supply
c) Longer operating life (more than 1,00,000 hrs)

It is recommended to install LEDs for panel indicator lamps at the design stage.

3) Light distribution :

Energy efficiency cannot be obtained by mere selection of more efficient lamps alone. Efficient luminaries along with the lamp of high efficacy achieve the optimum efficiency. Mirror-optic luminaries with a high output ratio and bat-wing light distribution can save energy. For achieving better efficiency, luminaries that are having light distribution characteristics appropriate for the task interior should be selected. The luminaries fitted with a lamp should ensure that discomfort glare and veiling reflections are minimised. Installation of suitable luminaries depends upon the height - Low, medium & High Bay. Luminaries for high intensity discharge lamp are classified as follows

a) Low Bay, for heights less than 5 meters
b) Medium Bay, for heights b/w 5-7 meters
c) High Bay, for heights greater than 7 meter.

System layout and fixing of the luminaries play a major role in achieving energy efficiency. Hence fixing the luminaries at optimum height and usage of mirror optic luminaries leads to energy efficiency.

Visual Comfort Probability (VCP) 80%. rating given to fixture which indicates the percent of the people who are comfortable with the glare. Thus a VCP 80% means 80% occupants are comfortable with the amount of glare

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6) Light control: Systems

The simplest and the most widely used form of controlling a lighting installation is 'ON-OFF' switch. The initial investment for this setup is extremely low, but the resulting operational costs may be high. This does not provide the flexibility to control the lighting, where it is not required. Hence, a flexible lighting system has to be provided, which will offer switch-off or reduction level, when not needed. The following light control systems can be adopted at design stage

Preset daily time scheme
1) Timers (Time scheduling control system)
2) Dimmer
3) Photocell (LDR)
4) Infrared presence sensor (PIR)
Passive infrared

a) Grouping of lighting system to provide flexibility in light control
– Grouping of lighting system, which can be controlled manually or by timer control

b) Installation of microprocessor based controllers:

Another modern method is usage of µp / infrared controlled dimming or switching circuits. The lighting control can be obtained by using logic units located in the ceiling, which can take pre-programme commands and activate specified lighting circuits. Advanced lighting control system uses movement detectors or lighting sensors to feed signals to the controllers.

7) Optimum usage of day lighting:

Wherever the orientation of a building permits, day lighting can be used in combination with electric lighting. This should not introduce glare or a severe imbalance of brightness in visual environment. Usage of day lighting (in offices / air conditioned halls) will have to be very limited, because the air conditioning load will increase on account of the increased solar heat dissipation into the area. In many cases a switching method to enable reduction of electric light in the window zones during certain hours, has to be designed.

8) Installation of exclusive transformer for lighting:

In most of the industries lighting load varies b/w 2 to 10%. Most of the problems faced by lighting equipment and the 'gears' is due to the voltage fluctuation. Hence, the lighting equipment has to be isolated from the power feeders. This provides a better voltage regulation for the lighting. This will reduce the voltage related problems, which in turn increases the efficiency of the lighting system.

8) Installation of Servo stabilizer for lighting feeder

Wherever, installation of exclusive transformer for lighting is not economically attractive, servo stabilizer can be installed for the lighting feeder. This will provide stabilized voltage for the lighting equipment. The performance of gears such as chokes, ballasts will also improve due to the stabilized voltage. In many plants, during the non-peaking hours, the voltage levels are on the higher side. During this period, voltage can be optimised without any significant drop in the illumination level.

9) Installation of high frequency (HF) electronic ballasts in place of conventional ballasts.

New high frequency (28-32 kHz) electronic ballasts have the following advantages over the traditional magnetic ballasts.

a) Energy saving upto 35%.
b) Less heat dissipation
c) Improved power factor
d) Light weight
e) Increase the life of lamp

The life of the electronic ballast is high especially when used in a lighting circuit fitted with an automatic voltage stabilizer.

Infrared Presence Sensors

Infrared presence sensors detect the presence of occupants by detecting their movement. The most common sensors used in the building sector are Passive Infrared (PIR) sensors that react to variations of infrared radiations due to movement of persons. The system consists of a sensor and a control unit with coverage of approximately 130 square feet per sensor. Sensors are mounted on the ceiling and usually can be directed towards specific workstations and combined with HVAC control units.

The infrared presence sensors have some disadvantages as some human activities are achieved w/o significant movement. eg. watching Television, reading, sleeping etc. Also they are position sensitive and may be irrelevant if looking to a dead zone.

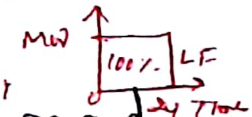
Demand Side Management

Introduction:

✓ Energy demand management, also known as Demand side management (DSM), deals with actions that influence the quantity or pattern of use of Energy Consumed by end users, such as actions targeting reduction of peak demand during periods when energy supply systems are constrained. Peak demand management does not necessarily decrease total energy consumption but could be expected to reduce the need or investments in networks and/or power plants. The term DSM was coined during the time of 1973 Energy Crisis.

✓ Demand side management programs consists of the planning, implementing and monitoring the activities of electric utilities that are designed to encourage consumers to modify their level and pattern of electricity usage.

Demand side management means the approaches and actions which aim at augmenting the systems capacity by decreasing the consumer's demand. It is widely recognised that DSM can be of great help in reducing electricity shortages and increasing reliability of electric supply



Load factor $= \frac{\text{Average load}}{\text{Peak load}}$

It can also be defined as the ratio of the Energy consumed in a certain time (say 24 hrs or a year) to the energy which would be consumed if the load is maintained at the max. value through that time

D.S.M is the 'scientific control of usage and demand of Electricity, for achieving better load factor and economy, by the Licensee / supplier'.

↳ has an effect on Power plant design, operation & cost of generation

D.S.M is the process of managing the consumption of Energy, generally to optimize available and planned generation resources. In the context of Power Sector DSM can be defined as "a set of measures to effectively manage the total demand on the integrated grid within its designed capacity to ensure acceptable quality of power supply to all the consumers".

According to the department of energy, D.S.M. refers to actions taken on the customer's side of the meter to change the amount or timing of energy consumption. Utility D.S.M. programs offer a variety of measures that can reduce energy consumption and consumer energy expenses. D.S.M strategies have the goal of maximizing end use efficiency to avoid or postpone the construction of new generating plants.

Why D.S.M is required?

1) It is an economic necessity; reduces overall cost of installed capacity.
2) It leads to efficient usage of overall power system
3) Ensures quality and equity of supply
4) To reduce power blackout (Power outage)
5) To increase the system reliability
6) To reduce the energy pricing
7) To avoid harmful gas emission to the environment
8) To reduce environmental pollution.
9) Reduces need for peaking stations (Pumped storage plant)
10) Essential during times of power/ Energy shortage.

Scope of Demand side Management:

D.S.M involves all activities which involve actions on the customer's side of the Energy meter. These activities may be undertaken by customers themselves or stimulated by the utility. The scope of DSM includes Load Management (shifting loads from peak to off peak periods), Energy Conservation, increased electrification (replacement of non-electric devices by electric devices).

Concept of DSM

The oil crises of 1973 had a profound effect on electric utilities and Electricity consumers. Utilities faced the problem of increased costs and shortage of fuel supply. The customers were squeezed by higher Electricity bills and shortages of electric supply. The higher prices and the problems associated with increased Energy use created a demand for more efficient technologies and services.

Thus the DSM concepts evolved due to the following

1) Utility planning was plagued by the uncertainty of future loads.
2) As electricity tariffs rose, the consumers felt greater attraction for Energy conservation
3) Utilities realized that promoting DSM measures is less costly than increasing installed generating capacity
4) Utilities sought methods to alleviate (lessen) customer dissatisfaction by providing service options that offered opportunity to exercise control over electricity bills.

Benefits of D.S.M.

1 **Benefits for supply Industry / utility**

- Reduction in customers bill
- Reduction in the need for a new power plant, transmission and distribution network
- Stimulating economic development
- Creating long term jobs due to new innovations and technologies
- Increasing the competitiveness of local enterprises
- Reduction in air pollution
- Reduced dependency on foreign Energy Sources
- Reduction in peak power prices for Electricity
- Improved operating efficiency & flexibility
- Improved load factor
- Increased efficiency of utilization of assets

2. **Customer benefits** :

- Satisfy Electricity demands
- Reduce / stabilize costs
- Improve value of Service
- Maintain / Improve lifestyle and productivity

3. **Societal benefits** :

- Reduce environmental degradation
- Conserve resources
- Protect global environment
- Maximize customer welfare

Different Techniques of DSM

1) Time of day pricing and Metering
2) Multi-Utility power exchange model
3) Load Management
4) Load control priority technique
5) Peak Clipping
6) Peak shifting, Valley filling
7) Strategic conservation
8) Energy efficiency improvement
9) Different time zones
10) Tariff Intervention options
11) Rain water harvesting.

1) Time of day pricing and metering

The rates which vary according to the time of the day is called time of day pricing. It is already being practiced in India for HV installations/ Industries/ large Commercial installations. The theory behind time-of-day rates is simply to vary the price of electricity in accordance with fluctuations in production costs when the cost of production is high, the price would also be high. Conversely, when the cost of production is low, the price would be low. If the utility charges the higher amount, some customers would cut down on their usage of electricity by adjusting thermostats, turning off lights, and the like. Implementation of such a pricing structure would require relatively expensive metering equipment, like magnetic recording. Hence, metering costs would undoubtedly be prohibitive for small customers. Sophisticated magnetic recording meters can monitor a customer's consumption minute by minute.

2) Multi-Utility Power exchange Model

Different utilities connect through the grid, for shifting of loads from one utility to the other. Optimizing ~~the~~ the peak load handling capacity < 10% difference b/w peak and average load is desirable

3) Load Management as a DSM strategy

The total demand of an area keeps on varying depending on the time of the day and the season. The load factor is the ratio of average power to peak power. A high load factor means lower cost of generation (Ref. fig ①). Every utility tries to improve the load factor to a value close to unity.

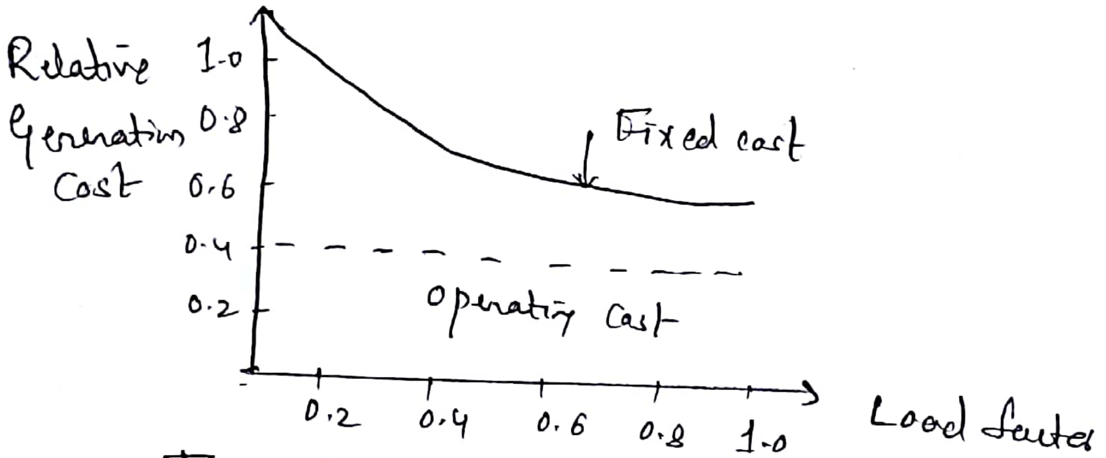


Fig ① Variation of Generation Cost with Load factor

Load Management is the concept of changing the consumer's Electricity use pattern. Load Management has the purpose of improving the effective utilization of the generating capacity and encouraging the best use of Electricity by all consumer categories. Moreover, the forced outages are reduced and the service reliability is improved. By controlling the load at consumer's premises, the load curve can be flattened. In this way, the power generation by low efficiency generation units can be minimized and some forced outages are avoided. The peak load reduction can make it possible to postpone the building of new power stations. By this, considerable savings can be achieved. Moreover, addition of new transmission and distribution facilities can be postponed thus resulting in additional savings.

The Scope of Load Management includes planning, development & implementation of programs whose objective is to actively shape the daily and seasonal load profile of consumers so as to result in better overall capacity utilization and lower the costs.

It is neither necessary nor feasible to alter the timings of all devices at consumer's premises. In residential areas the control of air conditioners, space heaters, water heaters and irrigation pumps can produce better results than control of illumination loads. Industrial loads should be controlled provided the production does not suffer.

Load Control can be achieved in different ways. Firstly, the consumers may control their loads voluntarily by altering the use of their equipments in response to tariff signals.

Secondly, the utilities may control the consumer's loads using a signal activated either remotely or at the point of use.

Both these methods have more or less the same impact on the load shape. In India the only method used by electric utilities is to de-energise a feeder (or a section) during peak demand hours so as to reduce the peak demand. The control techniques for control of load can be classified as direct load control techniques, local load control techniques and distributed load control techniques.

4) Load Control Priority Technique

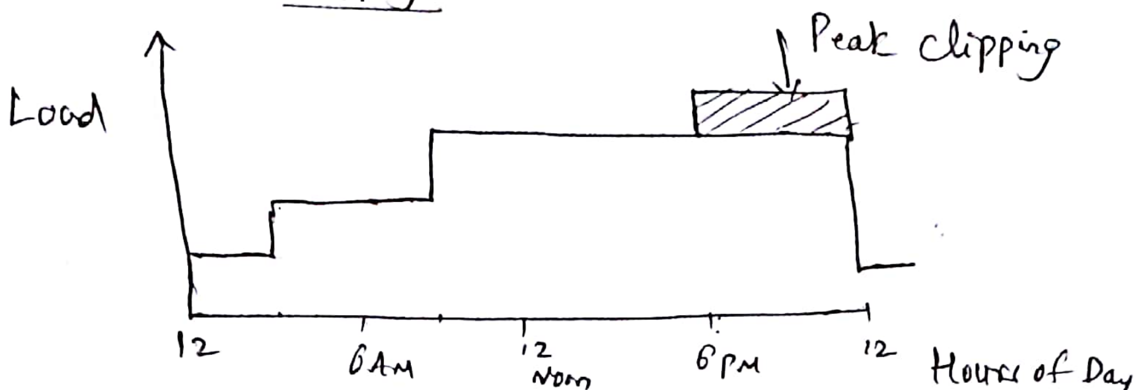
Load shedding widely used practice in India through 11kV & 33 kV feeder control, not very scientific and cannot differentiate b/w consumers, not a smooth way of managing the Load. Giving priority to important loads by listing of important loads.

a) Direct load control technique: The Utility control the consumers load without any interaction with consumer. One example of this technique is the power line carrier or ripple control system as used in Europe. This ripple causes the shedding of consumers space heating and water heating loads. After this technique was evolved and implemented, these ripples were also used to implement time of use (TOU) rates. In some cases ripple control is used to send signals to industrial consumers who have agreed to adopt DSM.

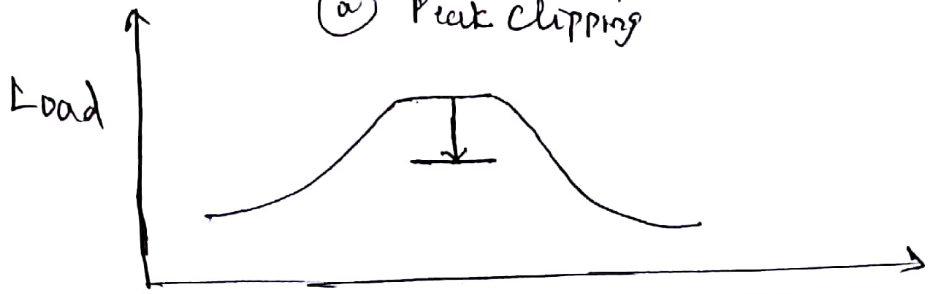
b) Local load control technique: In this technique, the consumers control the loads. One method to implement this technique is to have a circuit breaker at the consumer's premises. When load exceed a certain value (as per circuit breaker setting), the supply is switched off. Generally the consumer can identify the appliances which he can use simultaneously without exceeding the load limit. Another way to have interlocking devices which donot allow connection of several major power consuming devices at the same time.

c) Distributed control technique: In this technique the consumers control their loads in communication with utilities. This technique is used mainly for large industrial consumer with whom the utilities have special contracts such as interruptible loads.

5) Peak Clipping :



ⓐ Peak clipping



ⓑ Peak clipping

Peak clipping is defined as the reduction of utility load primarily during peak demand, other terms for peak demand control is the Ripple Control through identified loads, shifting electricity consumption from peak to no peak hours, appeal to large consumers for relief during peak hours.

Peak clipping or Peak load reduction is one of the classical forms of load management. Here some of the consumer's appliances are switched off by direct load control for some time. Evidently those appliances are those which consume large power and whose disconnection for some time can be tolerated without much inconvenience. It can be more beneficial in case of large industrial consumers. The relative peak clipping potential will be different in different industries. The ceiling demand required to be imposed in every case should be worked out in consultation with the participating industry and the time period required for this, when arithmetically summed up, should not exceed the power availability forecast for the cluster during that period. Fig ⓐ & ⓑ shows peak clipping

6) Load shifting:

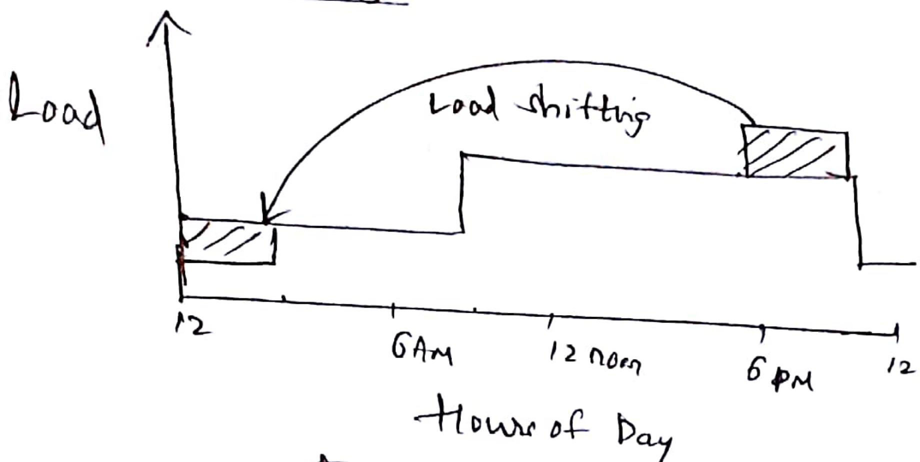


Fig Load shifting

Load shifting is the reduction of utility loads during periods of peak demand, while at the same time building load in off peak periods. Load shifting typically does not alter total electricity sales. During the periods of power shortage some dispensable appliances are switched off. the appliances are such that their switching off causes only minor inconvenience to consumers. Load shedding can be done on the entire system simultaneously or on different parts of the network turn by turn.

7) Valley filling:

Valley filling is the improvement in system load factor by building load in off peak periods.

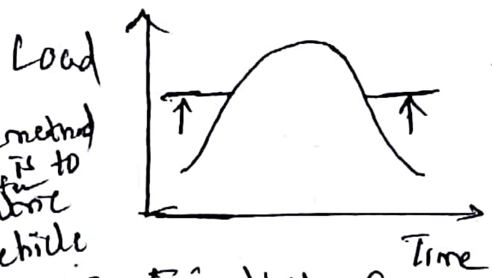


Fig. Valley filling

* one method is to offer Electric vehicle charging

* Incremental costs during off peak (generally night) hours are less than average costs of electricity. In such case building up loads during off peak hours may be advantageous.

* I.C arising from new investments in G, T, D needed to meet the extra demand

During nights there is surplus of generating capacity. By using this capacity economy of the utility can be improved. A part of these savings can be passed on to consumers as incentive. Some heavy power appliances (irrigation pumps, water heaters etc) are switched off during peak hours and switched on during off peak hours. This is known as Valley filling and is shown in fig.

8) Strategic Energy Conservation:

Strategic energy conservation is the reduction of Utility loads, more or less equally, during all or most hours of the day. Conservation of power in strategic locations aims at peak voltage management, reducing kVA loads at tail ends, appeal to Energy intensive industries and

— Photo sensitive switches for street lights and encouraging the use of high efficiency equipments. Thus it leads to reduction in Energy wastage. This leads to lower costs and lesser damage to environment.

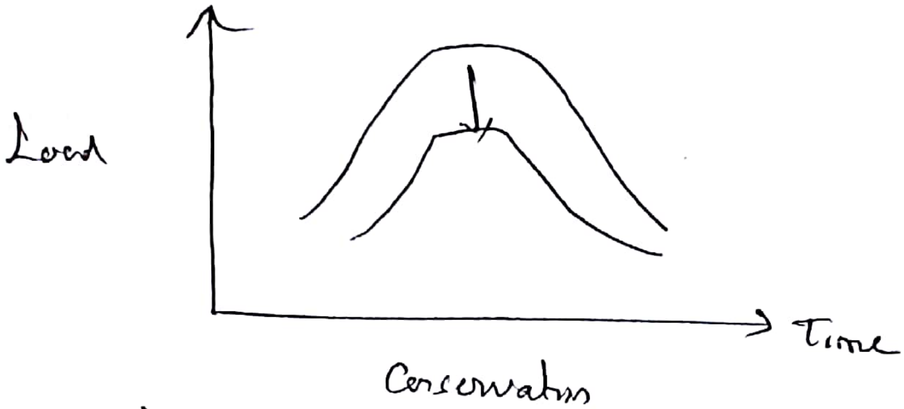


Fig. Strategic energy conservation

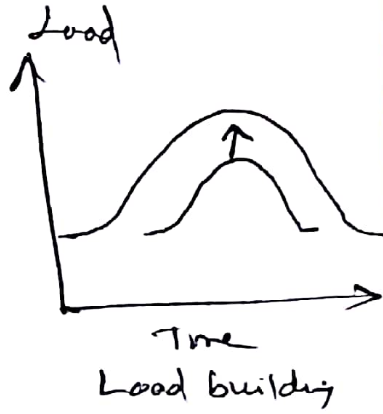


Fig strategic load growth

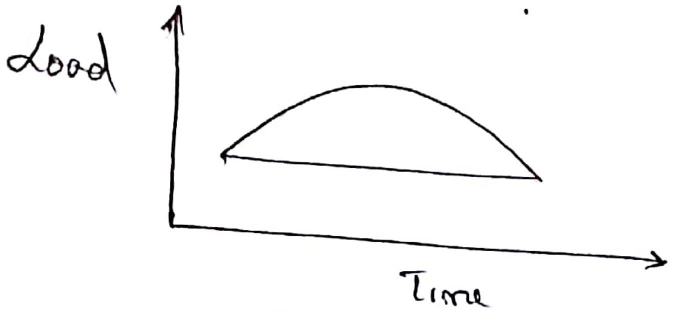
9) Strategic load growth

Load building is the increase of Utility loads, more or less equally, during all or most hours of the day. These loads are the ones which produce a general increase in sales beyond any increase from valley filling. It may be achieved by increasing the market share of loads or can be served by other fuels as well as general economic development

10) Flexible load shape:

The Utility is allowed to adjust the load shape to meet the reliability constraints. The consumers are given incentives for reduced levels of service. The most

Common reduced levels of service are interruptible or Curtailable service.



Flexible load shape

ii) Energy efficiency improvement :

T&D loss reduction is the biggest source of D.S.M Efficiency improvement in end use applications such as agricultural pumping sets, Usage of CFLs/LEDs in place of bulbs. BEE's estimation of savings: 10,000 MW Prayas energy's study: 30% savings in households; corresponds to about 25,000 MW of avoided generating capacity, the education programs to educate Consumers about use of Energy efficient devices have been undertaken in many Countries. It has been reported that due to the use of most efficient devices the average consumption in refrigerators reduced from 950 kwh/year and in deep freezer from 1100 kwh/year to 835 kwh/year. Many end use efficiency programs including cogeneration, promotion and sale of Energy efficient devices, Energy audit, Energy labeling of appliances etc have been initiated and implemented in Australia. In Germany the electrical energy consumption has decreased by about 20% for washing m/cs, 30% for dish washers & 45% for freezers. In sweden an improvement in end use efficiency method have resulted in reduction in Energy Consumption of refrigerators from 1.4kwh/lit/year to 0.9 kwh/litre/year.

↓

252 kwh/180 litre/Year

12) Different time zones

Appears to be necessity, India's large spread across longitude; 80 minute spread, shifting of peak load from one to other time zone needs adequate transmission capacity, HVDC lines & UHV systems are required for this purpose

India's Time Zones were estd in 1884. Originally there were two time zones, the Bombay Time & Calcutta Time.
↳ 39 minutes behind IST (came into existence in 1906)

13) Tariff options for DSM

The tariff structures which can promote DSM activities are a) Time of day tariff (TOD Tariff) b) Seasonal Tariff c) Curtailable / Interruptible (C/I) rates:

a) Time of day tariff (TOD tariff): It is also known as time of use (TOU) tariff. The technical development of metering equipment has made it possible to measure energy consumptions during different times of day, days of week and periods of year, economically. TOD rates make electricity more expensive when it costs more to generate additional electricity during peak hours and cheaper during off peak hours. Such a tariff structure encourages consumer to shift their load, wherever possible, from peak to off peak hours thus flattering the load curve. This would be favorable to the customers who find their bills reduced and also favorable to the electric utility who would gain by a decrease in peak load.

b) Seasonal Tariff: In this tariff structure, the rates change across the season. This type of tariff is an economical way of managing demand. Since the peak consumption months are more or less fixed, the tariff

• Working season months
• Off-season months

can be adjusted to reflect seasonal demand variations. Thus, the cost of Electricity is more during certain months of the year than that during others. This tariff system does not require the special Electricity meters needed for (TOD) tariff. Evidently the electricity billing frequency has to be synchronising with the times when seasonal rates come into effect.

c) Curtailable/Interruptible (C/I) rates:

C/I rates offer incentives to those consumers who reduce demand to a predetermined level, when they receive a notice to this effect. The success of this tariff system depends on reliable communication system.

It is an accepted fact that, offering incentives and pricing to consumers is the best way to promote DSM.

14) End Use Energy Conservation

End use energy conservation programs form a very important aspect of DSM. These programs reduce the customer's consumption of Energy thereby reducing their electricity bills. Cost effective conservation options reduce overall requirement of the utility and serve to reduce electricity tariff for all consumers.

i) Least cost utility planning:

It is an established fact that investments in Energy conservation and load management activities are less expensive per KW than addition of new generation facilities. In order to decide the best mix b/w capacity additions, conservation and load management programs many utilities in developed countries carryout least cost planning process. In this analysis the costs of new capacity additions, supply side efficiency improvements, end use efficiency measures are all examined critically. The mix resources which can meet the

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future power & Energy needs at the lowest cost are selected. This planning process can lead to substantial savings because some expensive new projects can be substituted by low cost efficiency improvement methods.

ii) Promotion of high efficiency technologies:

Many efficiency measures with good saving potential have been implemented in some countries. Examples are improved efficiency refrigerators, air conditioners, evaporative coolers, fan motors etc. Similarly electronic ballasts for fluorescent lights, variable speed drives using power electronics devices can also lead to substantial savings. The strategy should include R & D and demonstration projects with an emphasis on adopting technologies developed overseas to the Indian context.

1) Technical and financial assistance to the manufacturers so that high efficiency equipments are manufactured
2) Selective reduction in import duties both for manufacturing equipments (needed to manufacture high efficiency devices indigenously) as also the actual high efficiency devices
3) Mandatory efficiency standards for equipments
4) Preference for high efficiency devices by government and semi-government agencies.

iii) Energy Conservation Opportunities in Agricultural Sector:

Agricultural sector account for about 30% of electricity consumption in India. The current energy consumption in this sector is about 93,000 million kwh and the total no. of pump sets are 11,850,000. About two lakh pumpsets are added every year. It is evident that improved efficiency of agricultural pump sets can lead to enormous savings. The metering of electricity to irrigation pump sets is necessary. In many states the agricultural pump sets are charged flatly per kW of the rating of the motor. This practice leads to a lot of energy wastage. Use of inefficient motors and sub-standard accessories is leading to huge wastage of energy. Use of drip irrigation, keeping the pipe fitting losses to the minimum and the operation of pumps and threshers during off peak hours can also lead to saving in energy and energy costs.

iv) Energy Conservation opportunities in illumination systems.

A conventional incandescent lamp has a luminous efficiency of 12 lumens/watt. Fluorescent lamp has a luminous efficiency of about 60-70 lumens/watt. CFL are more energy efficient. Moreover CFL has long life and is environment friendly. CFL offer about 5% to 15% increase in efficiency and provide good color rendering. Moreover replacement of 40W fluorescent lamps by 36W CFL leads to 10% savings for the same illumination. A conventional choke consumes about 12-15 watts and operates at a very poor p.f. Electronic ballasts requires only about 1-4 watts of power and operate at good power factor. The only limiting factor is the higher cost of electronic ballasts as compared to conventional magnetic ballast. High pressure sodium vapor lamps and high pressure mercury vapor lamps should be preferred for street lighting.

v) Energy Conservation opportunities in Fans and Refrigerators

Fans are used very extensively in summer months. Use of high efficiency fan motor and use of electronic regulator (in place of conventional resistance regulator) can lead to about 20% saving in energy. The fans with aerodynamic designs and improved impeller consumes about 10% less energy but are 30% costly as compared to conventional fans.

The efficiency of refrigerators in India is rather poor. A typical 165 liter Indian refrigerator consumes about 540 kwh/year. On the other hand the 200 liter Korean model consumes about 200 kwh/year. These refrigerators use a different compressor design which is very sensitive to voltage of electric supply. Unless quality of electric supply is improved these refrigerator cannot be introduced in India. Nevertheless use of better insulation technique can bring about some improvement.

vi) Energy Conservation opportunities in cooling and heating Systems

Air Conditioners consume lot of energy. Efficiency of air conditioner is expressed in Energy Efficiency Ratio (EER) which is BTU of cooling output divided by watts of input power. BIS calls for an EER of 6.6-7 whereas most of the air conditioners used in India have an EER ratio of 5.0 only. Efficiency of Central AC systems can be improved by carefully designing the buildings to reduce heat gain into the buildings, improved thermostat and other controls. Slight reduction in thermostat setting can lead to considerable saving w/o loss of comfort. Reliable door closers can enhance the effectiveness of air conditioning by checking infiltration of outside air into the room. Desert Coolers are widely used in India in summer months. A typical cooler consumes 20% more energy than BIS standard.

The efficiency of a cooler can be increased by an improvement in efficiency of fan motor and that of water circulating pump. It has been reported that extra cost of Rs 500/cooler can lead to 20% improvement in efficiency. Energy saving in water heating can be achieved by using better insulation techniques. Reduction in Energy use by the water heaters can be achieved by covering the tank with an insulation blanket of fibreglass and backed with Vinyl. These blankets can also be used to cover the sides of water heater.

vii) Energy Conservation opportunities in Industrial sector:

Electric motors are very widely used in Industry. The most common motors are squirrel cage induction motor (upto a few kw rating) and wound rotor I.M (for large kw requirements). Use of high efficiency motors can mean an energy saving of 2-5%. However high efficiency motors are about 25-35% more costly than the std. efficiency motors.

Moreover, the use of Motors made by standard manufacturers is also pretty common. These motors are highly inefficient and operate at poor Power factor. The rewinding of motors reduces their efficiency because of poor rewinding, use of thinner conductor (than that required for the Motor size) and poor quality insulating materials.

Power electronic variable speed drives are energy efficient but expensive. Their use can lead to energy savings. Cogeneration should be encouraged in the industrial sector. Sugar, Paper, textile, fertilizer, cement, chemical and Pharmaceutical industries offer a good scope for cogeneration. The cogeneration systems are very energy efficient. The use of non-fossil fuels in some industries like sugar can lead to enormous saving of fossil fuels.

DSM Implementation Issues :

DSM techniques have been successfully implemented in many developed countries. However their implementation in developing countries has been limited by a number of technical, institutional and other barriers. Early DSM programs intended to focus on audit, spread of information, direct load control and rate making. More recently, utilities have begun to focus their attention on comprehensive programs incorporating a package of Energy efficient measures and multiple marketing and delivery techniques.

DSM programs donot necessarily mean advance technology or major process changes. Many changes require little investment. The need is to bring about awareness about energy saving. The end user, the manufacturer of high efficiency equipment, financial institutions, testing laboratories, industrial associations, consumer forums have to be involved in the process.

Most DSM programs achieve only partial success. The factors which restrain the consumers to move towards Energy Conservation are

1) Lack of Information : Information gap is one of the major constraints in the implementation of DSM programs. Consumers are generally unaware of the opportunities of improving energy efficiency. Information on Energy efficiency of equipment is not available or available only partially. Educational efforts customized to each end use segment can be helpful. Energy labels on equipments, devices, motors etc can be helpful.

2) Cost of Energy efficient equipment : Most of the consumers are not willing to purchase high efficiency equipments due to their high initial cost. Manufacturers have an important role to play in developing markets for high efficiency equipments. Incentives in the form of lower taxes and duties can help in making energy efficient equipments more popular.

3) Tariff: In many developing countries the tariff for some categories of consumers is very low even lower than cost of electricity generation. Such tariff structures need to be avoided.

4) Poor power quality and reliability: In many developing countries, planned and forced outages are very common. The poor power quality and reliability problems impede efficiency measures in many ways. Many types of equipments are very sensitive to low voltage & voltage fluctuations. Some equipment consumes more energy at low voltages. The equipments designed to withstand voltage fluctuations are always less efficient. For successful implementation of DSM programme, power quality and reliability must be improved.

5) Unavailability of efficient equipments: Many types of efficient equipments are not available in developing countries. Efficient refrigerators, air conditioners, evaporative coolers have not been marketed in developing countries. The manufacturers are reluctant to start production of such equipments due to unsure market conditions and demand. Moreover many raw materials and components to manufacture efficient equipments are also not available.

6) Small scale sector: Many devices like ballasts, lighting fixtures, small motors, pumps, fans, coolers etc are manufactured in small scale sector. Most of these devices are inefficient. The small scale industries donot invest in quality control measures and donot adhere to BIS. Moreover these manufacturers often produce low cost devices & ~~to~~ minimize the cost they ignore efficiency considerations.

7) Retirement of inefficient and old equipments: In developing countries, the equipments are repaired again and again and hardly thrown away. Most of the time the repair leads to increasing inefficiency because sub-std materials & components are use in repair.

8) Shortage of skilled staff: There is shortage of skilled staff who can provide technical assistance in identifying, installing and maintaining efficiency measures.

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DSM Implementation Strategies

Some of the strategies which can lead to successful implementation of DSM are.

1) Market transformation through Voluntary retirement.

The utilities should engage in direct negotiations with manufacturers to ban manufacture of low efficiency devices. Moreover the Utilities should takeup market campaigns to promote energy efficient devices. People should be educated about the replacement of poor efficient devices by new and more efficient devices.

2) Energy efficiency labeling

All participating brands of refrigerators, air Conditioners, fans, Coolers, pumps etc should carry an efficiency label which indicates efficiency, annual kwh consumption etc. This would induce customers to go in for energy efficient devices.

3) Customer oriented program design

Each customer has unique energy requirement and financial position. Therefore DSM programme should be flexible that, needs of every customer can be accommodated.

4) Public - Private sector partnership

Design and development of Energy saving devices needs special knowledge and skill. Utilities should subsidize the manufacturers in the development of such devices at least partly. Establishing a funding mechanism for DSM investments is essential for long term sustainability. Assurance of cost recovery for cost effective DSM investments is critical. It is difficulty to convince utility manager to engage in DSM activities. DSM expenses, if prudently incurred, are automatically passed on to all consumers through fuel adjustment charge