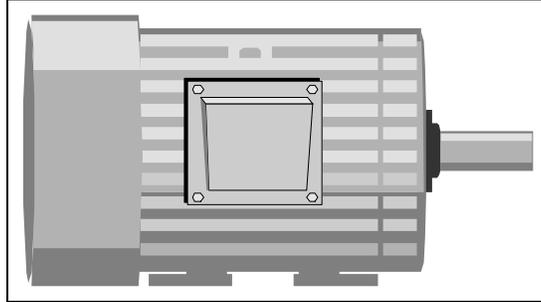# BEST PRACTICE MANUAL

ELECTRIC MOTORS

Prepared for

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1   INTRODUCTION

1.1   Background

Electric motors are intrinsically very efficient. Their efficiencies vary from 85% to 95% for motors of sizes ranging from 10 HP to 500 HP. This guide will discuss mainly the energy efficiency related issues in selection and application of three phase squirrel cage induction motors. They are very reliable, rugged and cover more than 90% of the installed capacity of electric motors in the industrial sector. Due to a large installed base of motors using electricity, even a small improvement in efficiency can result in significant savings from a broader national perspective.

The following figure 1.1 shows the break up of electricity use in motor driven systems in India.
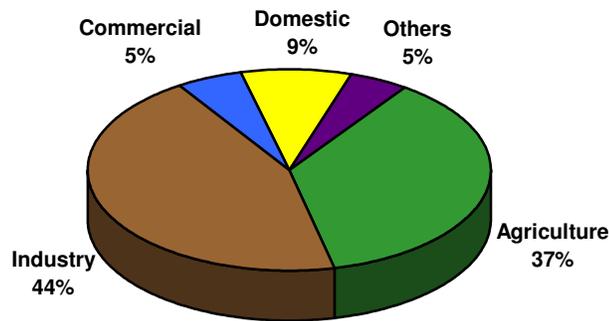
Figure 1.1:Sector-wise break up of electricity consumption in motor driven systems

Source: Complete guide to energy efficient Motors- ICPCI, Mumbai

1.2   Classification of Motors

Electric motors are of many types. The common types of motors are given below in figure 1.2.
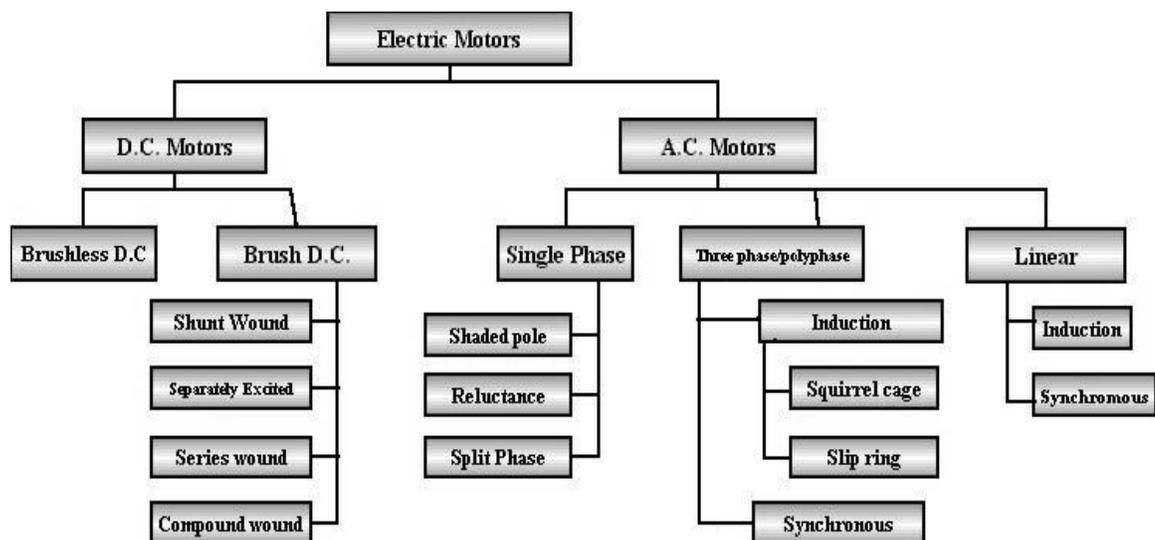
Figure 1.2: Classification of electric motors

Electric motors convert electrical energy into mechanical motion and are broadly classified into two different categories: DC (Direct Current) and AC (Alternating Current). Within these categories are numerous types, each offering unique abilities that suit them well for specific applications.

In industry, most commonly used motors are 3 phase squirrel cage induction type. Use of Synchronous motors and DC motors for heavy duty and precision drives etc. are also common. With the introduction of variable frequency drives for speed and torque control, the 3-phase induction motors are finding increasingly acceptable for applications where DC drives were earlier used.

2   FUNDAMENTALS

2.1   Principle of Operation

A large percentage of AC motors are induction motors. This implies that there is no current supplied to the rotating coils (rotor windings). These coils are closed loops which have large currents *induced* in them.

Three-phase currents flowing in the stator windings leads establish a rotating magnetic field in the air gap. This magnetic field continuously pulsates across the air gap and into the rotor. Refer figure 2.1. This is a single phase representation of windings and current flow.
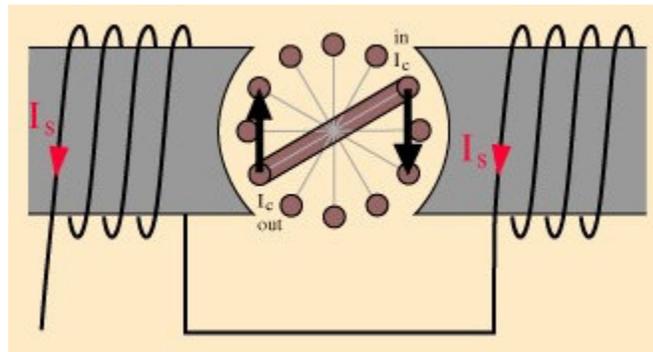
Figure 2.1: Induction motor principle

The rotor consists of copper or aluminium bars connected together at the ends with heavy rings.
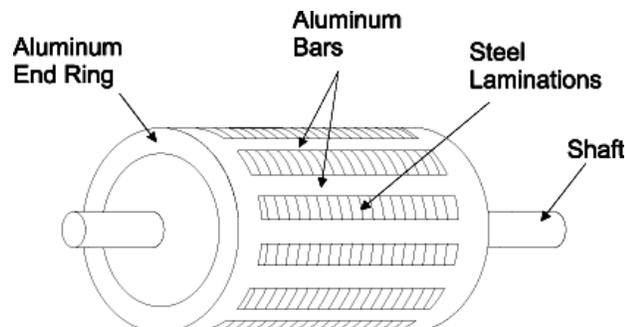
Figure 2.2: Aluminium Rotor

As magnetic flux cuts across the rotor bars, a voltage is induced in them, much as a voltage is induced in the secondary winding of a transformer. Because the rotor bars are part of a closed circuit (including the end rings), a current circulates in them. The rotor current in turn produces a magnetic field that interacts with the magnetic field of the stator. Since this field is rotating and magnetically interlocked with the rotor, the rotor is dragged around with the stator field.

Wound-rotor motors — Although the squirrel-cage induction motor is relatively inflexible with regard to speed and torque characteristics, a special wound-rotor version has controllable speed and torque. Application of wound-rotor motors is markedly different from squirrel-cage motors because of the accessibility of the rotor circuit. Various performance characteristics can be obtained by inserting different values of resistance in the rotor circuit.

Wound rotor motors are generally started with secondary resistance in the rotor circuit. This resistance is sequentially reduced to permit the motor to come up to speed. Thus the motor can develop substantial torque while limiting locked rotor current. The secondary resistance can be

designed for continuous service to dissipate heat produced by continuous operation at reduced speed, frequent acceleration, or acceleration with a large inertia load. External resistance gives the motor a characteristic that results in a large drop in rpm for a fairly small change in load. Reduced speed is provided down to about 50%, rated speed, but efficiency is low.

2.1.1 Speed, Torque and Power

Synchronous Speed of an ac induction motor depends on the frequency of the supply voltage and the number of poles for which the motor is wound. The term poles refers to the total number of magnetic north and south poles produced by the stator winding when supplied with poly phase current. The higher the input frequency, the faster the motor runs. The more poles a motor has, the slower it runs at a given input frequency.

Slip represents the inability of the rotor to fully keep up with the moving AC voltage waves generated on the stator. **Slip** of an induction motor defined as:

$$s = \frac{n_s - n}{n_s}$$

Where,

s = slip
n_s = synchronous speed
n = actual speed

Full-load slip varies from less than one percent (in high-HP motors) to more than five percent (in fractional-HP motors).

Torque is the force that produces rotation. It causes an object to rotate. Torque consists of a force acting on distance. Torque, like work, is measured is Newton-metre. However, torque, unlike work, may exist even though no movement occurs

Power or shaft power takes into account how fast the crank is turned. Turning the crank more rapidly takes more horsepower than turning the crank slowly. It is the rate of doing work. The nameplate power rating of a motor is generally the rated output power.

Rated current & voltage: - It is the current drawn by motor while delivery rated power at rated voltage. The rated current and voltage of the motor are given on the nameplate. Voltage of three-phase motor is generally kept at 415 volts. However, these can be operated continuously at ± 10% voltage; ± 5% frequency and combined voltage and frequency variation of ± 10% (Absolute sum). As per 1S: 325, all motors are rated to withstand an overload and excess torque of 60% of their rated torque at rated voltage and frequency for 15 seconds. These are normally designed for 75^{0}C temperature rise (for Class B insulation) above ambient temperature of 45^{0}C

2.1.2 Load Considerations

The driven equipment characteristics decide how much shaft power the motor has to deliver at the operating point. Examples of the common types of loads are given below along with the expected variation in torque and power with speed. Understanding this behaviour is important while selecting motors and more so when selecting variable speed drives. Table 2.1 summarises various types of loads

Constant torque: Most frequently encountered type of load (essentially friction loads), where the torque required by the load is constant throughout the speed range. The constant torque characteristic is needed to overcome friction. Friction loads require the same amount of torque at low speeds as at high speeds. For example, a 10-ton load on a conveyor requires about the same

torque whether the conveyor speed is 5 or 50 feet per minute. The horsepower requirement, however, increases with speed. Common applications include general machinery, hoists, conveyors, printing presses, etc.

Table 2.1: Load Characteristics

$T \propto 1/N$	$T \propto$ Constant	$T \propto N$	$T \propto N^2$
$kW \propto$ Constant	$kW \propto N$	$kW \propto N^2$	$kW \propto N^3$
Winders Facing lathes Rotary cutting machines	Hoisting gear Belt conveyors process machines involving forming Rolling mills planers	Calendars with viscous friction Eddy-current brakes	Pumps Fans Centrifuges

Constant power: In this group, the load decreases with increasing speed. Common applications are processes that are changing diameters such as lathes, winders, unwinders, and metal-cutting tools operating over wide speed ranges. With an initial large diameter work piece, maximum torque and slow speeds are required. As the work piece diameter decreases, torque decreases; but speed increases to provide constant surface speed.

Variable Torque: These loads increase with speed and are usually associated with centrifugal fan and pump loads, where, in theory, the horsepower requirement varies as the cube of the speed change. When driving positive-displacement pumps, some mixers, and some types of extruders, in theory, the horsepower requirement varies as the square of the speed change. These applications usually have the greatest opportunities for energy savings as well as improved control.

Shock Loads: These loads may range from a small fraction of rated load to several hundred percent for a small fraction of the time. Examples include crushers, separators, grinders, and, perhaps, conveyors, winches, and cranes. Under these conditions, the drive has two fundamental tasks: to move the load and to protect the prime mover and driven equipment. For example, the electric motor as a prime mover can experience bearing damage from shock loads.

2.1.3   Power Factor

Power factor is not a measure of efficiency. It is a ratio of Real Power, in total kilowatts, to total Apparent Power, in kilovolt amps. If a load draws Reactive Power, the power factor is said to be "lagging." Most electric motors have a lagging power factor. The operation of electrical systems with low power factor results in reducing the overall power carrying capacity of the power supply system. As an incentive for customers to operate at high power factors, utilities levy power factor penalties to customers whose overall power factor falls below certain levels.

An understanding of the difference between the three aspects of power, kilowatts, kilovolt-amps, and kilovolt-amps reactive, is essential to an understanding of power factor. Useful mechanical work derives from "real power," the energy consumed by the load. Real power is expressed in kilowatts. Figure 2.3 gives the vector diagram showing all three types of power for lagging p.f. load.

KW= Real power

θ

KVAR= Reactive power

KVA = Apparent power
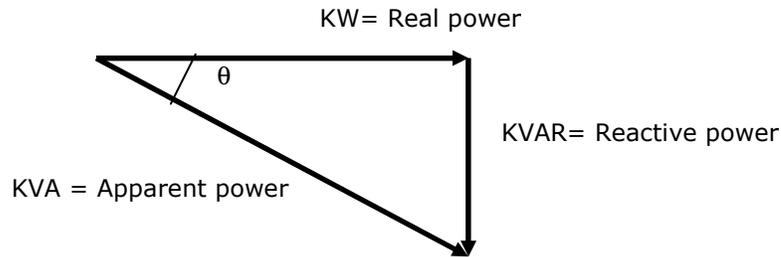
Figure 2.3: Vector diagram

A motor is an inductive load. The current drawn by the motor lag behind the voltage applied. In this situation, the reactive power is drawn by the motor. Reactive power does not provide useful mechanical work. However, most AC motors do require reactive power for developing magnetic fields. Reactive power is expressed as Kilovolt-amps Reactive, or kVAR. The vector sum of Real Power and Reactive Power is Apparent Power, expressed as kilovolt-amps or kVA. Apparent Power is calculated by multiplying voltage and amperage.

A motor operating at a given load and supply voltage, draws active and reactive power. If the motor is connected to the grid, without any capacitors, the entire active and reactive power is drawn from the grid. Refer fig 2.3 (a).

A capacitor is a device which draws a leading current, and is ready t o discharge current when motor need it. If capacitor is connected at the motor, the reactive power drawn by the motor from the grid will be less or almost nil in case of unity power factor correction. Refer fig 2.4(b).
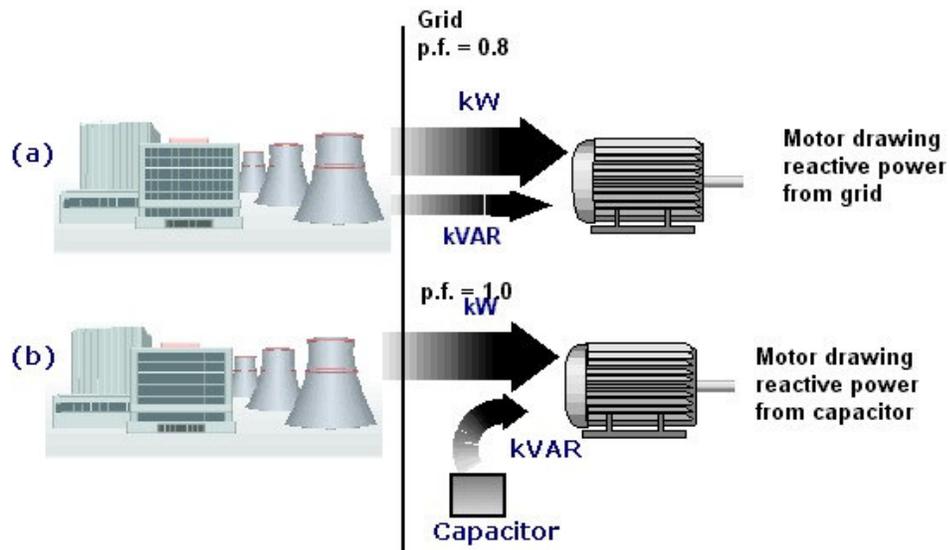
Figure 2.4: Power factor correction by use of capacitors

It is not necessarily to have higher power factor for a high efficiency motor. It is often difficult to get a good a motor design by concentrating on high power factor. The motor designer has to consider a number of parameters such as temperature rise, torque characteristics and efficiency, as well as power factor, and he can't optimize them all. It's costly to try to design both high power factor and

high efficiency into a motor, and some of the design changes that improve power factor, such as a reduced air gap, actually have the opposite effect on efficiency.

2.1.4   Efficiency

Motor efficiency is a measure of the effectiveness with which a motor converts electrical energy input to mechanical energy output to drive a load. It is defined as a ratio of motor power output to source power input. The difference between the power input and power output comprises electrical and mechanical losses. Higher horsepower ratings generally correspond to higher efficiency ratings. Small fractional horsepower motors tend to have low operating efficiency, while large integral horsepower motors are generally very efficient.

At a particular operating voltage and shaft load, the motor efficiency is fixed by design; it cannot be changed externally, while power factor can be corrected externally.

The power consumed by a 3-phase AC motor is given by:

Power input = √3 X line voltage X line current X power factor

If the voltage is in volts and the current in amperes, the power will be in watts (w). The power in watts divided by 1000 is Kilowatts (kW). The power input to the motor varies with the output shaft load.

Electric Power Input (kW) = Mechanical shaft output in kWx100
                                              Motor Efficiency (%)
Electric Power Input (kVA) = Power Input (kW) x 100
                                              Power Factor (%)
Typical variations of motor efficiency and power factor with load are shown in fig 2.5.
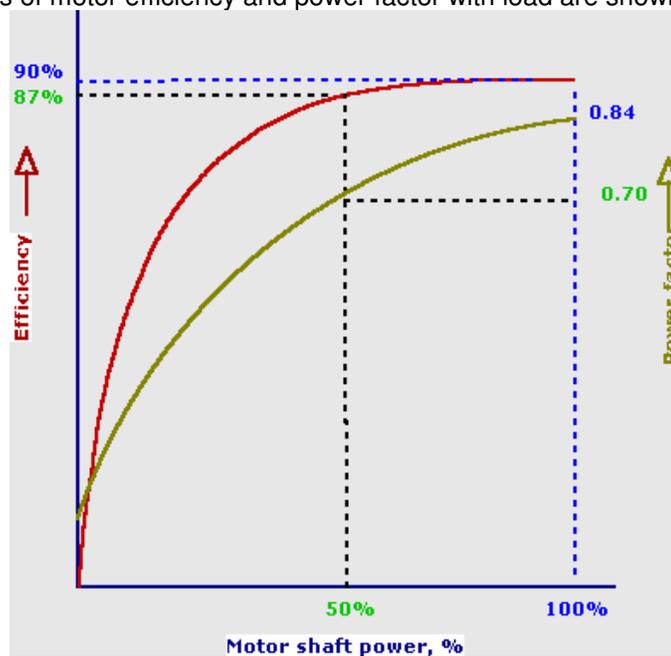
Figure 2.5: Motor efficiency and power factor

The following may be noted from these curves.

1. The motor efficiency remains almost constant up to 40% load, below which the efficiency drops significantly and becomes zero at 0% load.

2. For a particular operating voltage and shaft load, the motor efficiency is determined by design, it cannot be changed externally.

3. The power factor reduces with load. At no load the p.f. is in the range of 0.05 to 0.2 depending on size of the motors.

4. Note that at 50% load, the efficiency has dropped by 3%, where as the power factor has dropped from 0.84 to 0.7 for the same load change.

5. At no load, the power consumption is only about 1 to 5%; just sufficient to supply the iron, friction and windage losses.

6. The no load current is however, of the order of 30 to 50% of the full load current. This magnetising current is required because of air gap in the motor.

2.1.5   Torque & Current /vs. Speed Characteristics of Motors

Torque speed and current speed characteristics of different types of motors are shown in fig. 2.6

Torque speed curve shows how a motor's torque production varies with the different conditions of its operation.

Starting torque, also called **locked rotor torque**, is produced by a motor when it is initially turned on. Starting torque is the amount required to overcome load friction at standstill.

Pull-up torque is the minimum torque generated by a motor as it accelerates from standstill to operating speed. If a motor's pull-up torque is less than that required by its application load, the motor will overheat and eventually stall.
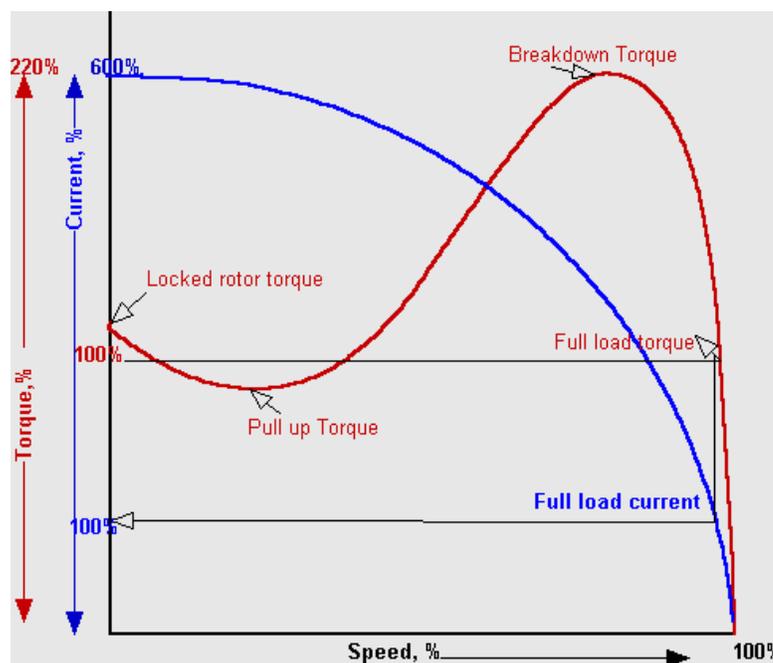
Figure 2.6: Torque & Current .vs. Speed

Breakdown torque is the greatest amount of torque a motor can generate without stalling. High breakdown torque is necessary for applications that may undergo frequent but short time overloading. One such application is a conveyor belt. Often, conveyor belts have more products placed upon them than their rating allows. High breakdown torque enables the conveyor to continue operating under these conditions.

Full load torque is produced by a motor functioning at a rated speed and horsepower. The operating life is significantly diminished in motors continually run at levels exceeding full load torque.

Note:

1. The starting torque is 100% to 200%; the maximum torque is 200% to 300% of rated torque.
2. The current remains at a high value of more than 500% of rated current up to 75% to 80% speed and then drop sharply.

2.2   Motor Loading

Use of a portable power analyser (also known as load analyser, clamp on power meter etc.) is required to establish the power consumption of any equipment. Measurement of voltage, current and guessing the power factor of motor to calculate power consumption, can lead to large errors. This can, in turn, lead to wrong estimation of energy saving as well.

Estimation of shaft loading on the motor is very important while assessing motor performance. However, there is no direct measurement of shaft power possible under typical site conditions. Ratio of the measured current with the rated full load current on the motor in percentage terms gives the % current loading. Many times, this ratio is mistakenly used as % loading (read 'shaft loading') on the motor.

This can be inaccurate if the current drawn is much less than full load current. This is because the current a no load (i.e. zero shaft load) can be about 25% to 40% of the full load current of the motor. To estimate % shaft loading from % current loading, figure 2.7 can be used. Note that this figure is indicative only and it represents a large number of motors in different ratings combined together.
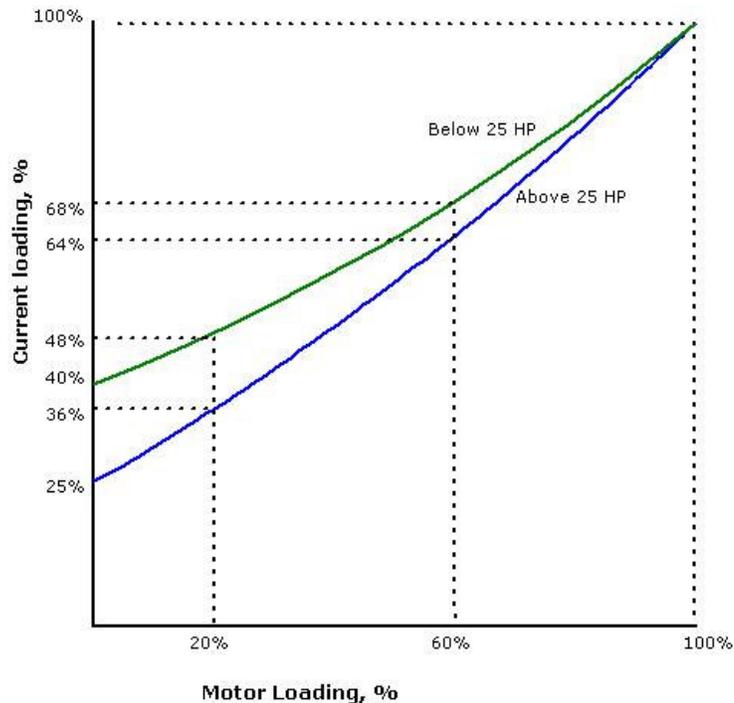
Motor Loading, %
Figure 2.7: Current loading .vs. Shaft loading

2.3   Power Losses in Motors:

Typical losses in motors are discussed below. Figure 2.8 shows the cross section of motors.

Core Losses: This consists of hysteresis and eddy current losses mainly in the stator core. The frequency of rotation of the magnetic field within the rotor is small during running condition and hence the rotor core loss is negligible.

Windage and Friction Losses: These losses are due to bearing friction and rotation of the rotor and fan in the air. Core loss and friction and windage losses are considered as fixed losses as they do not vary significantly with load.
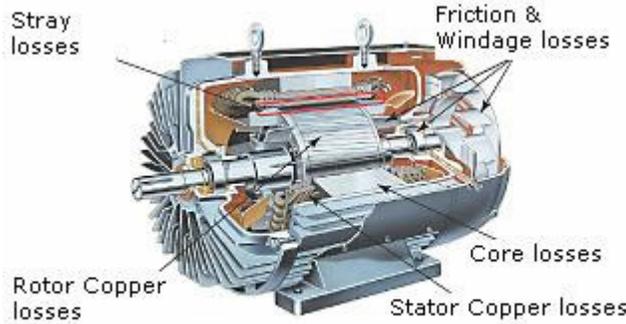
Figure 2.8:Motor losses

Stator Copper Losses: These losses are due to flow of current in stator conductors and are normally called I^2R losses.

Rotor Copper Losses: These losses are due to flow of current in rotor conductors and end rings.

Stray Load losses: These losses are extra magnetic and I^2R loss due to effects of slot openings, leakage flux and harmonic fields. These losses are difficult to measure or calculate.

The typical distribution of losses is summarised in Table 2.2

Table 2.2:Motor Loss Categories

Losses	2- Pole average	4- pole average	Factors affecting losses
Core losses	19%	21%	Electrical steel, air gap, saturation
Friction & Windage losses	25%	10%	Fan efficiency, Lubrication, bearing
Stator Copper losses	26%	34%	Conductor area, mean length of turn, heat dissipation
Rotor Copper losses	19%	21%	Bar and end ring area and material
Stray Load losses	11%	14%	Manufacturing process, slot design, air gap

2.4 Effect of Voltage Unbalance on Motor Performance

Percentage Voltage Unbalance is defined by NEMA as 100 times the deviation of the line voltage from the average voltage divided by the average voltage. If the measured voltages are 420, 430 and 440V, the average is 430V and the deviation is 10V. The Percentage Unbalance is given by

$$\frac{10V}{430V} \times 100 = 2.3\%$$

1% voltage unbalance will increase the motor losses by 5%. Fig 2.9 shows the increase in motor losses due to voltage unbalance.
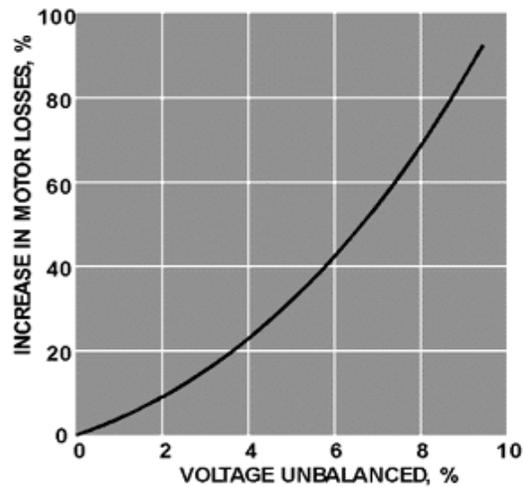
Figure 2.9 Effect of voltage unbalance on motor losses

The motor performance is also affected by voltage and frequency variation, the effects are summarised in table 2.2

Table 2.3: Effect of voltage and frequency variation on motor performance

	Voltage		**Frequency**	
	110%	90%	105%	95%
Torque, starting & maximum running	Increase 21%	Decrease 19%	Decrease 10%	Increase 11%
Speed				
Synchronous	No change	No change	Increase 5%	Decrease 5%
Full Load	Increase 1%	Decrease 1.5%	Increase 5%	Decrease 5%
% slip	Decrease 17%	Increase 23%	Little change	Little change
Efficiency				
Full load	Increase 0.5 to 1 point	Decrease 2 points	Slight increase	Slight decrease
¾ load	Little change	Little change	Slight increase	Slight decrease
½ load	Decrease 1 to 2 points	Increase 1 to 2 points	Slight increase	Slight decrease
Power Factor				
Full load	Decrease 3 points	Increase 1 point	Slight increase	Slight decrease
¾ load	Decrease 4 points	Increase 2 to 3 points	Slight increase	Slight decrease
½ load	Decrease 5 to 6 points	Increase 4 to 5 points	Slight increase	Slight increase
Current				
Starting	Increase 10 to 12%	Decrease 10 to 12%	Decrease 5 to 6%	Increase 5 to 6%
Full load	Decrease 7%	Increase 11%	Slight decrease	Slight increase

3 SELECTION & EFFICIENT OPERATION OF MOTORS

3.1 Importance of motor running cost – Life Cycle Costs:

The classic challenge for energy users is to determine whether it is appropriate to spend more money now in order to save money in the long term. However, just because something saves money in the long term does not necessarily mean that it saves an amount sufficient to justify the required additional investment. The law of diminishing returns suggests that even a good thing can be overdone. Properly applied, life-cycle cost analysis (LCCA) is a decision support tools that will lead to appropriate energy project choices.

In many applications it is worthwhile replacing motors even when considerable working life remains. Motors can run without problems for 20 years or more with good protection and routine maintenance. However, if they are running inefficiently, it is worthwhile replacing them as running costs are much more than first costs. Motors can be considered as consumable items and not capital items, considering the current energy prices. The importance of running cost can be seen from and Table-3.1. The following points may be noted:

Table 3.1 Importance of Running Cost of Motor Driven Equipment

Motor rating (kW)	7.5	7.5	37	37
Efficiency, p.u	0.86	0.88	0.92	0.93
Power input (kW)	8.72	8.52	40.22	39.78
Running hours/year	6000	6000	6000	6000
Energy input (kWh/year)	52320	51120	241320	238680
Running cost @ Rs. 5 per kWh	2,61,600	2,55,600	12,06,600	11,93,400
Running cost for 10 years (Rs.)	2,616,000	2,556,000	12,066,000	11,934,000
First cost (Rs.)	15000	18000	80000	96000
First cost as % of running cost for 10 years	0.6	0.7	0.8	0.9

1. Even a small motor of 7.5 kW consumes, at full load, electricity worth Rs.26 lakhs in 10 years. Similarly, a 37 kW motor consumes about Rs.1.2 crore worth of electricity in 10 years.

2. The first cost is only around 1% of the running coast for 10 years. Hence running costs are predominant in life cycle costing.

3. Even a small difference in efficiency can make a significant difference in running cost.

4. When economically justified, motors may be replaced, even if these have been recently installed.

3.2 Motor Rating Survey

It is worthwhile that a motor rating survey is carried out in industrial plants. The following methodology can be adopted.

1. Select important motors by size and long running hours. Initially, ignore small motors (below 3.7 KW) as well as those running for few hours (less than 3000 hours/annum).

2. Measure normal running current and input power. Kindly note that even on no load, motors take 30% to 40% of the rated current. Hence percentage motor load is not given exactly by the ratio of motor input current to rated current. Fig. 2.7 gives approximate curves for estimating motor load from motor current.

3. Identify motors with loads less than 40%, out of these again categorise frequently rewound motors.

4. Prepare a list of desired, properly sized motors for all important applications.

5. Interchange by properly sized   motors (available in the plant) whenever possible.

6. After motor burnouts, instead of rewinding, replace with properly sized high efficiency motors.

3.3   Stopping Idle/Redundant running of motor driven equipments

In all industrial plants, careful study will reveal that some motors are running idle.

➢ In many engineering industries, prolonged idling of machine tools, conveyors, exhaust fan etc. is common; stopping of such motors can save 100% of the power consumed by these motors.

➢ Care may be taken to stop idle running of auxiliaries like cooling towers, air compressors, pumps etc. during prolonged stoppage of production machines.

➢ In many production shops, lights continue to remain on during recess hours or at times when nobody is working or no production machine is on.

Redundant running implies that equipment is working without any effect on the production quantity or quality. Unless these are operating from safety considerations, stoppage of these motors can lead to large savings; e.g. operation of cooling tower fans or air-conditioning systems when ambient conditions are favourable.

➢ Large factors of safety are taken in design of machines and processes. Machines and plants many times operate permanently at throughput different from their design capacity.

➢ Similarly change in raw material, product mix and ambient conditions, also affect the requirements of process.

➢ Heat exchangers are always designed for worst case ambient conditions and maximum throughput conditions. The heat load many times turns out to be low permanently.

➢ Cooling water temperatures also may be quite low. Continuing with design flows will lead to wastage of energy and water.

➢ Similarly, humidification plants are designed considering full heat load of machines and worst summer conditions. These conditions rarely occur in practice. Number of humidification plants can be switched off in such   cases.

Examples:

➢ In a woven sacks manufacturing plant, a blower was used to suck away the broken tapes during the process. It was observed that the breakage of tapes at the point took place only while starting the machine. A timer was installed to switch off this blower 30 minutes after starting. The power saving was 6 kW. The annualised savings are about 36,000 kWh/annum i.e. about Rs. 1.6 lakhs/annum.

➢ For a rolling mill, drive of 1100 kW, 20 kW motors were used for cooling this main drive. It was found that drive idles for about 2 to 3 hours every day. The cooling fan motors were switched off for this period.

> ➢ A 7.5 HP Cooling tower fan, consuming 5.0 kW was put on automatic thermostatic control, to avoid fan operation during favourable ambient conditions.

> ➢ 10 HP rated agitator motors in process vessels were switched off when careful analysis revealed that agitators were not required during a few hours per batch when turbulence due to boiling is good enough.

3.4   Proper Sizing of Motors

It is important to remember that it is the load that determines how much power the motor draws. The size of the motor does not necessarily relate to the power being drawn. For example, a fan requiring 15 kW could be driven by a 15 kW motor; in which case, it is well matched. It could also be driven by a 30 kW motor, and although it would work, it would not be very efficient.

Motors are often oversized because of:

1. Uncertainty about load;
2. Allowance for load growth,
3. Rounding up to the next size;
4. Availability;

Because motor efficiency curves vary substantially from motor to motor, it is difficult to make a blanket statement as to which motors should be downsized. In general, if the motor operates at 40% of its rated load or less, it is a strong candidate for downsizing. This is especially true in cases where the motor load does not vary much. If you have a 100 horsepower motor that is typically operating at 35 horsepower, for example, but periodically is required to operate at 90 horsepower, it may not make sense to downsize the motor. If your motor operates at 50- 100% of its rated load, it is probably not a good candidate for downsizing, since it is operating near its peak efficiency

It often makes sense to replace oversized motors even if the existing motor has not failed. Remember, energy costs for a motor over the course of a year can be up to five times the cost of a new motor. This is especially true in cases where the motor is operating at a lower efficiency level due to over sizing.

Of course, there are benefits to over sizing motors in certain cases that should not be overlooked when determining what the proper motor is for a given application. In addition to providing capacity for future expansion, oversized motors can accommodate unanticipated high loads and are likely to start and operate more readily in under voltage conditions. These advantages can normally be achieved, however, with a modest over sizing margin.

The efficiency of motors operating at loads below 40% is likely to be poor and energy savings are possible by replacing these with properly sized motors.

Table 3.2 gives comparison of cost of owning an oversized motor.

Table 3.2: Increased Costs Due To Oversized Motor

Description	Unit	Motor Rating		
Motor Load Requirement	KW	15	15	15
Motor Rating	KW	15	30	55
Motor Efficiency at operating load	%	89	89	84
Input Power	KW	16.85	16.85	17.85
Input Energy Input Energy Cost @ Rs.5/-(for 6000 hrs/annum)	KWH	101100	101100	107100
Motor Power Factor		0.89	0.75	0.50
Input KVA		18.93	22.44	35.70
Energy Difference	KWH	-	-	6000
Investment	Rs.	25000	55000	95000
Increase in Investment	RS.	-	30000	70000
Increase in Running Cost	Rs.	-	-	24000

Oversized Motors lead to the following problems:

- Higher investment cost due to larger size.
- Higher running cost due to decrease in efficiency.
- Higher maximum demand due to poor power factor.
- Higher cable losses and demand charges.
- Higher switchgear cost.
- Higher installation cost.
- Higher rewinding cost (in case of   motor burnout)

There are two methods to optimise loading of a running motor.

- ❑ Connecting motors in STAR
- ❑ Use of Soft starter with energy saving features

Principles of these methods are explained below.

3.4.1   Operation of Under-Loaded Delta-Connected Motors in Star Connection

Fig.3.1 shows the efficiency, power factor, speed and current vs. motor shaft load characteristics in both Delta and Star connections.

'In Delta-Connection', the line voltage is impressed on each motor phase winding. Whereas in 'star connection', line voltage divided by √3 is impressed on each phase winding.

The vertical dark band (40 to 50% loads) is the 'Changeover' region, which differentiates possible Delta operating zone (right hand side) and Star operating zone (left hand side).

Observing the efficiency curves, it is clear that at light loads (30% or less); operation of motor in Star connection can save energy, as the efficiency is significantly better. It should be noted that, at light loads, change over to Star connection results in drastic drop in current. However, due to improved power factor, the drop in energy consumption is small and in likely to be about 5% to 20% in most cases (again remember that this is 5% of the actual motor input at light loads and NOT 5% of the motor rated load).

In star connection, the speed may drop by about 1% to 2% resulting in some additional savings in the case of centrifugal pumps and fans.

The following suggestions are made:

1. If a motor is oversized and continuously loaded below 30% of its rated shaft load, the motor can be permanently connected in Star.

2. If the motor is normally loaded below 30% but has a high starting torque requirement, then the motor can be started with a suitable starter and, after overcoming the starting inertia, be automatically switched from Delta to Star, using timer control or current sensing.

3. If the load is below 30% most of the time, but if the load exceeds 50% some times, automatic Star-Delta changeover Switches (based on current or load sensing) can be used. However, if the changeover is very frequent the contactors would get worn out and the savings achieved may get neutralised by the cost of frequent contactor replacements.

4. If the motor is nearly always operating above 30% of the rated load and sometimes runs below 30% load, star-delta changeover will not be economical.
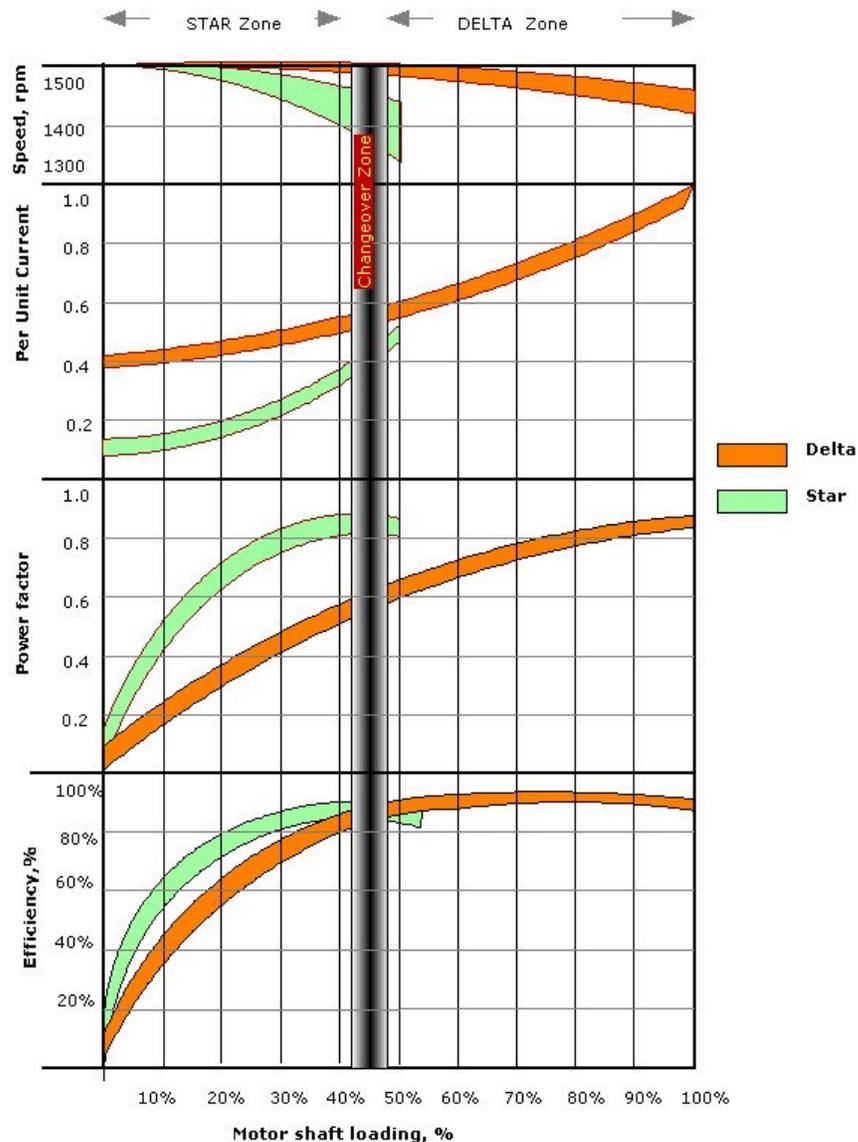

Figure 3.1: Star- Delta Operation of motor

An induction motor draws current from the supply in order to magnetize the core. At rated load, full magnetizing flux is needed for the machine to operate satisfactorily. At part loads however, full flux is not required but is still maintained if the terminal voltage is held at the nominal level. Therefore, for a motor operating at light load, the losses associated with maintaining full flux will be a significant proportion of the motor demand; hence the motor runs with a lower efficiency.

Soft starters are essentially stator voltage controllers, suitable for the following applications having:

•   restriction On starting current
•   frequent starts and stops
•   undesirable jerky starting due to step change in voltage
•   problem of sudden deceleration when supply is switched off.

This reduction in voltage causes the motor's magnetizing current to reduce, with a corresponding improvement in power factor, and the actual energy consumed is indeed reduced for an extremely lightly loaded motor.

Fig. 3.2 shows likely savings as a percentage of the motor rated power at different shaft loads for motor ratings from 5 hp to 100 hp.
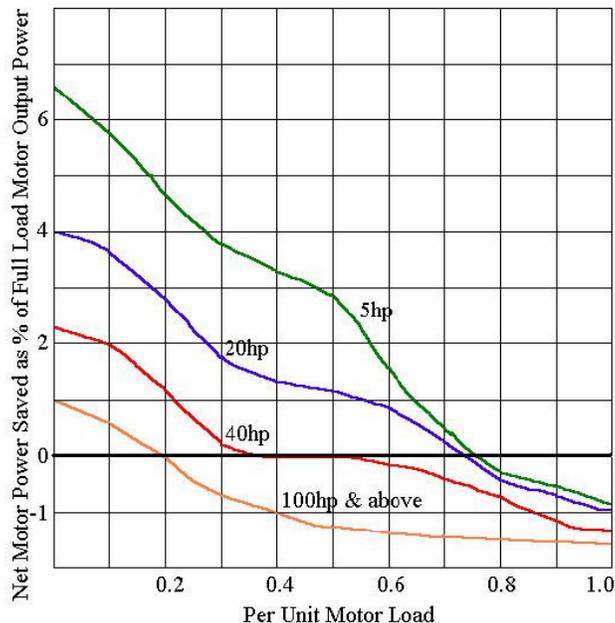

Figure 3.2: Energy Saving Potential by   Use of Soft Starter with Energy Saving Feature

Take a 40 HP motor. If it is loaded to about 20%, by use of a soft starter (with energy saving feature at low loads), saving is about 1.2% of the rated full load output power. If it is loaded to 70%, the savings are negative and you may actually end up consuming more power. However, for a 5 HP motor, even at 70% loading, a soft starter can save some energy and more savings if loading is still lesser.

So, the actual savings are highly application specific. The typical applications include machines which are operating at low loads for considerable amount of time.

3.5 Selection & Application of High Efficiency Motors

3.5.1 Design

The following steps are taken to improve motor efficiency and reduce losses. It must be emphasised that normal motors have reasonably good efficiencies.

- ✓ Core losses are reduced by using low loss steel (cold rolled), lower density (larger core area) and thinner steel stampings. The material is more expensive.

- ✓ Friction and windage losses are reduced by better fan design, improved bearings and improved aerodynamic design of rotor and airflow. In high efficiency motors, losses are low and hence cooling requirements are also lower.

- ✓ Stator copper losses are reduced by increasing the copper cross-section of winding wires; hence resistance and I^2R losses reduce, the weight of copper increases.

- ✓ Rotor copper losses are reduced by increasing the section of rotor bars and end rings, again more material is used.

- ✓ Stray losses are reduced due to increase in air gap, better electromagnetic design of slots and windings.

It is clear that high efficiency motors use more and better material and hence are more expensive. It should be understood that high efficiency motors have better performance even at partial loads.

3.5.2 Efficiency Standards

Values of efficiency of 4 pole motors is given in IS 12615: 2004 is summarised below in Table 3.3. There are two efficiency categories of efficiency viz. Eff1 & Eff2. To get good high efficiency motors, users are advised to specify efficiencies of new motors as per this standard.

Always mention efficiency values and do not just mention 'high efficiency motor'.

In general the following rules will apply:

1. For purchase of motor for a new application, the pay back period on the differential price is likely to be up to 1 year, depending on the rating, running hours and the tariff.

2. For replacing an existing running motor, the pay back period is likely to be about 1-2 years, after considering some salvage value for the existing motor.

3. For replacing a burn-out motor, which otherwise would have been rewound the pay back period is likely to be about 1.0 to 1.5 years.

Table 3.3:Values Of Performance Characteristic Of 4 Pole Energy Efficient Induction Motors

IS 12615: 2004

Rating Output kW	Frame Size Preferred	Full Load Speed Min. Rev./Min.	Full Load Current Max. Amps. (415 V)	Efficiency (equal or above)	
				Effi. 2	Effi. 1
0.37	71	1330	1.4	66.0	73.0
0.75	80	1360	2.2	73.0	82.5
1.5	90L	1380	3.8	78.5	85.0
3.7	112M	1410	8.1	84.0	88.3
5.5	132S	1420	11.4	85.7	89.2
7.5	132M	1430	15.4	87.0	90.1
11.0	160M	1440	22.0	88.4	91.0
18.5	180M	1440	36.0	90.0	92.2
30.0	200L	1450	56.0	91.4	93.2
45.0	225M	1460	84.0	92.5	93.9
75.0	280S	1470	134.0	93.6	94.7
90.0	280M	1470	164.0	93.9	95.0
110.0	315S	1480	204.0	94.4	95.2

3.5.3   A Note of Caution

• High efficiency motors have lower slip and hence these operate at slightly higher speeds. Hence in the case centrifugal pumps and fans, this may lead to slightly higher flows and some increase in power. Hence for these applications, use of high efficiency motors should be done carefully to ensure that the increased power requirement does not neutralise the reduction in motor losses.

• Measures like change in pulley ratios or trimming of impellers may have to be done to maintain the flow at existing levels.

3.5.4   Estimation of energy saving

Estimation of energy saving is illustrated by the following example.

Replacement of a Standard 7.5 kW Motor with a High Efficiency Motor

η_{std} = 85%
η_{HE} = 88%

$$\text{Power saving} = 7.5 \times \left(\frac{1}{0.85} - \frac{1}{0.88} \right) = 0.3 \text{ kW}$$

For 6000 hours/annum operation,

Energy saved = 0.3 x 6000   = 1800 kWh/annum

At a tariff of Rs. 5 per kWh,
Savings = Rs. 9000/- per annum

Price of a standard 7.5 kW motor is approximately Rs. 10,000/-. The premium for High Efficiency Motors is about 20% to 40% i.e. in this case about average Rs. 3000/- extra.

$$\text{Payback period} \quad = \frac{3000}{9000}$$

(on additional cost)   i.e. about 4 months

3.6   Motor Maintenance & Rewinding

Motors rarely burn out due to overload. Usually the abnormal conditions in the driven equipment, bearing seizure, failure or wrong setting/malfunction of protection devices, abnormal ambient conditions are the cause. Please investigate the cause before sending the motor for rewinding and repair.

3.6.1   Proper Lubrication

Proper lubrication is essential to long operating life for motors and all mechanical equipment. It must be done periodically and consistently—it is too late when the motor audibly communicates its needs. Many times service personnel try to quiet a noisy motor by pumping lubricant into the bearing. This may work for a short while but the life of a noisy bearing is limited and over-lubrication may result.

Too much lubrication can be just as harmful as too little. Excess oil or grease tends to accumulate: Windings become coated and this film collects even more dirt, moisture and, if brushes are involved, carbon dust. Oil and grease on the stationary switch contacts may cause them to overheat, arc or burn, and even to weld themselves closed. Lubricants harm many internal motor parts. If the manufacturer has lubricant recommendations they should be followed, especially in severe duty applications.

3.6.2   Belts and Pulleys

The efficiency of mechanical power transmission depends on grip between pulley and belt, which further depends on μ (Co-efficient of friction) and strength (Tensile) of the belt. In case of rubber coated canvas belts or leather belts available earlier, μ was as low as 0.2. Then with the coming up of V-Belt, effective μ improved up to 0.55.

Then with the introduction of chrome leather belts, μ improved to 0.7. Lately Elastomer coating started being given at the pulley side surface of flat belts and μ further improved to 0.75. Tensile strength also improved to 70,000 psi with the introduction of Polyamide belts. The efficiency of V-Belt is generally 90-95% against 95 to 98% of flat belt resulting in saving of 3-5% due to following reasons: -

➢   In V Belts, grip is good but it is less as compared to latest polyamide belts (Flat) with elastomer coating.
➢   V-Belt being thick has more resistance in bending at pulley surface.
➢   Being more in weight, outward pull due to centrifugal force is more, thus requiring more power to keep it pulled towards pulley.
➢   Elongation with use is more in case of conventional V-Belts, which reduces the grip and thus causes slippage over pulley resulting in loss of power, and also production of heat, which is due to loss of power.
➢   When multiple belts (v-belts) are used, these are generally not tight equally and do not work in synchronism, thus reducing transmission efficiency by further 3% which generally become 89%. In a six belt drive, even if two belts are mismatched, the life of belt is reduced by as much as 80%.
➢   Due to wedging between V-Belt and Pulley groove, resistance is more. This increases manifold in a misaligned and non-matched belt and pulley. The resistance causes unnecessary power loss, heat, deterioration of belt and uneven load on different belts.

Losses in a V-Belt are generally as below:

Table 3.4: Losses in V Belts

Sr. no.	Motor HP	Losses %
1	2	8-15
2	3	7-13
3	4	6-12
4	6	5.5-10
5	8	5-9
6	10	4.5-8.2
7	20	3.5-7
8	30	3.2-6
9	40	3-5.5
10	60	2.8-5
11	80	2.5-4.5
12	100	2.5-4.5

Pulleys also need to be precisely aligned for optimum performance. They must also be properly spaced for belts to have the right tension. Both parallel and angular misalignment will result in unnecessary friction between belt and pulley. Belt tension is achieved by moving the pulleys. If they are too far apart, undue stress is placed on the bearings of the pulley shaft, shortening their life. If too close together, the belt will slip on the pulleys, losing efficiency and wearing excessively. Belts and pulleys must be kept clean. Dirt, oil or grease on either can lead to shortened belt life and inefficient transfer of power. If needed, belts should be cleaned with a rag dampened with a light, non-volatile solvent. Belts should not be soaked or brushed with solvent All bearings require maintenance to perform properly and achieve their service lives.

3.6.3 Bearings

Bearings can be classified as sleeve or anti-friction types. In sleeve bearings the shaft rides in a thin film of lubricant between the shaft and the bearing. Antifriction bearings have ball or roller bearings that spin between the shaft and the bearing housing. There is considerable overlapping in the use of both types in electric motors. Proper maintenance consists simply of keeping the bearing clean, lubricated and loaded not in excess of its rating.

3.6.4 Rewinding

Efficiency is sometimes lost in rewinds for several reasons.

1. Core losses increase due to the high temperatures experienced during failure
2. Stripping the motor for repair also damages the laminations
3. Copper losses increase because of the practice of using smaller conductors, increasing I^2R losses.
4. Fitting of universal cooling fans, which may not be designed for the particular motor, leads to an increase in windage losses.

To avoid loss of efficiency during rewinding, the following points may be noted.

1. Rewind the motors as per the original winding data. If not available, contact the manufacturer.

2. Select a good rewinder following good practices.

3. Do not allow rewinders to use open flame or heat the stators above 350°C for extracting the old, burned out winding. This can damage the inter-laminar insulation of the steel core and increase the core losses.

4. Without heating, it is possible to remove windings by using special solvents.

5. Sand blasting of the core and/or grinding of laminations can also create shorts in the core, leading to higher core losses.

6. Keep data on no load inputs (current, power at a measured voltage) for all new motors, including motors returning after rewinding. These can be used for comparison and replacement decisions.

Motor rewinding does not necessarily lead to drop in motor efficiency. There are no general rules about the likely drop in efficiency. Motor efficiency reduces 1% to 2% by repeated rewinding. This is mainly due to increase in the core losses.

3.6.5   Maintenance of Motors

i). Daily: -
   ➢   Clean the motor and starter.

ii). Weekly: -
   ➢   Clean slip rings with soft brush dipped in white spirit.
       -
iii). Monthly: -
   ➢ Check earth connections of motor and starter.
   ➢ Blow through motor and starter with dry compressed air at 2 Kg/Cm^2.
   ➢ Check tightness of cable connections.
   ➢ Check motor for over heating and abnormal noise / sound, sparking and for proper bedding of brushes.
   ➢ Tighten belts and pulleys to eliminate excessive losses.

iv). Quarterly: -
   ➢ Check motor terminal voltage for balanced supply. If more than +1% of average, then check from transformer onward.
   ➢ Carry out SPM checks viz. vibrations and sound of bearing. Record reading and compare with earlier / other motor readings.
   ➢ Slip Ring: - Inspect the brushes and make sure that they move freely in the brush holder clips. Clean brushes, holder chip and wipe with cloth dipped and in gasoline. Replace the brush if they are worn out less than 5 mm in length from brush holder.
   ➢ Clean the starter and motor contacts with white spirit.

v). Six Monthly Maintenance: -
   ➢ Check over load mechanism of starter.
   ➢ Check alignment of motor with driven equipment.
   ➢ Check no load current and compare with earlier / original.
   ➢ Check / change lubrication as per lubrication schedule given on next pages.
   ➢ Check the securing foundation nuts for tightness.
   ➢ Inspect the paint coating and do-touching wherever required.
   ➢ Check IR of motor and starter with 500 V megger. It should not be less than 2 MΩ

3.7   Drive Transmission

3.7.1   Belt Drives

Direct drive is the most preferred option as it avoids transmission loss.

V-belt drives may have an efficiency of 85% to 90%; efficiencies of loose belts may be lower. Modern synthetic, flat belts have an efficiency of 96% to 98%. The losses in V-belts are higher as the belt wedges-in and wedges-out of the pulley grooves. Many users have achieved 5% to 8% savings by replacement of V-belts by flat belts. Synthetic flat belt technology has matured and is a preferred option, especially for new belt driven equipment.

For retrofit applications, expert advice should be taken in the selection of new flat belt and pulleys widths to avoid failures. Care should also be taken to ensure that the speed of the driven equipment does not increase after the changeover, as this may lead to increase in the basic power drawn by the driven equipment.

3.7.2 Gear Drives

The several types of gear drives include: helical, spur, bevel, and worm gear drives. Helical and bevel gear drives are the most widely used and are quite efficient. Spur gears appear in many older systems, but are rarely used in newer applications due to low efficiency.

Worm gears have the quality of largely reducing ratios, and they come in a rather small package. The major disadvantage with worm gears is their inconsistent efficiency. Worm gears are less expensive than helical gears for applications up to about 10-15 horsepower.

Helical gears are normally selected for larger loads. One interesting thing about helical gears is that if the angles of the gear teeth are correct, they can be mounted on perpendicular shafts, adjusting the rotation angle by 90 degrees.

The lower efficiency typical of worm gears many times necessitates a larger motor to drive a given load than a comparable helical gear setup.

Different types of gears have different efficiencies (Table 3.5). Energy savings can be achieved in some applications by replacing inefficient worm gears by helical bevel gears.

Table 3.5: Efficiency of Gear Drives

Type	Shaft orientation	Typical ratio per stage	Efficiency %
Spur Gear	Parallel	6:1	96
Bevel gear	Perpendicular, non intersecting	5:1	95
Worm gear	Perpendicular, non intersecting	75:1	65-80
Helical Gear	Parallel	8:1	90
Planetary Gear	Parallel	4:1	97-98

When compared to some larger worm gear units with high reduction ratios that may be only 65% efficient, the planetary solution is very much more efficient, at 98% efficiency per stage. This increased efficiency is based on reduced friction; a planetary gearbox is driven by a centre shaft that is connected to a carrier plate carrying three smaller gear wheels. The gear wheels run inside a toothed outer ring and drive a central gear cut around the central output shaft. This means that the load is spread among many contact points around each gear. Many, lighter contact points mean less friction, hence increased efficiency.

Since gear drives generally supplied by the OEM as part of the equipment, there may be some physical constraints in retrofitting more efficient gear drives.

3.8 Application of Adjustable speed drives

3.8.1 Energy saving by use of ASDs

Adjustable-speed drives (ASDs)—also known as variable-speed drives, variable-frequency drives, or variable-frequency inverters—use electrical waveform modification to vary the voltage and frequency of the alternating current that drives the motors. By controlling motor speed so that it closely corresponds to varying load requirements, ASD installations can reduce energy consumption (in some cases energy savings can exceed 50 percent). ASDs can also improve power factor and provide other performance benefits such as soft-starting and over speed capability. The following figure gives a schematic of a typical adjustable frequency drive system.
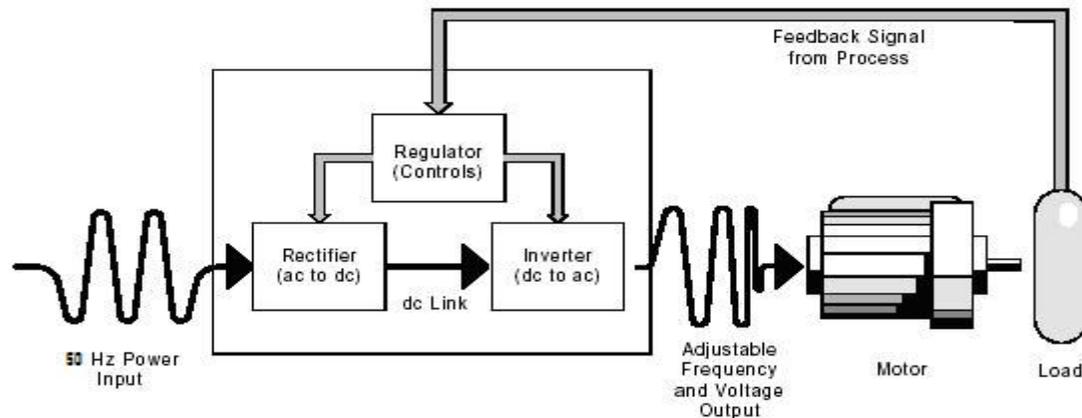
Figure 3.3: Adjustable frequency drive system schematic

ASDs require a small amount of power to operate, and so motors with an ASD consume more power at full load than single-speed motors. However, it takes very little time operating at part load to make up the difference.

Good applications for variable-speed control are those which:

➢ Are fixed at a flow rate higher than that required by the load.
➢ Are variable-flow, where throttling (by valves or dampers) provides the variation and where the majority of the operation is below the design flow.
➢ Use flow diversion or bypassing (typically via a pressure-reducing valve).
➢ Are greatly oversized for the flow required. This situation can occur where successive safety factors were added to the design, where a process changed so that the equipment now serves a load less than the original design, and where a system was over designed for possible future expansion.
➢ Have long distribution networks and have flow control by on-off cycling.
➢ Have a single large pump or fan rather than a series of staged pumps or fans that come on sequentially as the process needs increase.
➢ Can reduce the pressure at the outlet of the fan or pump at lower flow. For example, a pump that pumps water into a long pipeline that can move the water at a lower pressure when the flows are low (due to the decreased frictional losses into the pipes) would be a good candidate for a ASD.

Loads ideal for ASD application: Variable Torque (centrifugal pumps, fans etc.)

Liquids and gases when moved require a pressure proportional to the square of the velocity (i.e. volume moved). These loads, torque increase with square of the speed and are usually associated with centrifugal fan and pump loads, where, in theory, the horsepower requirement

varies as the cube of the speed change. These applications usually have the greatest opportunities for energy savings as well as improved control.

In some instances, as in a very low velocity mixing processes, torque is proportional to speed. Power will be proportional to square of the speed.

Loads requiring careful ASD application: Constant Torque loads (Positive displacement air compressors, conveyors, crushers etc)

Constant-torque loads require the same torque regardless of speed. Although constant-torque loads are suitable for ASDs, operation of these loads at low rpm will be limited, and the ASD must be carefully sized to ensure adequate starting torque. Power is proportional to speed.

Loads difficult for ASD application: Constant power loads (Machine Tools)

In this group, the load torque decreases with increasing speed. This application usually applies to processes that are changing diameters, such as lathes, winders, unwinders, and metal-cutting tools operating over wide speed ranges. With a large diameter, maximum torque and slow speeds are required. As the diameter decreases, the torque decreases, but speed increases to provide constant surface speed. There is rarely scope for energy saving from speed reduction in constant power loads.

3.8.2	Some Issues for Consideration When Using Electronic Ac Variable Speed Drives

Users of electronic AC variable speed drives should be aware of some of the issues related to reliability for motors with electronic variable speed drives. For critical and large motors, care may be taken, at the time of system design, to mitigate these undesirable effects.

Leakage Currents
High frequency harmonics of inverters can cause an increase in the magnitudes of leakage currents in the motor due to reduction in the capacitive reactance of the winding insulation at higher frequencies. Established and safe grounding practices for the motor frame should therefore be followed.

Voltage Spikes
Inverters used to supply adjustable frequency power to induction motors do not produce sinusoidal output voltage waveforms. In addition to lower order harmonics, the waveforms also have superimposed on them steep-fronted, single-amplitude voltage spikes. Turn-to-turn, phase-to-phase and ground insulation of stator windings are subjected to the resulting dielectric stresses. Suitable precautions should be taken in the design of drive systems to minimise the magnitude of these spikes.

Shaft Voltages and Bearing Insulation
Inverters may generate common mode voltage, which shifts the three phase winding neutral potential significantly from the ground potential. This common mode voltage oscillates at high frequency and is capacitively coupled to the rotor. This results in peak pulses as high as 10-40 volts from shaft to ground. The current path could be through either or both bearings to ground. This can lead to pitting of bearings ad reduction of bearing life. Interruption of this current therefore requires insulation of both bearings. Alternatively, shaft grounding brushes may be used to divert the current around the bearing. However, there is no conclusive information on the relationship between peak voltage from inverter operation and bearing life.

Neutral Shift
When inverters are applied to motors, the motor windings can be exposed to higher than normal line-to-ground voltages due to the *neutral shift effect*. Neutral shift is the voltage difference between the source neutral and the motor neutral. Its magnitude is a function of the total system

design and a proper method to reduce the neutral shift should be incorporated by the system designer.

Motor damage from ASDs located too far from motor.

Pulse-width modulated (PWM) drives can cause significant damage to motors if the length of cable between the ASD and the motor exceeds 50 to 100 feet. (The number seems to differ by manufacturer.) Older motors with long cable runs may have shortened lives using PWM ASDs. Carefully watch motor lead lengths, consider buying an inverter-duty motor, or select an ASD system that will specifically guard against this hazard with inductive filters or other methods. Now new generation of inverter drives have been developed to take care of above problems. They are expensive. Motor winding wires are also provided with thicker insulation for inverter duty.

4   INTEGRATED SYSTEMS APPROACH

There is always a tendency among industrial users and consultants to start with replacement of standard motors with high efficiency motors, as an initial consideration in energy conservation programs. This approach needs a critical review, as it is the end uses which consume lot of energy and it is very important to understand and analyze the system which the motor drives; like a compressor, a pump or a fan. This doesn't mean that motors do not deserve attention. But understanding systems and requirements helps to re-size the motor better, if a motor replacement is desired.

A detailed study of end-use i.e. flows, pressures, temperatures etc. and equipment like air compressors, pumps, blowers, refrigeration machines etc. and system components like piping, ducting etc. is required to achieve large savings.

4.1   Pumping Systems

Integrated systems approach in a pumping system includes the following:

Optimising the Use of Water
- Optimal use of water for various applications can significantly reduce the raw water pumping energy consumption.

- Review of water circulation rates to optimise flow rates for process cooling can also have a significant effect on energy consumption

Selection of Pumps to Match Head / Flow Requirements

- Pumps have a good efficiency in a very narrow flow zone; operation at higher or lower than design flows can lead to drastic drop in efficiency from the design value.

- Mismatch in pump selection is often overcome by throttling of valves, however this leads to large wastage of energy.

Number of Pumps in a System
- For systems with large flow requirements and for critical applications, pumps are generally operated in parallel. The sizing of these pumps also offers the possibility for energy saving for applications where the flow can be varied depending on process conditions or seasons.

Use of Variable Speed Drives
- Use of mechanical, electrical or electronic variable speed drives can help in improving the pumping system efficiency in cases that require variable flow or in cases where the pumps are oversized and the flow is controlled by throttling of valves.

Optimising Pipeline Sizes
- Pipe friction losses depend on the pipe diameter, material, surface condition and age.

- Use of larger pipes can reduce losses. The pipe pressure drop is inversely proportional to the fifth power of the pipe diameter.

Maintenance
- Wear and tear of pumps and scaling of pipes and heat exchangers can affect the energy consumption.

- Proper maintenance of pumps and proper water treatment is necessary to maintain reasonable efficiencies

Monitoring & Control
- Proper instrumentation is necessary to monitor the performance of pumps and associated systems. This can help identify opportunities for optimising flow, pressure and energy consumption.

Electric Motor
- The motor may be selected close to the rated power requirement of the end use equipment. For new purchases, high efficiency motors may be preferred. Apply high efficiency motor carefully to avoid excess flow due to high full load speed of high efficiency motor.

4.2   Compressed Air

Compressed air is an expensive utility. Cost of compressed air is sometimes as high as 10 times energy cost compared to other electro-mechanical alternatives. The useful energy content in compressed air which is available at the end use is only about 10 to 20% even in a well designed system.

The Integrated Systems Approach in Compressed Air System has the following steps.

Reducing Compressed Air Use
- Many uses of compressed air like cleaning, material conveying, scouring, agitation and aeration of liquids etc. are not justified at the present energy prices.
- For applications like cleaning & conveying, blowers can be used. For material conveying, use of efficient alternatives like belts, bucket elevators, screw conveyors etc. can be used. For agitation or aeration of liquids, low-pressure Roots compressors or submersible (pump type) agitators can be used. More efficient, portable electrical tools can replace pneumatic portable tools.
- In many plants, pneumatically operated controls are being replaced by electronic and electrical controls, thus reducing the requirement for instrumentation air. In all these cases, the potential for energy saving is about 80% to 90%.

Pressure Reduction
- A thorough study of the end-use pressure requirements and the compressor discharge pressure should be done. An opportunity to reduce the discharge pressure should not be missed as it can give significant energy savings due reduced compression power as well as reduced air leakage.
- An approximate thumb rule is that 10% reduction in compressor discharge pressure reduces energy consumption by about 5%; the savings due to leakage reduction are additional.
- In cases where higher pressures are set to overcome the problem of pressure fluctuations, increase in receiver capacity and use of newly developed pressure & flow controllers can help reduce pressure settings.

Air Leakage Reduction
- Compressed air leakage can vary from 5% to 70% or higher depending on the house keeping efforts on the compressed air distribution system.
- At the present energy cost, all plants should attempt to operate at leakage levels below 5%. Even a small leakage of 50 cfm is equivalent to a loss of Rs.3.0 lakhs per annum (@ Rs. 4.50 per kWh). Air leakage generally take place from threaded pipe joints, hose connections, valve stems, buried underground lines etc.

Distribution System
- Decentralised installation of compressors can lead to smaller distribution systems and hence reduced pressure and leakage losses. However, whether a system should be decentralised or centralised depends on the air utilisation patterns for various end uses in the plant. If uses are highly variable and the equipments (with significant air consumption) are spread out over a large area, a decentralised system may be preferred, with interconnections with isolation valves for emergencies.
- A decentralised system facilitates switching off compressors when air is not required in a particular area.
- Pipe sizing should be done to minimise pressure drops, say less than 0.3 bars from the receiver at the compressor end.
- Isolation valves should be provided at convenient, accessible locations to shut off air when not required in certain areas for known time periods.

Selection of Compressors & Capacity Control
- Compressors should be selected with a good understanding of the air utilisation pattern. Reciprocating, Screw or Centrifugal or Roots compressors can be used depending on the pressure, quantum of air required and the air demand variations.
- All compressors have the facility for capacity control; part load efficiencies depend on the type of compressor and the method of capacity control; prolonged operation at part loads results in higher energy consumption.
- Compressors consume 10% to 50% of their rated power (depending on the type of compressor and capacity control method) even at no load. The attempt should be to ensure that the operating compressors run close to their rated load.
- Automatic controls are available to detect and switch off compressors operating in unloaded condition for prolonged period.

Maintenance
- Routine maintenance checks on compressors and the distribution system is necessary to ensure efficient compressed air generation and utilisation. The performance of reciprocating compressors can deteriorate significantly due to poor maintenance.

Drive Transmission
- Directly coupled drives have no transmission losses. However, in the case of belt driven equipment, the possibility of use of more efficient, synthetic flat belts should be explored.

Electric Motor
- The motor should be selected close to the rated power requirement of the end-use equipment. For new purchases, high efficiency motors may be preferred.

4.3   Refrigeration & Air-Conditioning

An integrated systems approach to Refrigeration and Air conditioning emphasizes on the following issues.

Reducing the Need for Refrigeration
- At the present energy prices, the use of chilled water, brine and air-conditioning should be minimised, as these are very expensive utilities.
- For process cooling applications, many foreign machinery suppliers specify chilled water at 10°C to 15°C as these are the normal cooling tower water temperatures in cold countries for most time of the year.
- The possibility of replacing chilled water with cooling water with higher flows can be considered.
- Air-conditioning should be restricted to small spaces, as guided by process requirements. Comfort air-conditioning should be provided only if necessary in small areas.

Increase Temperature Settings
- Operation at 1ºC higher temperature can save about 3% energy. Hence the opportunity to operate at higher chilled water/brine temperatures should not be missed, after careful trials to assess its impact on process productivity and quality.
- For comfort air-conditioning, operation at 26º or 27ºC air temperature, instead of 24ºC, is possible, provided better air movement is provided with fans.

Reduce Heat Ingress
- Vessels, pipelines and pipe fittings (like valves, flanges, bends etc.) handling refrigerant, chilled water or brine should be well insulated.
- For air-conditioned spaces and cold stores, appropriate methods like double doors, fast closing doors, air curtains and low emissivity films (sun control) for glass windows should be incorporated.
- Building insulation is strongly recommended for air-conditioned buildings, this aspect is usually neglected in India.

Better Heat Exchanger Design and Maintenance
- Use of larger and better heat exchangers (evaporators & condensers) can help in increasing the refrigerant temperature in the evaporator and decreasing the temperature in the condenser for the same end use temperatures and cooling loads. The potential for savings can be 10% to 30%. This can be ideally addressed at the time of purchase of new equipment.
- The quality of circulating chilled and cooling water should be maintained within tolerable limits to prevent scaling and ensure efficient heat transfer. Proper water treatment is necessary for maintaining the efficiency of a refrigeration plant.

Better Monitoring & Control Techniques
- Good control of the compressor based on accurate sensing of end use temperatures can result in significant savings in systems prone to super-cooling.
- In addition, for air-conditioning systems, use of occupancy sensors can save significant amount of energy.

New Developments for Relative Humidity Control
- Use of special air-to-air heat exchangers can eliminate the need for duct heaters and desiccant dehumidifiers for relative humidity control. By use of these new technologies, some plants have achieved 30 to 50% energy savings.

Energy Storage
- Some electricity boards have adopted *Time of Use* energy pricing, which implies higher energy prices during certain hours. By operation of compressors in off-peak hours (when energy price is low), *Cooling Effect* can be stored in ice banks, some special salts etc.
- In addition to the advantage of lower energy cost, this method can also help reduce the peak kW and kVA demand of the plant, resulting in lower Maximum Demand charges.

Inter-fuel Substitution: Use of Absorption Chillers
- Vapour Absorption System, which uses a heat source to achieve cooling, can reduce the electricity requirement by 80 to 90%. The economics depends on the cost of heat energy. This technology has found good acceptance in locations having waste heat or access to cheaper alternative fuels.

Drive Transmission
- Directly coupled drives have no transmission losses. However, in the case of belt driven equipment, the possibility of use of more efficient flat belts should be explored.

Electric Motor
- The motor should be selected close the rated power requirement of the end use equipment. For new purchases, high efficiency motors should be may be preferred.

5 CASE STUDIES

5.1 Switching off Idle/redundant operation of motor driven equipment

5.1.1 Case Study-1: Thermostat based operation of cooling tower fan

Industry / **Sector** : Glass	
Year of Implementation: 1999	
Cost Benefit Analysis	
❑ Type of Measure: Low cost measure	
❑ Annual energy Savings: 51,000 kWh	
❑ Actual cost savings: Rs 1.53 lakhs/annum	
❑ Actual investment: Rs 25,000/-	
❑ Payback: Immediate	

Principle	Automatic temperature control for the operation of cooling tower fan resulted in switching off cooling tower fan whenever heat load on the cooling tower is reduced.

Background	The unit has centralized cooling tower to meet the cooling water requirement. The major heat loads are a glass furnace and refrigeration condensers. The cooling tower has three cells and each cell is served by individual fan. All three fans were operated and no control systems were installed to the cooling tower for the auto operation of fans. Detailed analysis and measurement carried out during full production of the plant. Design cooling load of the cooling tower : 4 lakh kcal/h No of cells : 3 Design heat load of each load : 1.33 lakh kcal/h Design range : 5 ºC Measured range : 5 ºC Measured approach : 0.5-1.0 ºC Design cooling water flow rated : 800 m3/h Actual water flow rate (measured) : 485 m3/h Present heat load : 2.43 lakh kcal/h Power consumption by one fan : 6 kW It can be seen that the actual heat load is about 60% of the total heat load which can be met by two cells only. Plant has taken immediate steps and incorporated the thermostat to one fan. It was observed post-implementation that the fan remained switched off continuously since two cooling tower cells were able meet the demand.

5.2   Matching motor with the driven load

5.2.1   Case Study-2: Operation in STAR connection for under loaded motors

Industry / **Sector** Edible Oil manufacturing Plant	
Year of Implementation: 1995	
Cost Benefit Analysis	
❑ Type of Measure: No cost measure	
❑ Annual energy Savings: 4560 kWh	
❑ Actual cost savings: Rs 18,240	
❑ Actual investment: Minor	
❑ Payback: Immediate	

Principle	When motors are under-loaded, their torque requirement is less compared to that at full load. Hence the impressed voltage required at the motor windings is less due to less torque required. 'In Delta-Connection', the line voltage is impressed on each motor phase winding. Whereas in 'star connection', line voltage divided by √3 is impressed on each phase winding. When 'star' connected, the current drawn by the motor drops significantly, power factor increase also takes place. Overall power saving is likely to be 10 to 20% depending on the extent of under loading.

Background	In this edible oil (Vanaspati) manufacturing company, A 25 hp/18.5 KW motor was driving a cooling water circulation pump. The electrical measurements in 'delta connection' were as follows :
	
	        Voltage : 415 V
	        Current : 18.5 A
	        Power Factor : 0.505
	        Power Input : 6.72 KW
	        Speed : 1469 rpm
	
	Considering the fact that the load was less than 30%, it was decided to operate the motor in star connection.
	
	        Voltage : 415 V
	        Current : 9.5 A
	        Power Factor : 0.873
	        Power Input : 5.96KW
	        Speed : 1454 rpm
	
	It may be noted that the current has dropped but the power Considering the fact that the load was less than 30%, it was decided to operate the motor in star connection.
	
	Note that the reduction in power from 6.72 kW to 5.96 kW is not only due to reduction in motor losses, but also a due to reduction in speed of driven equipment.

5.2.2 Case Study-3: Use Of Electronic Soft Starters on Conveyors System

Industry / **Sector** Sea Weed manufacturing
Year of Implementation: 1996
Cost Benefit Analysis
❑ Type of Measure: Major investment
❑ Actual cost savings: £178
❑ Actual investment: £275
❑ Payback: 18 months

Principle	When motors are under-loaded, their torque requirement is less compared to that at full load. Hence the voltage to be impressed on the winding is also less due to less torque required. For loads that are idling for most of the time and loaded time is less, use of voltage controllers to optimise voltage supply can save some energy.
	
	Use of a soft starter is considered in this case due to the fact that it helps in smooth starting of the conveyors, reducing jerks and spill over. The benefits were:
	
	    ➢ Soft Start
	    ➢ Energy Saving Optimisation
	    ➢ ' No-load' Timed Cut Off
	    ➢ Reduced Maintenance Costs
	    ➢ Quieter Machinery
	    ➢ Reduced Downtime

Background	The Company process commercially dredged seaweed to produce agricultural fertilizer for grazing land. Their prime consumption of electricity within the facility is through the use of conveyors, which transport the calcified seaweed from the quay into the main building, where it is dried and bagged for distribution. The AC Induction Motor driving the conveyor must be sized to handle a full load on the conveyor. Many conveyors run with varying loads or continual partial loads. No soft start was in operation initially and associated maintenance issues were therefore apparent. A trial with a soft starter with energy saving features at low loads was undertaken on two conveyors within the seaweed facility. The conveyors are hopper fed, which creates a continual but partial load. *Table 5.1: Energy saving by use of softstarters* | Description	Value
Annual Consumption	£475.00
% Savings	38%
Annual Savings	£178.00
Cost of soft starter	£275.00
Pay back period	18 months | When the results were measured using a high quality 3-phase analyser, it was identified that kW savings obtained were 38%, which equated to a return on investment of just over 18 months.

5.3 Use of High efficiency Motors

5.3.1 Case Study 4: Replacement of Inefficient Motor by High Efficiency Motor

Industry / Sector: Dry Cell Manufacturing plant
Year of Implementation: 1997
Cost Benefit Analysis
❑ Type of Measure: Medium investment
❑ Annual energy saving: 8766 kWh/annum
❑ Actual cost savings: Rs 35,000/-
❑ Actual investment: Rs 35,000/-
❑ Payback: 1 year

Principle	Replacement of standard efficiency motors with high efficiency motors can give savings of about 2 to 5% depending on the ratings. The savings can be still higher if the efficiency of existing motor is poor. In this case a motor which is frequently rewound and very high no load current is replaced with a high efficiency motor.
Background	A 15 kW motor was being used to drive an air-conditioning compressor. This motor had been rewound a few times. The normal load current was 32.5 A. Since this was higher than the rated current. The no load current (after removing the belts) was observed to be 24 A (85% of the full load current) and the no load power loss was 2.334 kW, which is very high. The operating efficiency of the motor was estimated to be about 76%. This motor was replaced by a new *High Efficiency* Motor. Existing Motor: Make: Bharat Bijlee, Rating: 15 kW/20hp, Voltage: 415V, Current: 28A, Speed: 1445 rpm New Motor: Make: Bharat Bijlee, Rating: 15 kW/20hp, Voltage: 415V, Current: 26.1A, Speed: 1450 rpm, Efficiency: 90.8%, Power Factor: 0.88 The measured no load current was 6.6 A and the no load power was 0.873 kW. The saving in no load power itself was 1.461 kW (from 2.334 to 0.873kW). Ignoring the reduction in copper losses, the minimum saving for about 6000 hours operation is 8766 kWh/annum i.e. Rs. 35,000/- per annum. The investment in the new motor was Rs. 35,000/-. The pay back period was one year.

5.3.2 Case Study-5 : Replacement of Inefficient, Oversized Motor with High Efficiency Motor

Industry / Sector: Commercial Building/Hotel
Year of Implementation: 1998
Cost Benefit Analysis
❑ Type of Measure: Medium investment
❑ Annual energy saving: 2628 kWh/annum
❑ Actual cost savings: Rs 11,406/-
❑ Actual investment: Rs 11,000/-
❑ Payback: 1 year

Principle	Replacement of standard efficiency motors with high efficiency motors can give savings of about 2 to 5% depending on the ratings. Along with using a high efficiency motor, if proper sizing also can be done. Energy savings will be more and investment less.
Background	For a coffee shop in a hotel, a 7.5 hp motor was used. It was loaded to 44% and hence replaced by a 5 hp energy efficient motor.

Table 5.2: Energy Saving by use of high efficiency motors

Particulars	7.5 hp standard motor	5 hp high efficiency motor
Motor rating (hp)	7.5	5.0
Input voltage (V)	400	400
Power factor	0.84	0.89
Frequency (Hz)	50	50
Full load speed (rpm)	1430	1450
Measured speed (rpm)	1469	1462
Blower speed (rpm)	755	746
Measured current (Amp)	8.6	7.18
Energy consumed (kWh /hour)	5.0	4.4

The annual savings for 4380 hours/annum operation was 2628 kWh i.e. Rs 11406/- per annum @ Rs 4.34 per kWh. The investment was Rs. 11,000/- and the payback period was one year. It may be noted that the saving are very attractive in this case, as an appropriately sized, smaller motor has been selected. Also some additional savings have been accrued due to the marginally lower speed with the new motor.

5.3.3 Case Study-6: High efficiency motor in place of standard motors when replacing equipments

Industry / Sector: Plastics

Year of Implementation: 1992

Cost Benefit Analysis

❑ Type of Measure: Long term, medium investment

❑ Annual energy saving: kWh/annum

❑ Actual cost savings: £ 408.74/annum

❑ Additional investment: £ 408 668.29

❑ Payback: 1.67 year

Principle	In the majority of cases the use of higher efficiency motors should be considered for new plant or when an existing motor is to be replaced. The comparison will therefore be between a new standard motor and a new higher efficiency motor.
Background	Delta Extrusion, part of Delta plc, operates from two production sites in the heart of the West Midlands. Both sites are designed and planned for the efficient manufacture of high quality semi-finished brass products. At Delta Extrusion five motors were replaced with higher efficiency motors to give a reasonable cross section of the range of cast iron motor ratings. Three of the motors were running continuously; the remaining two ran on a 5-day, 3 shift operational pattern.

Measurements of average load and data on motor efficiency were used to compare |

the running costs of the new higher efficiency motors with the equivalent standard motor. A comparison was also made with the running costs of the motors which had been originally installed. The table below details the selected motors, their application and their running hours.

Table 5.3: Motors Tested

Rating(kW)	RPM	FrameSize	Application Description	Running hours/year
30.0	1,465	D200L	Mecatherm billet reheat furnace exhaust fan	4,704
18.5	2,950	D160L	Mecatherm billet reheat furnace combustion air fan	4,704
7.5	2,870	D132S	Induction furnace cooling fan	8,760
5.5	2,870	D132S	Induction furnace coil cooling fan	8,760
1.1	2,800	D80	Induction furnace capacitor pump	8,760

Table 5.4: Table of Savings Summary

Rating(kW)	Average Load (%)	Running Hours	Savings(£)	Premium(£)	Payback Period (years)
30.0	49	4,704	80.67	271.6	3.37
18.5	27	4,704	110.38	179.9	1.63
7.5	87	8,760	76.65	94.5	1.23
5.5	60	8,760	110.38	85.4	0.77
1.1	77	8,760	30.66	36.89	1.20
Totals			**408.74**	**668.29**	**1.64**

The electrical energy savings are converted into financial savings by applying an average electricity cost of 3.5p/kWh. This figure is the average annual electricity cost to Delta Extrusion. Overall the savings achieved from the fitting of higher efficiency motors provided paybacks on the differential cost between standard and higher efficiency motors of between 9 months to 3.4 years. Across the group of five motors the savings were £408.74 with a payback of 1.64 years. Thus higher efficiency motors can be justified as cost-effective where a motor is new or requires replacement.

5.4 Improve Drive Transmission efficiency

5.4.1 Case Study-7: Flat Belt in Place of V Belt in Air compressor:

Industry / Sector: Engineering Industry-Office equipment Division	
Year of Implementation: 2001	
Cost Benefit Analysis	
❑ Type of Measure: Minor Investment	
❑ Annual energy saving: 40000 kWh/annum	
❑ Actual cost savings: Rs 160,000/-	
❑ Actual investment: Rs 75,000/-	
❑ Payback: 6 months	

Principle	Use of Nylon Sandwiched flat belts in place of V belts can save 5 to 10% of energy in pulley drive equipments. V-belt drives may have an efficiency of 85% to 90%; efficiencies of loose belts may be lower. Modern synthetic, flat belts have an efficiency of 96% to 98%. The losses in V-belts are higher as the belt wedges-in and wedges-out of the pulley grooves

| Background | In Place of 'V' belt drives, modern synthetic flat belts are installed in the engineering Co. manufacturing Office equipments. The replacement was done on air compressors and refrigeration compressor drive systems.

Type of Machine : Reciprocating Air Compressors -   500 cfm capacity
Connected Motor Specs. - 100 KW/135 HP, Slip Ring, SPDP,1500 rpm

Motor Pulley Dimensions- 358 mm (Dia.) x 238 mm (width)
Power consumed with 6 nos V Belts   -   90 KW
Power consumed with 1 no. flat belt   -   82 KW
Power Savings with flat Belt   -   8 KW
% Power Saving with flat belt   -   8.88%

For 5000 hours/annum operation, annual energy saving was found to be 40000 kwh. i.e Rs 1.6 lakhs per annum. Investment required was Rs 75,000/- for belts and new pulleys. Pay back period was 6 months. |
|---|---|

5.4.2   Case Study-8: High efficiency planetary gears in place of worm gears:

Industry / Sector: Chemical-Pesticides
Year of Implementation: 2004
Cost Benefit Analysis
❑   Type of Measure: long term- major investment
❑   Annual energy saving: 1,86,000 kWh/annum
❑   Actual cost savings: Rs 9,29,000/-
❑   Actual investment: Rs 5,46,000/-
❑   Payback: 7 months

Principle	Worm gears have been the workhorse of chemical industry in speed reducing/torque multiplying applications like agitators, reactor vessels, blenders etc. Efficiency of worm gear is very poor, varying from 65 to 80%. Replacing these gears with more efficient planetary gears and helical bevel gears can save energy. In fact, more savings are possible by changing gears, compared to changing motors.

| Background | Objective is to minimize the operating cost of gearboxes and reduction in noise level. In DVACL & MPBAD plant, nine Reactors were having worm type gearboxes, which were working on 74% efficiency. For these reactors helical and planetary gearboxes were installed. There efficiencies are around 94 %. This had reduced not only the operating cost of the system but also the noise level.

Technical & Financial Implementation :
Power consumption = 112 kWh (with worm type gear box)
Power consumption = 90 KWH (with planetary & helical type gear boxes)
Total power saving   = 1.86 Lac kWh / annum
Total saving   = Rs 9.29 Lac
Total Investment   = Rs 5.4 Lac

Impact of Implementation:
Noise level reduction
Less space |
|---|---|

5.5 Improvement in motor driven systems

5.5.1 Case Study-9: Proper Sizing of Pumps

Industry / **Sector**: Engineering Industry-Office equipment Division	
Year of Implementation: 2002	
Cost Benefit Analysis	
❏ Type of Measure: Major investment	
❏ Annual energy saving: 3,27,000 kWh/annum	
❏ Actual cost savings: Rs 13,20,000/-	
❏ Actual investment: Rs 2,00,000/-	
❏ Payback: 2 months	

Principle	When new systems are selected, the OEM(Original equipment manufacturer) may select equipments without having customised for the given situation. This case study refers to such a situation where, for a spray Phosphating plant incorrect selection of pumps by the OEM resulted in energy wastage. For maintaining a spray pressure of 1.0 bar, the pump was selected for a pressure of 2.5 bar. Selection of pumps should be done carefully to match the system flow and pressure requirement so that the pump operating at the best efficiency point. Even if equipments are new, it is still worthwhile to replace them with more efficient equipments when economically feasible.

Background	In an engineering plant, manufacturing steel office equipment, the pumps of the Spray Phosphating Plant were studied. All the existing pumps were rated for 25m head and 40 lps flow. The actual operating pressures, estimated flow, power consumption data, estimated efficiencies of the pump and the system are shown in table 5.5 below. In some cases the pumps were throttled, the system efficiency has been calculated to get a feel of the useful system power requirement. It may be noted that the pump efficiency (taking into account the differential pressure across the pump) figures are in the range of 34% to 59%, which is very poor. The system efficiencies (taking into account the differential pressure across pump minus discharge valve pressure drop) are in the range of 34% to 39%, which is also very poor, considering the fact that pumps are located very close to the end use points.

Table 5.5: Group replacement of pumps

Pump no.	Power input, kW	Discharge pressure, kg/cm^2	Pressure After valve kg/cm^2	flow, Lps	Pump effic'y, %	System effic'y, %
Hot water rinse-1	19.1	1.01	1.01	62	34.5%	34.5%
Knock off degrease-3	19.4	1.06	1.06	55	33.9%	33.9%
Degrease-2	18.2	1.19	1.19	50	39.1%	39.1%
Degrease-4	18.6	1.19	1.19	50	39.1%	39.1%
Phosphating pump-1	14.3	1.28	0.90	48	51.6%	36.3%
Phosphating pump-2	14.6	1.28	0.90	52	51.6%	36.3%
Passivation pump	16.8	1.93	0.99	42	58.8%	30.1%
Water rinse-1	19.1	1.63	1.14	52	41.8%	29.3%
Water rinse-2	14.0	2.37	0.99	41	77.4%	32.3%
Water rinse-3	16.2	2.23	1.01	45	65.9%	29.9%

Table 5.6: Specification and power consumption of new pumps

Pump no.	Recommended New pump		Power input to new pump kW	Power input to existing pump kW	Saving kW
	Head mWC	Flow lps			
Hot water rinse-1	14	60	6.7	16.2	9.2
Knock off degrease-3	14	60	12.6	18.9	6.2
Degrease-2	14	60	13.4	19.1	5.7
Degrease-4	14	60	12.9	18.1	5.2
Passivation pump	14	60	10.5	16.8	6.3
Water rinse-1	12	40	6.7	14.6	7.9
Water rinse-2	12	40	7.8	14.2	6.4
Water rinse-3	12	40	7.7	15.0	7.3
TOTAL			78.3	132.9	54.6

	After the energy audit, it was recommended that the existing pumps be replaced, while retaining the existing motors. The new recommended pump specifications and the power consumption figures are given in Table 5.6. The total energy saving measured was about 54.6 kW. For 6000 hours/annum operation, the annual energy saving was 3,27,000 kWh/annum and energy cost saving was Rs 13.2 lakhs/annum. Total investment for the pumps was Rs 2.0 lakhs. Payback period of 2 months.

5.5.2 Case Study-10: Use of variable frequency drive for a Cooling Tower Pump

Industry / **Sector**: Chemical plant-Paints	
Year of Implementation: 2001	
Cost Benefit Analysis	
❑ Type of Measure: Long term, major investment	
❑ Annual energy saving: 1,16,000 kWh/annum	
❑ Actual cost savings: Rs 4,66,000/-	
❑ Actual investment: Rs 5,00,000/-	
❑ Payback: 13 months	

Principle	Use of variable frequency drives on applications where flow variations/valve controls are incorporated can save energy. In this case study, a cooling tower pump motor was driven by a variable frequency drive to vary water flow to meet the varying process cooling water demand.

Background	This is a case study from a chemical plant manufacturing resins, used for manufacturing paints. A cooling tower with a 125 HP pump was used for process cooling applications. There were many applications requiring flow, and in the existing system, flow variation was through closing/opening valves at the end use points. Also, in the existing system, the return water line of the cooling was throttled to control the flow. After installation of an inverter to control the motor speed, this valve was fully opened, thus eliminating the throttling losses. Motor Rating: 125 hp, 415 V, 170A, 2975 rpm. Throttled Condition : Valve only 20% open Power (with throttling) : 53.5 kW With inverter at frequency of 44 Hz, valve fully open Power (With inverter) = 40.0 kW Savings = 13.5 kW The annual savings are about 1,16,000 kWh i.e. Rs. 4.66 lakhs per annum. The investment in the inverter was Rs. 5 lakhs, giving a payback period of 13 months.

RECAP

❑ Stopping idle or redundant running of motor driven loads like conveyors, air compressors, exhaust/ventilation fans, cooling tower fans, agitators/stirrers/grinders etc.

❑ In the 50% to 100% load range, motor efficiency is almost the same and is close to the rated efficiency. Below 50% load, the motor efficiency drops significantly. Try to ensure that motors are not loaded below 50% of their rated load for long periods.

❑ Explore possibility of connecting motors, which are loaded to about 30% in STAR connection permanently or by using STAR-DELTA auto-controllers.

❑ Soft starters to reduce motor starting current. If the motor load is less than 30% for long periods, soft starters will save energy.

❑ While specifying motors for new equipments, use only realistic safety margins.

❑ Use of synthetic flat belts in place of V belt drives.

❑ Use helical bevel gears in place of worm gears wherever possible.

❑ The *Bureau of Indian Standards* has published a standard for High Efficiency motors; IS:12615-2004. While purchasing new motors, always specify efficiency values from new BIS standards or IEEMA standards. The payback period on differential cost is about 1.0 to 1.5 years.

Avoid repeated rewinding of motors. For replacing a burnt out motor with a high efficiency motor, payback period is 1 to 2 years.

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