ENERGY CONSERVATIVE TECHNOLOGIES

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ABSTRACT

In sugar industry or any process industry energy cost is one of the major components of the production cost. Production cost can be reduced by adopting the energy conservation technologies. This paper explains the efficient utilization of energy by installing energy efficient equipments like Variable frequency drives (VFDs), Thermo compressors, Energy efficient motors, Biogas, Diffuse, Cogeneration, HP boilers and Use of boiler's flue gases/exhaust in economizer.

It briefly explains the principle, advantages of aforementioned technologies and compare their performance with that of conventional method but due to time constrains it is not possible to explain all these technologies. So we will discuss only first four technologies. This paper covers the basic function, principle, block diagram, pay back calculations recommendation for good application practices and tells how substantial amount of energy can be save using above mentioned technologies and all these things are elaborated through formulas, calculations and graphs.

Numerous benefits can be taken from above mentioned technologies, but only if the proper attention is given to selecting it correctly. That's why the importance of design is addressed. Concluding the work, application case study results are presented and discussed.

INTRODUCTION

In eighteen century, most industrial plants generated their own electricity using different type of fuel. Many of the plants used exhaust steam for industrial purpose. But when different electrical power plants and national grids were constructed by government, many industries stopped producing electrical energy and started to purchase electricity from different electric supply companies. Factors that deprive the industry from energy conservative technologies were excessive electricity production and low fuel or energy cost.

Situation changes completely in nineteen century when power demand cross the supply limit Fuel cost rises dramatically that causes the problem of energy crisis. So industries started to think about energy conservative technologies and they are moving towards complete self dependent. The technologies that are energy efficient have become very popular now due to high fuel cost and uncertainty of fuel supply. For these reasons, sugar industry in different develop countries are taking an active role in the increased use of energy conservative technologies.

Today Pakistan is facing the problem of energy crisis and the power supply short fall of over six thousand mega watts may become worse because the gap between supply and demand is increasing day by day. Several studies and experience in different parts of the world shows that sugar industry is one of the best candidates that can help to overcome this short fall and can make a measureable contribution to power supply. This report is designed for rapid introduction of energy conservative technologies in sugar industry.

The study in this report goes beyond the previous work in this area by specifying and evaluating the feasibility and pay back calculation. By using energy conservative technologies, sugar industry can produce power not only for its own purpose but also export power to surrounding areas.

ENERGY CONSERVATIVE TECHNOLOGIES

With the advent of power electronics, thousands of new technologies has been invented that can safe energy and efficiently utilize the energy. Some of them are given below

1) Variable frequency drive
2) Multiple motor drive
3) Energy efficient motor
4) Thermo compressor
5) Biogas plant

6) Diffuser
7) Cogeneration
8) Use of boiler's flue gases/exhaust in economizer
9) HP boiler

1. THE VARIABLE FREQUENCY DRIVE (VFD)

1.1 Introduction:

"Variable-Frequency Drive" (VFD) is a system for controlling the rotational speed of an AC electric motor by controlling the frequency of the electrical power supplied to the motor".

The operating speed of a motor connected to a VFD is varied by changing the frequency of the motor supply voltage. This is done completely automatically and without operator involvement, allowing continuous speed and flow control. There are some basic things that need to be pointed out about VFD's.

1.2 VFD Basics

1. The Hz or frequency of the power going into your motor will control the speed.
2. The voltage being applied to the motor will control the torque of motor

VFD can also be termed as

- ASD(Adjustable Speed Drive),
- VSD(Variable Speed Drive),
- AFD(Adjustable Frequency Drive),
- AC Drive
- Or most common name is Inverter.

1.2.1 Principle:

All electrical motors operate at 50Hz frequency. Speed of motor depends upon frequency of the supply. As frequency changes, speed of the motor also changes.

$$n = \frac{120\ x\ f}{P}$$

1.2.2 How Safe Electrical Energy:

VFD is an energy saving device that can safe up to 30%
Power consumed by electrical motor is directly proportional to cube of speed of motor.

Power $\propto$ Speed^3

If motor runs at 90% speed, power consumed will be only 73% (0.9^3)
If motor runs at 80% speed, power consumed will be only 51% (0.8^3)
If motor runs at 75% speed, power consumed will be only 42% (0.75^3)
If motor runs at 50% speed, power consumed will be only 12.5% (0.5^3)

1.3 Advantages of VFD

The advantages of VFD are

- No need of soft starter or star delta starter.
- Less electrical stress on motor winding

When VFD method is used it initially apply small voltage and frequency that avoids high inrush current that flows if full voltage is applied to motor. It gradually ramps up the voltage to the rated value in a controlled manner without any electric stress on the motor.

- Less mechanical stress on motor bearings

If the motor is driven with motor starter, although it gradually increases the voltage either in two(star delta) or three (autotransformer) steps, but due to this motor is subjected to abrupt high voltage that causes high torque and high current surge that is 8 times the normal rating current. But if we use inverter it ramp up the voltage to desire level that causes smooth rise in torque and current. In this way motor is subjected to less mechanical and electrical stress that increases the service life of motor. And results smother, longer lasting and more efficient operation.

- Increases motor's service life
- No need of mechanical pulleys and gear to change the speed and torque of motor
- Reduces the maintenance by reducing mechanical components.
- VFD's save money on annual maintenance cost of motor.
- It improves power factor

The lower the power factor is on your utility bill, the more it is costing you to run any kind of motor. If your utility bill is showing a power factor below .90 than you may want to think about adding drives to your motors. One of the benefits of using a VFD on any motor is improved power factor. After applying VFD to the motor power factor of motor will now between .92 to .95, regardless of how inefficient the supply voltage to the VFD is.

- Regenerative AC drives have the capacity to recover the braking energy of a load moving faster than the designated motor speed (an overhauling load) and return it to the power system.

Regeneration is only useful in variable-frequency drives where the value of the recovered energy is large compared to the extra cost of a regenerative system, and if the system requires frequent braking and starting. An example would be conveyor belt drives for manufacturing, which stop every few minutes. While stopped, parts are assembled correctly; once that is done, the belt moves on. Another example is a crane, where the hoist motor stops and reverses frequently, and braking is required to slow the load during lowering. Regenerative variable-frequency drives are widely used where speed control of overhauling loads is required. Cycloconverters and current-source inverters inherently allow return of energy from the load to the line, while voltage-source inverters require an additional converter to return energy to the supply.

- Inverter is environment friendly.

The energy that causes this equipment to put into motion is the electrical energy. According to study in 2008 alone more than half of electricity of the world is produced coming from power plants that are feed by burning fossil fuels like oil, gas and coal. Burning fossil fuels produced carbon emission that is harmful to our environment. Global warming is the principal effect of excessive carbon dioxide in the atmosphere. Any methods that could reduce energy consumption could also directly reduce the excessive carbon dioxide in the atmosphere.

- Reduce peak demand charges.

When motor pumps are activated, the power is literally "slammed" to the motor, and the motor that was peacefully at rest, is jolted into action. This abrupt start-up will cause a spike in power consumption which is registered by the power company on your "demand" meter, located in most commercial electrical meters. Higher "demand charges" will normally mean that you pay a higher electrical rate (for ALL your power) than a customer with lower demand charges. By using VFD, motor ramps up upon start up, and ramps down during shut-down. The VFD does not register a spike in power consumption, will reduce your demand charges and can contribute to a lower overall energy cost.

- The biggest advantage of it is saving up to 30% energy through its inherent nature.

It uses high frequency switching power device called IGBT (Insulated Gate Bi Polar Transistor). The applications with the greatest amount of energy savings in industry are still centrifugal pumps and fans. Experience shows that premium efficiency motor can safe energy up to 2-8%.however the energy saved by VFD can exceed 30% based on several factors .

- Most VFD installations will pay for themselves quickly; normally payback will occur within 12-18 months.
- Removal Of Voltage Sags :
- Eliminates starting inrush current

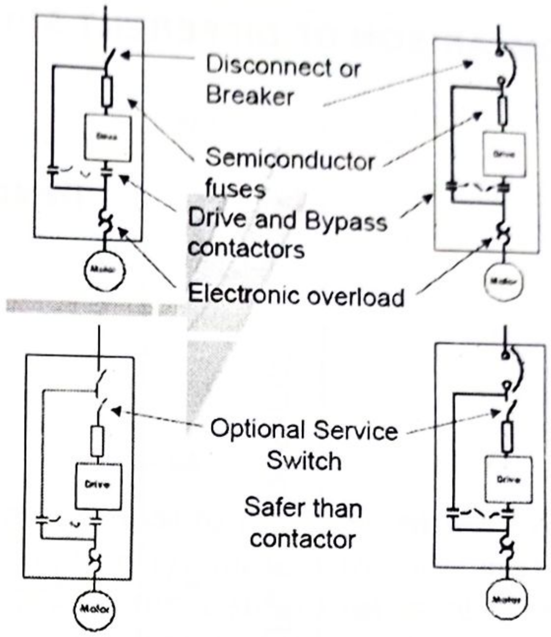
When a VFD starts a motor, it initially applies a low frequency and voltage to the motor. The starting frequency is typically 2 Hz or less. Thus starting at such a low frequency avoids the high inrush current that occurs when a motor is started by simply applying the voltage by turning on a switch. It gradually increases the voltage and frequency to operate the motor keeping the current within the safe limit.

- Built In Motor Protection :

Under voltage, overvoltage, over current protection, short circuit protection, over heating protection and motor stall protection is built in VFD.

- Bypass option:

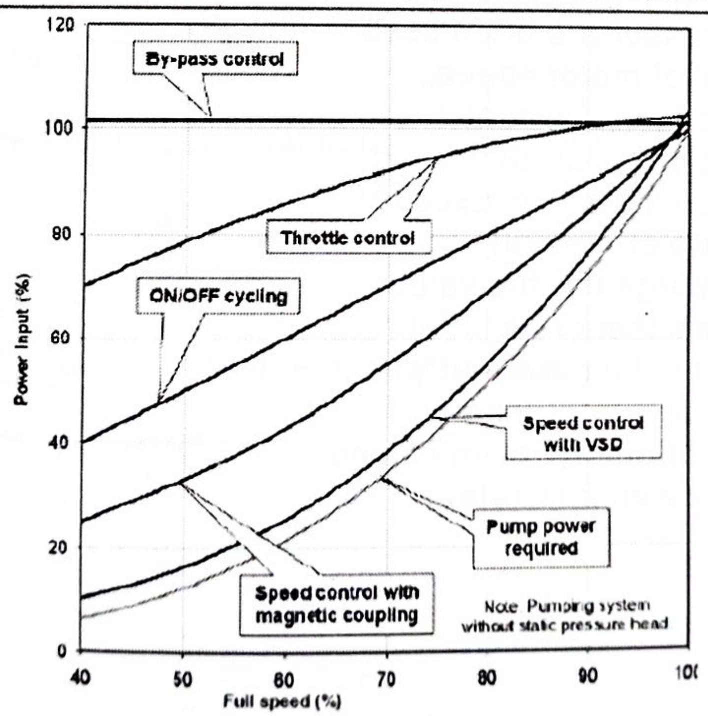
"Bypass" is added to bypass the VFD and to run the motor on main power line to avoid the interruption if VFD get out of order or require maintenance



- Reduced audible noise
- Equipment Life Span Increased exponentially with speed reduction & soft start!
- Reduced wear on motors, belts, and other components.
- Optimize the power usage in response to actual load :

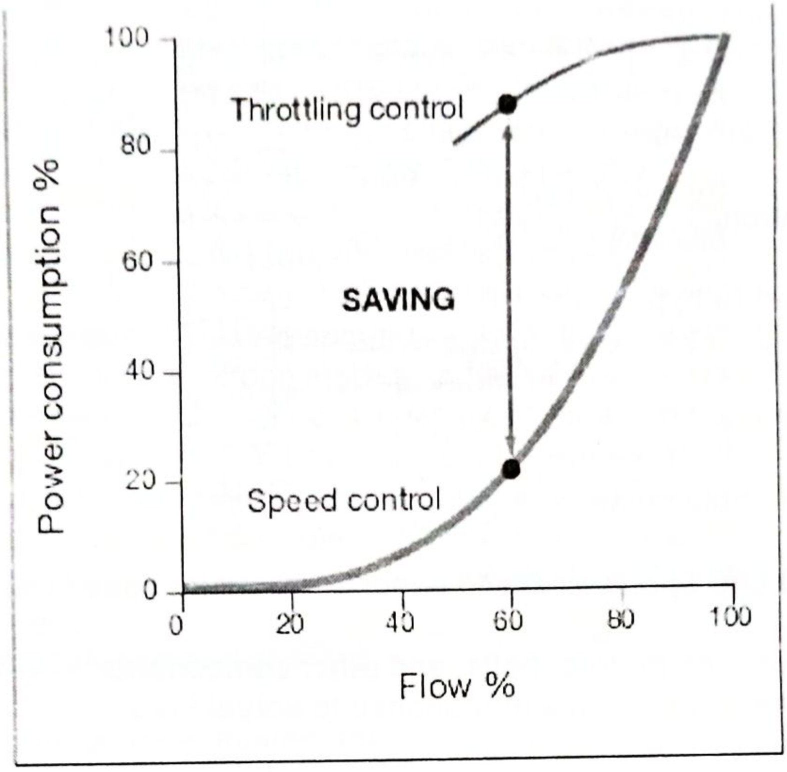
VFD provides as much power as need. If you using throttling value, unfortunately motor will VFD have a better control of the process, due to optimal pressure or flow control that saves substantial amount of energy. We assume a motor, driving a pump, directly connected to supply, always running at full speed. The process requirement may change and motor is not required to operate at full capacity. One possible solution is to use throttling value where opening and closing a value controls the flow but motor is still running at full power, this is the wastage of power and increases maintenance cost. It is just like that you are driving your car with brakes on. The use of VFD is the optimal and most energy efficient control method. That provides that only energy which is required by the driven mechanical load.

Figure 24: Energy savings with speed control for a centrifugal pump without static pressure head



Source: Ferreira, 2009.

COMPARISON OF DIFFERENT SPEED CONTROLLING METHODS



COMPARISON BETWEEN THROTTLING VALUE AND VFD CONTROL WITH 60% FLOW

If flow is controlled with throttle valve, motor will consume 100% power. But if flow is controlled with VFD, VFD will reduce the speed of motor to 60 % so power consumed will only be 0.6^3 = 22% so Energy Saving = 78%

1.4 Disadvantage of damper:

Flow generating equipments like fan, pumps and compressor are often used without the control of motor speed. Instead, flow is traditionally controlled by throttling with a value or damper. If the valve restriction method is used to control the flow rate or flow rate is controlled by discharge throttle value or through dampers there is a lot of energy wastage. It is just like that you are driving your car with brakes on. VFD harnesses that energy by matching the speed of motor with flow rate.

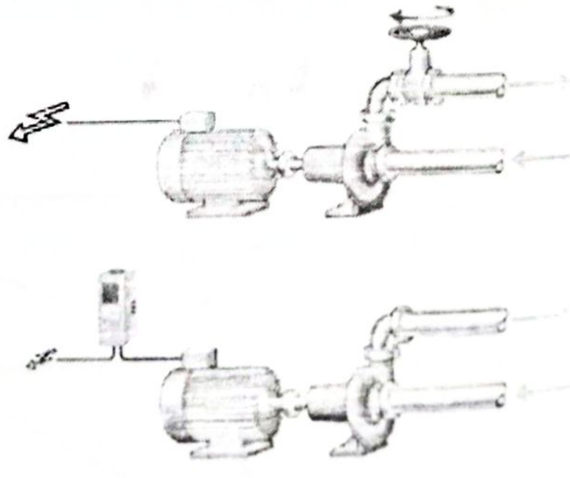


Fig. 1: The principle of energy saving with VFD speed control

1.5 How VFD reduce electric consumption

Formula for Affinity Law of centrifugal loads is

$$\frac{P_2}{P_1} = \left(\frac{n_2}{n_1}\right)^3$$

Where P= power and n= speed

In centrifugal pumps, energy consumption is proportional to the cube of the flow rate Variable frequency reduces electric consumption in relation to the type of application by which the electric motor is used. The application that is referred here is the centrifugal loads such as fans and pumps. The reduction of speed of motors used in centrifugal applications has corresponding power reduction as described in the relation that the power is directly proportional to the cube of the shaft speed. This scientific law is commonly known as law of affinity. From the given formula its shows that a reduction of 80% speeds will result into 50% reduction in power.

1.6 Affinity Laws:

The affinity laws are used in hydraulics and HVAC to express the relationship between variables involved in pump or fan performance (such as head, volumetric flow rate, shaft speed) and power. They apply to pumps, fans, and hydraulic turbines.

Law 1. With impeller diameter (D) held constant:

Law 1a. Flow is proportional to shaft speed.

$$\frac{Q_1}{Q_2} = \left(\frac{N_1}{N_2}\right)$$

Law 1b. Pressure or Head is proportional to the square of shaft speed:

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

Law 1c. Power is proportional to the cube of shaft speed:

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

Where

- Q is the volumetric flow rate (e.g. CFM, GPM or L/s),
- D is the impeller diameter (e.g. in or mm),
- N is the shaft rotational speed (e.g. rpm),
- H is the pressure or head developed by the fan/pump (e.g. ft or m), and
- P is the shaft power (e.g. W).

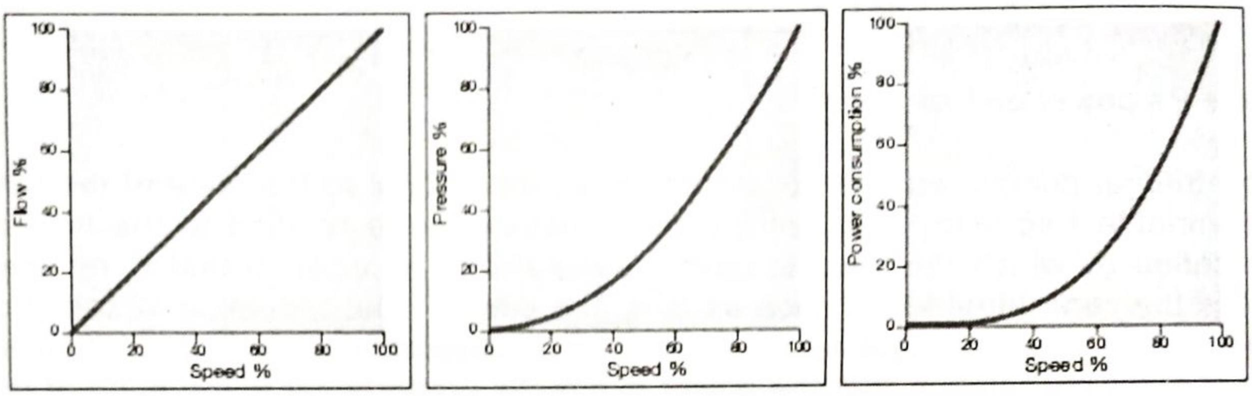
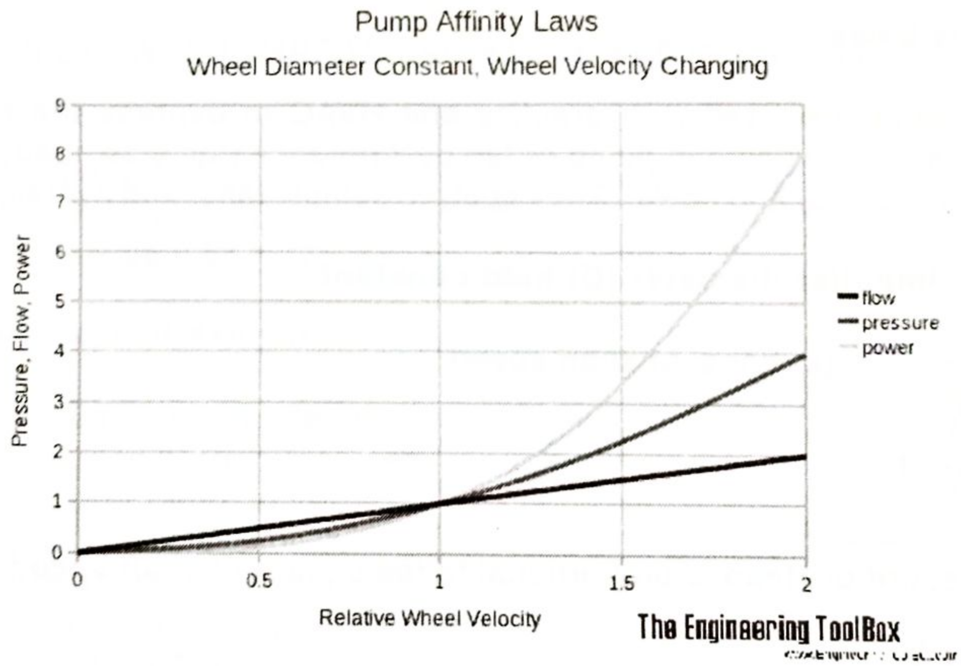


Fig. 2: Affinity laws express relationship between rotational speed and other variables.



Note! If the speed of a pump is increased with 10%

- the volume flow increases with 10%
- the head increases with 21%
- the power increases with 33 %

1.7 How great are the savings?

A motor running at 50% of full speed capacity has a motor torque of 25% of full speed. In addition, electricity required to operate the motor at 50% of full speed is 12.5% of the amount of electricity required if the motor was running at 100% full speed capacity. Thus, reducing motor speed can significantly reduce the electrical energy consumption.

1.8 How it reduces current?

As we know the power of three phase motor is given as

Let suppose we have motor with following characteristics

Power = 100 hp
Speed = 1,785 rpm
Voltage = 460 V
Full load current = 115 A
Power factor = 0.86

"A VFD will convert its incoming power, a fixed voltage and frequency, to a variable voltage and frequency."

Suppose that motor is operating at half of the rated speed producing full load torque and drawing full load current. Frequency has to be half (30Hz).In order to keep the V/F ratio constant the voltage will also be half (230V) so frequency and voltage at the output of VFD is 30HZ and 230V respectively. So the power at the output will be

For ideal VFD device

Note that the input current is now less than half of the rated current.
Suppose that motor is operating at rated speed then
F=60Hz
V=460V
P.F=0.86

So power at the output will be

This is lower than rated current by 4A. Difference in power factor makes it possible to have high output current.

Side	Power (kW)	Voltage (V)	Current (A)	Frequency (Hz)	Power Factor
Input	39.4	460	115	60	0.89
Output at half speed	39.4	230	55.6	30	0.86
Output at half speed	39.4	460	111.12	60	0.86

Note

- By VFD we can improve P.F
- Difference in current is more when motor is operating at half or lower then rated speed
- There is a little difference when operating at full speed so before choosing inverter for a particular application, we have to check that either it will be suitable for that particular application or not.

1.9 Selection of VFD

Variable frequency drive is an electrical device that can be used to reduce speed of an induction motor from rated speed down to zero speed. Since this equipment is relatively expensive therefore a well trained engineers in this field should be consulted in selecting the type of VFD to be used in a particular installation. Improper selection of VFD may result into undesirable result and could damage other equipments in the vicinity. When looking to apply VFD control to an existing pump, a basic overview of the application should be investigated. The motor drives that do not require to operate at full speed can save energy by using adjustable speed drive energy. Cost saving will be more with variable torque. If motor operate at constant speed, there will be limited save in energy (may be only 5%). In variable torque applications such as fans and blowers, the torque required varies roughly with the square of the speed, and the horsepower required varies roughly with the cube of the speed, resulting in a large reduction of horsepower for even a small reduction in speed.

The motor will consume only 25% as much power at 63% speed than it will at 100% speed.

1.10 Where VFD can be used

Feeder table	Primary cane carrier
Clear and raw juice pump	Cane cutter motor
ID, FD, Secondary Fans of boiler	Sugar elevator
Feed water pump	Hot and cold air blowers
A centrifugal drive	Mill house motors

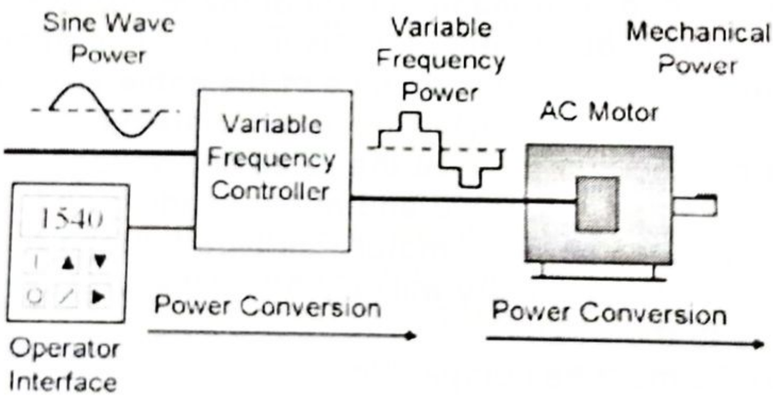
1.11 Classification of inverter

VFD can be classified as:

- Voltage source Inverters
- Current source inverters

The most common type of packaged VF drive is the voltage source type, using pulse width modulation to control both the frequency and effective voltage applied to the motor load.

Most advance method used in inverters is vector control method. In this method we can precisely control the torque and speed. The most usual method for inverters is PWM. It produces quasi-square wave.



Motor used in VFD is mostly three phase induction motor.VFD can be used for single phase motors but three phase induction motors are preferred.
If the motor is designed for 460V and 60Hz and operated at 30Hz then voltage must be reduce to 230V to keep the V/F ratio constant.

Flux

If we decrease the frequency, it causes saturation in the core of induction motor. Saturation produces high magnetization current that causes

- Heating
- Losses

To avoid saturation we have to vary the voltage also.
If we increase frequency then voltage must also increase
If we decrease frequency then voltage must also decrease.
As frequency increases we increases voltage but voltage is limited to rated value in order to safe the insulation winding.

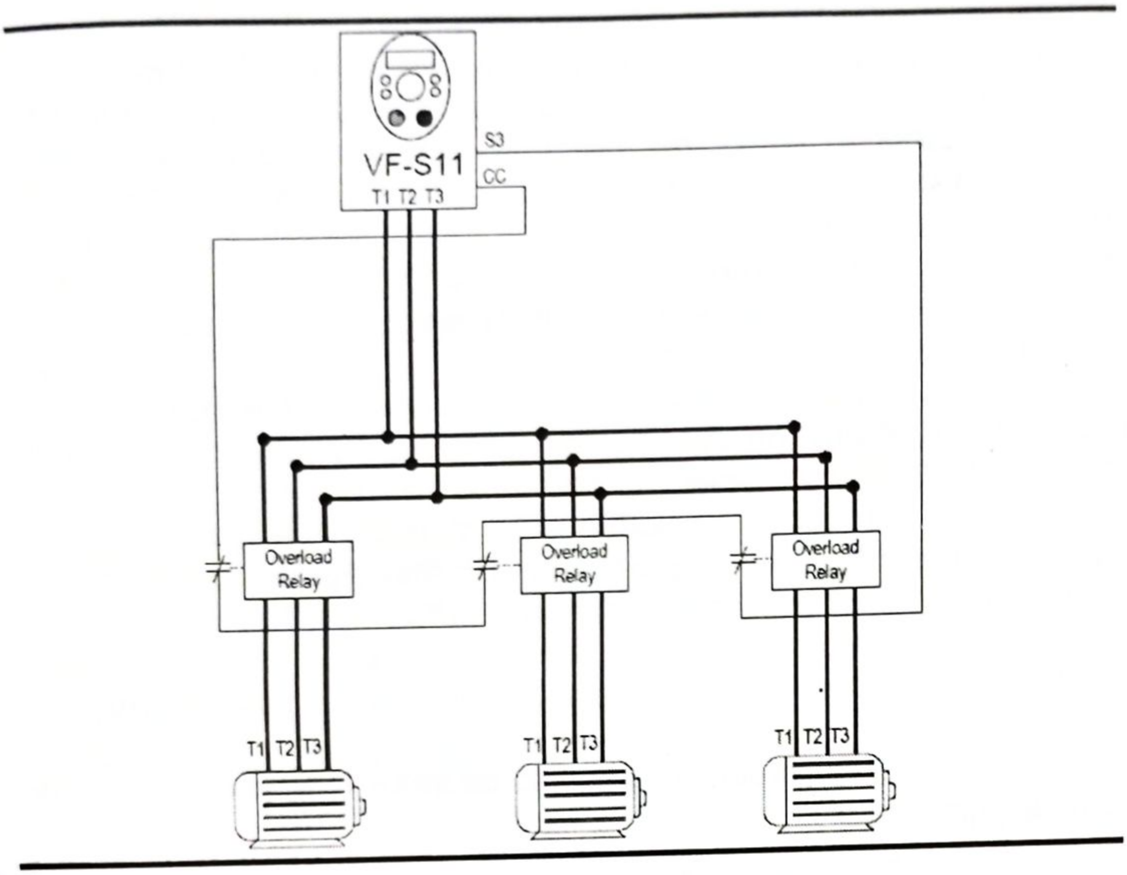
The stopping sequence of the inverter is just the reverse of starting sequence. Inverter ramps down the voltage and frequency.

Let suppose we have a motor of ratings 100Hp,460V and 60 Hz frequency and four pole . So this motor will operate at speed 1800 RPM.if we operate this motor at 75Hz then flux reduces and torque will be reduces to 60/75 x 100=80% of the rated torque and motor enters into a region called field weakening region. At higher speeds the torque is limited to lower values due to decrease in flux. Thus rated power can be typically produced only up to 130...150% of the rated name plate speed.

1.12 Disadvantages of VFD:

- If motor has to run at lower speed, some cooling method must be used other wise overheating of the winding may occur.
- A VFD can be adjusted to produce a steady 150% starting torque from standstill right up to full speed. Note, however, that cooling of the motor is usually not good in the low speed range. Thus running at low speeds even with rated torque for long periods is not possible due to overheating of the motor. If continuous operation with high torque is required in low speeds and external fan is usually needed. The manufacturer of the motor and/or the VFD should specify the cooling requirements for this mode of operation.
- Since the transmission-line impedance of the cable and motor are different, pulses tend to reflect back from the motor terminals into the cable. The resulting voltages can produce up to twice the rated line voltage for long cable runs, putting high stress on the cable and motor winding and eventual insulation failure. Increasing the cable or motor size/type for long runs and using 480V or 600V motors instead of 230V will help offset the stresses imposed upon the equipment due to the VFD.
- Motors and VFDs must be compatible.
- The high frequency current ripple in the motor cables may also cause interference with other cabling in the building. This is another reason to use a motor cable designed for VSDs that has a symmetrical three-phase structure and good shielding. Furthermore, it is highly recommended to route the motor cables as far away from signal cables as possible.
- VFD is expensive equipments.
- VFD are complex
- Experienced, trained and qualified personnel are required for its maintenance.

2. Multiple Motor Drive:



Multiple Motor Running With One VFD

One VFD can be used to run multiple motors running parallel at same desired speed at same time.

2.1 Where it is used?

Applications that use dual pump or fans are good candidate of multiple motor drive. Multiple motor drive can also be used in overhead traveling cranes where two drive wheel motors must run at the same speed. In addition to it Exhaust supply fans or array of fans can also be drive by one VFD.

2.2 Design constrains

There are some design constrain that must be considered and special attention must be given while selecting multiple motor drive for a particular application.som design constrain are explained below:

- All motors must be of same rating i.e power rating of the motor, rated speed of motor and voltage must be same because all motors are connected to the same VFD

  Provide overload protection to each motor individually.VFD can not sense the current of each motor separately, it can sense only total current drawn by all motors. VFD does not know which motor is drawing more current. So it can not provide overload, over current or short circuit protection to each motor that's why it is imperative to apply over load protection to each motor separately. For instance, a 50hp/65amp VFD might be controlling four 10hp/14amp motors for a total connected load of 56amps as shown in Figure 1. If one of the motors was overloaded and drawing 22 amps while the other three motors continued to operate normally, it would be difficult to configure the VFD's protection circuits to sense the overload condition. Overload protection is designed to disconnect the individual motor from the VFD if the motor draws current greater than normal but less then eight times its FLA for a prolonged period of time. This protects the motor and the motor conductors from excessive heating. The most common types of motor overload protection technologies are bimetal and solid state.

Short circuit protection is designed to protect against short circuit and ground fault conditions where the over current condition is greater than eight times the motor's FLA. These types of conditions can be very destructive, so the motor must be disconnected within a fraction of a second. The two main types of short circuit protection devices are fuses and circuit breakers.

- With individual motor protection, only the motor that faults is disconnected, and the remaining motors continue to run. This is a must in applications that can't afford to have the entire system shut down while a single motor is repaired or replaced.
- Current rating of VFD must be equal to or more than the *sum of all motor* current ratings i.e.

Current rating of VFD = n × Motor Current Rating
Where n is the number of motors running parallel

This formula is valid only if you start all motors at same time. If motor are not required to run simultaneously, you must increase the rating of VFD as explained in example given below.

- Total motor lead length must be less than the critical length as specified by the manufacturer.
- Auxiliary contacts on the overload relay should be in series including the emergency stop button.
- To minimize the size of VFD all motors must be started at same time. One of more motors can not be started while one or more motors are already running unless VFD is sufficiently oversized.

2.2.1 EXAMPLE:

Suppose we have 3 motors of rating

5 HP with an FLA 6.2A, 460 volts AC
5 HP with an FLA 6.2A, 460 volts AC
10 HP with an FLA 14A, LRA = 86.5, 460 volts AC

If all motors are accelerated, decelerated and run in unison, the sum of the connected motor FLA allows use of a 20 HP drive. If it were necessary to accelerate and run the 5 HP motors and then start the 10 HP, the sum of the FLA must be recalculated.

The FLA figures of 5 HP motors would be used, but the Locked Rotor Amps (LRA) for the 10 HP must be used. As this motor would not be accelerated from zero frequency and voltage to its running condition, it would require its full LRA rating to accelerate to drive's output frequency. This effect on sizing is shown below:

6.2 + 6.2 + 86.5 = 98.9 AMPS

In this example, a 75 HP drive with 112 Amp continuous rating would be required.

2.3 Advantages of multiple motor drive :

- Saves money
- Reduces maintenance time and cost
- It requires less space
- Reduces control system complexity
- One big VFD produces less heat as compared to multiple smaller units.
- The overall system becomes much simpler, instead of connecting many VFDs to the main controller, usually a PLC, and synchronizing their operation, only one VFD speed control loop is needed.
- If one motor fails, it is possible to continue the operation with rest of the motors

All above advantages justify the use of multiple motor drive.

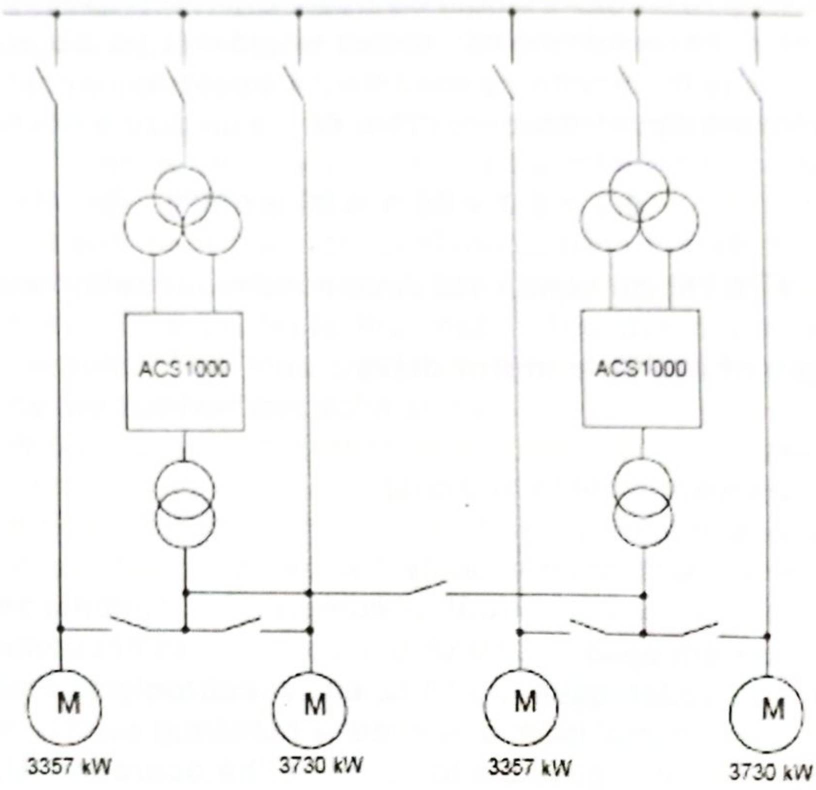
2.4 Case Study:

2.4.1 VFD as Soft start for mechanical vapor compressor :

AL-Khaleej sugar in Dubai, UAE has been using VFD for mechanical vapor compressor. The installation of mechanical vapor compressor to reuse waste vapor is the latest ongoing innovation project at AL -Khaleej sugar. Two air cooled ACS 1000 MV-VFD are used as soft starting device to avoid high inrush current and voltage dips during motor start.

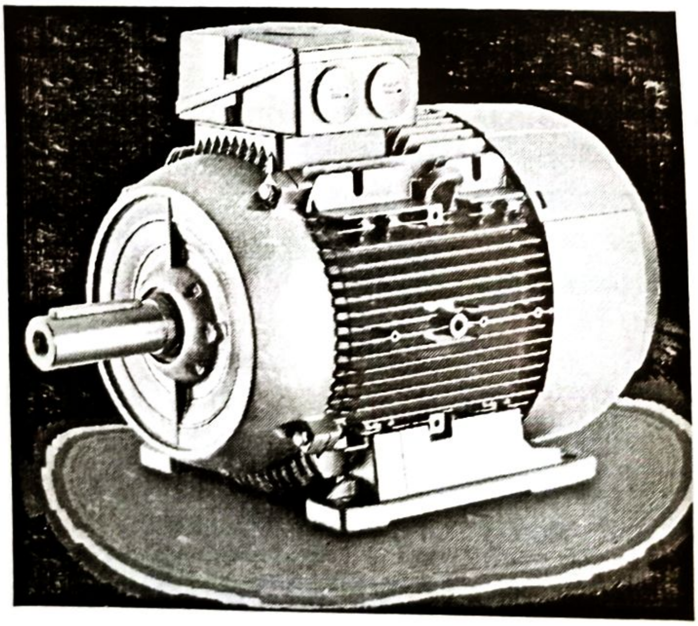
Steps:

Step 1 : Motor is smoothly accelerated with VFD from standstill up to nominal speed.
Step 2: Motor is synchronized with supply network.
Step 3 : Motor is then transferred to grid or main supply



VFD Installed at AL-Khaleej sugar industry for mechanical Vapor compressor

3. Energy Efficient Motors



3.1 Introduction:

The problem of energy crisis can be reduced by two ways. One way is to increase the capacity which is not possible due to limited fuel resources and second ways is to efficiently utilize the existing energy sources by the use of energy efficient technologies that will automatically increase the power capacity.

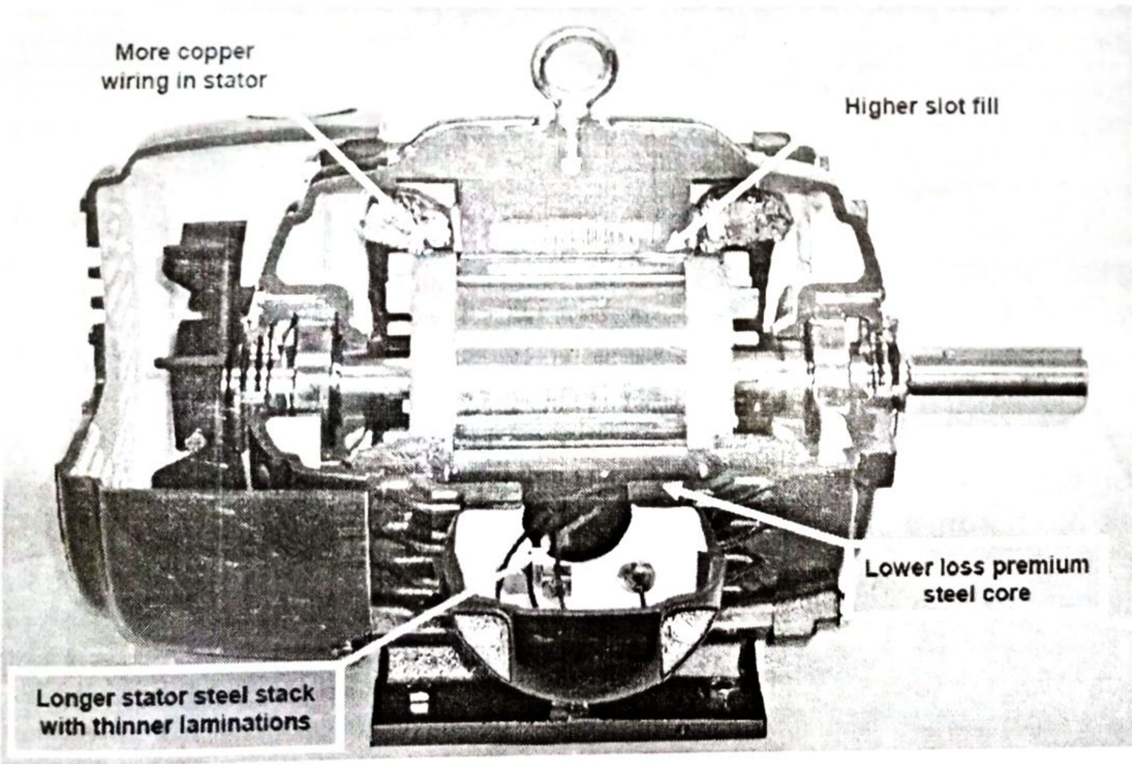
Electrical motor consumes 70% of the total electricity produced in industry. Motors are the largest consumer of electricity in industry so even a small efficiency improvement can lead to very large saving. EEM is a specially designed motor having high efficiency as compared to standard efficiency motor and losses (copper losses, iron losses, core losses, and stray losses) are negligible. EEM have following characteristics:

- High Efficiency
- Low Losses
- Continuous Duty
- Enclosure Protection IP55
- Insulation Class F(155°C)
- Temperature Class B (105°C)

3.2 Characteristics of Energy Efficient Motor

In energy efficient motors different changes has been made that increases its efficiency. Bars on the rotor are made of copper instead of aluminum that reduces I2R.High quality steel core is used that reduces hysteresis losses. Core is made up of thin laminated sheet that reduces the eddy losses. Thicker conductors and more copper contents are used that reduce copper loss due to lower resistance. Longer core length, reduced and uniform air gap between stator and rotor reduces the stray losses.

Figure 16: IE3 Premium-Efficiency motor



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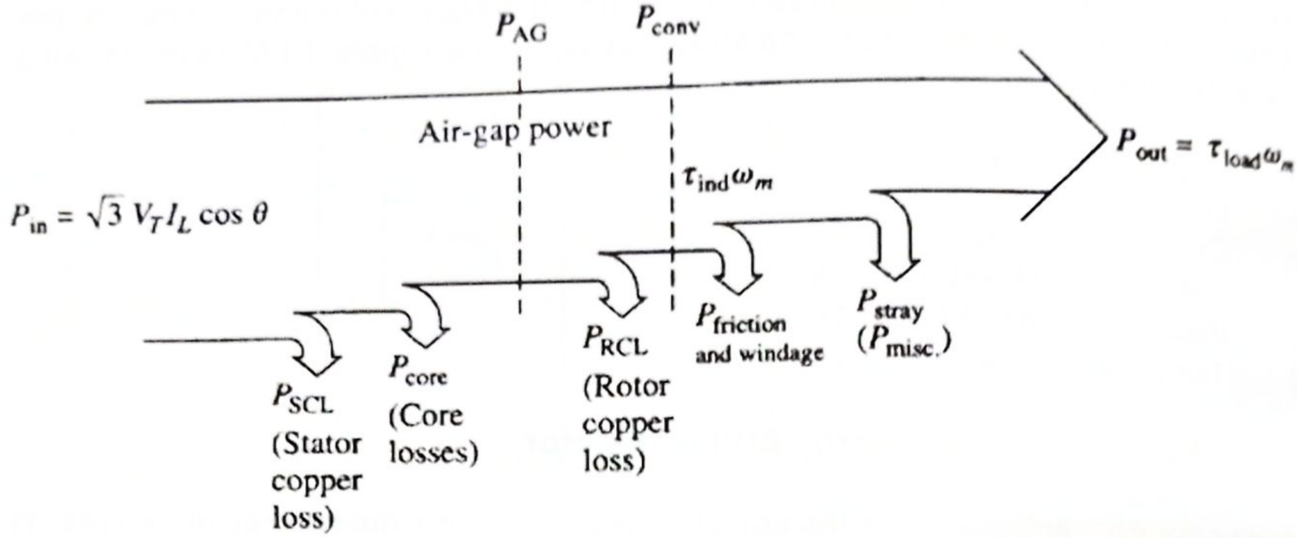
3.2.1 Losses in Induction Motor

Different losses in motor and their percentage are given below



Typical losses in an AC induction motor

	Typical losses in 4-pole motors	Factors affecting these losses
Stator losses	30 - 50%	Stator conductor size and material
Rotor losses	20 - 25%	Rotor conductor size and material
Core losses	20 - 25%	Type and quantity of magnetic material
Additional load losses	5 - 15%	Primarily manufacturing and design methods
Friction and windage	5 - 10%	Selection/design of fan and bearings

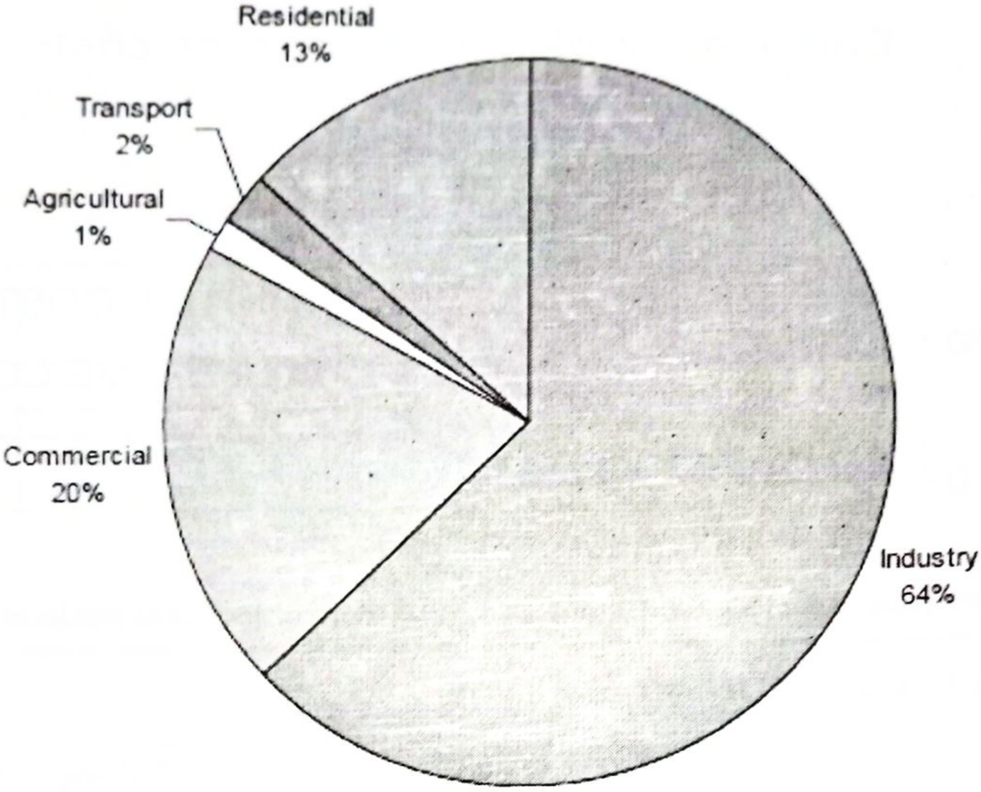
Abbreviation: AC = alternating-current.

Source: IEC 60034-31, draft 2009.

3.3 Energy Consumption by Sector

The largest proportion of motor electricity consumption is attributable to mid?size motors with output power of 0.75 kW to 375 kW. Many different motor technologies and design types are available, but asynchronous alternating current (AC) induction motors are most frequently used and consume the most energy. Electric motors and the systems they drive are the single largest electrical end?use, consuming more than twice as much as lighting, the next largest end?use Motors in the mid?size range are most commonly found in industrial applications, but they are also widely used in commercial applications, infrastructure systems and, less often, in the residential sector.

Sector	Electricity consumption	% of all EMDS electricity	% of sector electricity
Industrial	4 488 TWh/year	64%	69%
Commercial	1 412 TWh/year	20%	38%
Residential	948 TWh/year	13%	22%
Transport and agriculture	260 TWh/year	3 %	39%



tics, 2006; A+B International, 2009 (motors).

3.4 Motor initial cost:

Despite being slightly more costly to purchase than standard motors, higher?efficiency motors (HEMs) with over 1 000 hours of operation per year are more cost?effective over the system life for end?users in all applications because motor?energy costs typically account for over 95% of a motor's life?cycle cost. Motor initial cost is only 8% of whole life cycle cost.

For Example:

If we have a 30HP motor then:

- Initial Purchase price = Rs. 80,000
- Operating hour = 24 x 120 x 15 hr = 43200 hr
- KWH = 43200 x 0.746 x 30 = 966816 KWH
- Running Cost = 966816 x 10 = Rs. 9,668,160

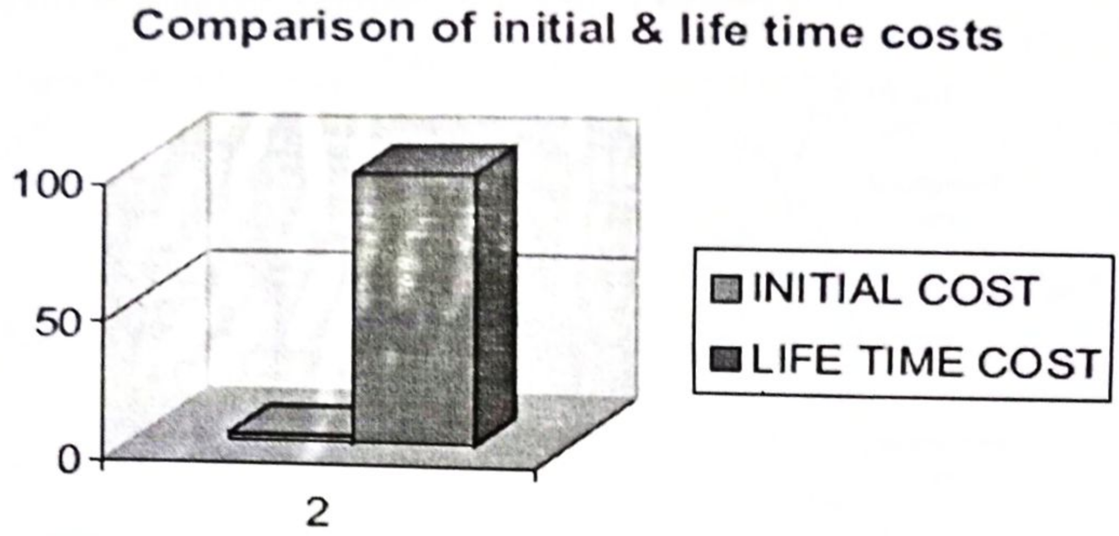
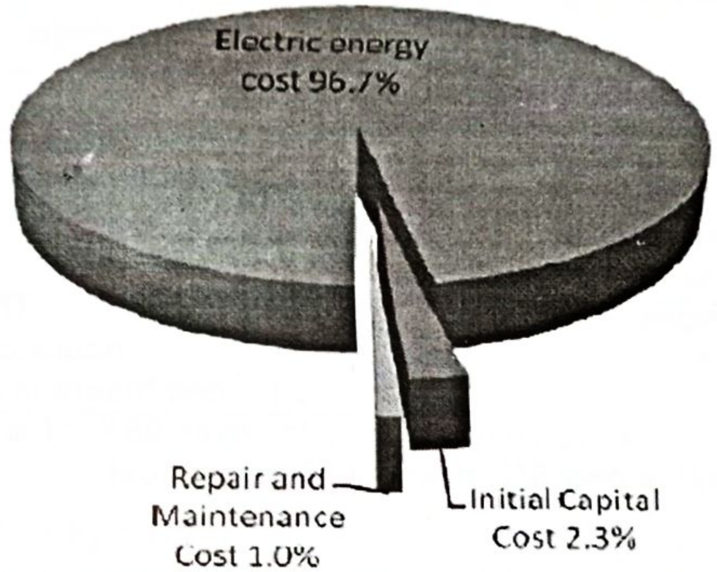


Figure 35: Life-cycle cost of 11 kW IE3 motor with 4 000 operating hours per year



Source: De Almeida *et al.*, 2008b.

3.5 Motor Efficiency Classes in Different Countries:

Keeping in view the shortage of fuel, many develop countries are moving towards energy efficient motors. They have made some standards that motor must fulfill otherwise not allowed to operate in the country Energy-efficient motors are becoming more and more significant. New energy efficiency laws are being drawn up in many countries to protect our environment. In addition to the European Union and associated countries, China and Brazil are also making the high IE2 efficiency class mandatory. With the changeover to IE2 motors, you are not only protecting the environment but you are also benefiting from significantly lower operating costs. More than 90% of the life cycle costs of a motor account on the operation and the energy costs make up the largest portion of this. Different efficiency standards are given below

Motor efficiency classes in different countries and the corresponding international standard

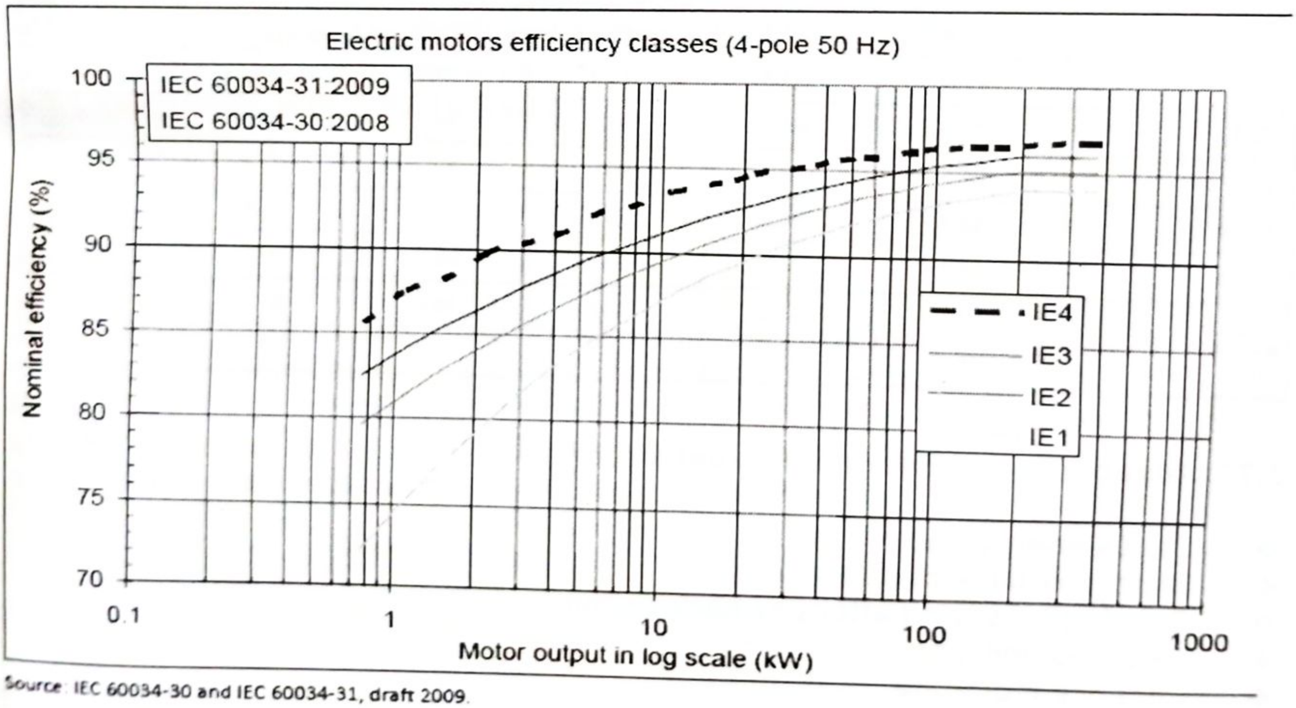
Motor efficiency class	International	United States	European Union (old system 1998[1])	European Union (new system 2009)	China	Australia
Premium	IE3	NEMA Premium	-	IE3	-	-
High	IE2	EPAct	Eff1	IE2	Grade 1 (under consideration)	AU2006 MEPS
Standard	IE1	-	Eff2	IE1	Grade 2	AU2002 MEPS
Below standard	IE0 (used only in this paper)	-	Eff3	-	Grade 3 (current minimum)	-

Abbreviations: EPAct – US Energy Policy Act, 1992; MEPS – minimum energy performance standard;

3.6 International Efficiency Standards

There are different efficiency standards. International standard of efficiency are as follow:

- IE1 (standard efficiency)
- IE2 (high efficiency)
- IE3 (premium efficiency)
- IE4 (super premium efficiency)



Source: IEC 60034-30 and IEC 60034-31, draft 2009.

(international energy agency) pass laws to set compulsory energy efficiency standard to protect environment and allow us to reduce operating cost.

The following chart shows that different countries have made it compulsory for every motor to fulfill the efficiency class standard. Even india is thinking about it.

The following chart gives the efficiency of different motors according to their power and number of poles

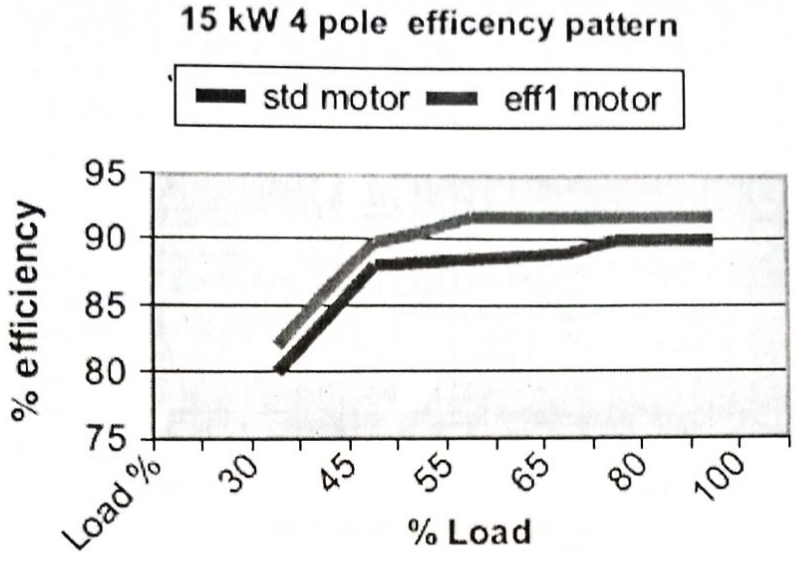
Table 32: Nominal minimum efficiencies (η) for electric motors in Europe (50 Hz)

Rated output power (kW)	Number of poles					
	IE2 efficiency level[1]			IE3 efficiency level[2]		
	2 poles	4 poles	6 poles	2 poles	4 poles	6 poles
0.75	77.4	79.6	75.9	80.7	82.5	78.9
1.1	79.6	81.4	78.1	82.7	84.1	81.0
1.5	81.3	82.8	79.8	84.2	85.3	82.5
2.2	83.2	84.3	81.8	85.9	86.7	84.3
3.0	84.6	85.5	83.3	87.1	87.7	85.6
4.0	85.8	86.6	84.6	88.1	88.6	86.8
5.5	87.0	87.7	86.0	89.2	89.6	88.0
7.5	88.1	88.7	87.2	90.1	90.4	89.1
11.0	89.4	89.8	88.7	91.2	91.4	90.3
15.0	90.3	90.6	89.7	91.9	92.1	91.2
18.5	90.9	91.2	90.4	92.4	92.6	91.7
22.0	91.3	91.6	90.9	92.7	93.0	92.2
30.0	92.0	92.3	91.7	93.3	93.6	92.9
37.0	92.5	92.7	92.2	93.7	93.9	93.3
45.0	92.9	93.1	92.7	94.0	94.2	93.7
55.0	93.2	93.5	93.1	94.3	94.6	94.1
75.0	93.8	94.0	93.7	94.7	95.0	94.6
90.0	94.1	94.2	94.0	95.0	95.2	94.9
110.0	94.3	94.5	94.3	95.2	95.4	95.1
132.0	94.6	94.7	94.6	95.4	95.6	95.4
160.0	94.8	94.9	94.8	95.6	95.8	95.6
200 - 375	95.0	95.1	95.0	95.8	96.0	95.8

3.7 Advantages of Energy Efficient Motor

- Saves energy and money
- Short pay back period
- Substantial saving after pay back period
- Reduces pollution
- Enhance motor life
- Increases the plant capacity
- High power factor
- Low noise and vibration

3.8 Comparison of Standard And Energy Efficient Motor



3.9 Energy Saving And Payback Calculation

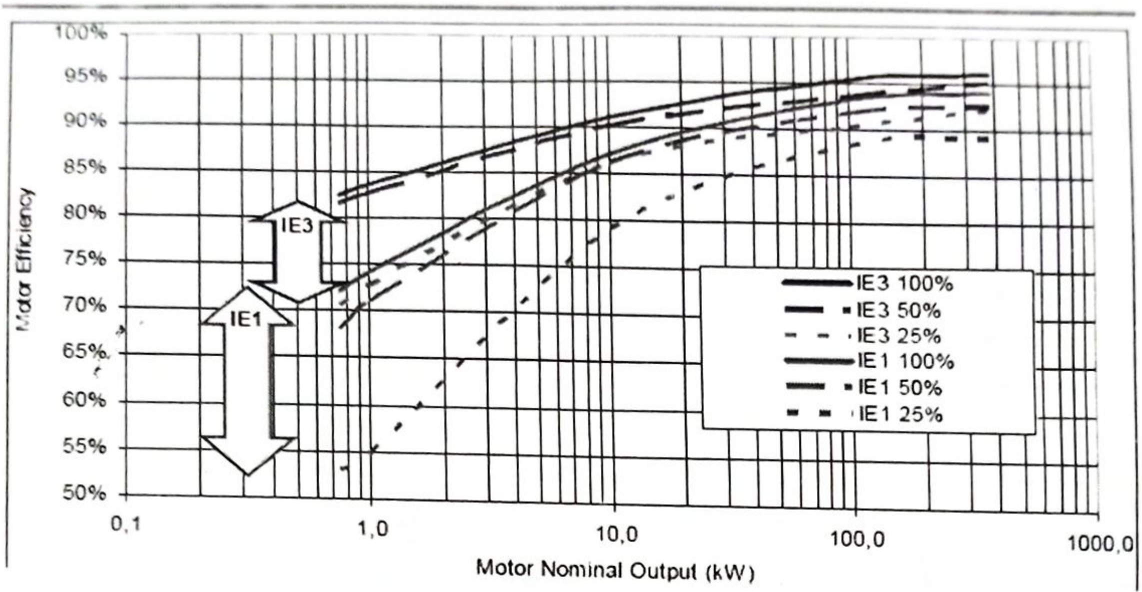
Let's suppose we have 30HP motor with following data:

- **Motor power = 30HP**
- **Cost of energy efficient motor = Rs 60,000**
- **efficiency of old standard motor = 83%**
- **Efficiency of energy efficient motor = 93%**
- **No of operating hours = 24 x 120 = 2880 hr**
- **Tariff Rate = C = Rs.10/KWH**
- **Load factor = L = 0.75**

3.10 Misconception about Motor

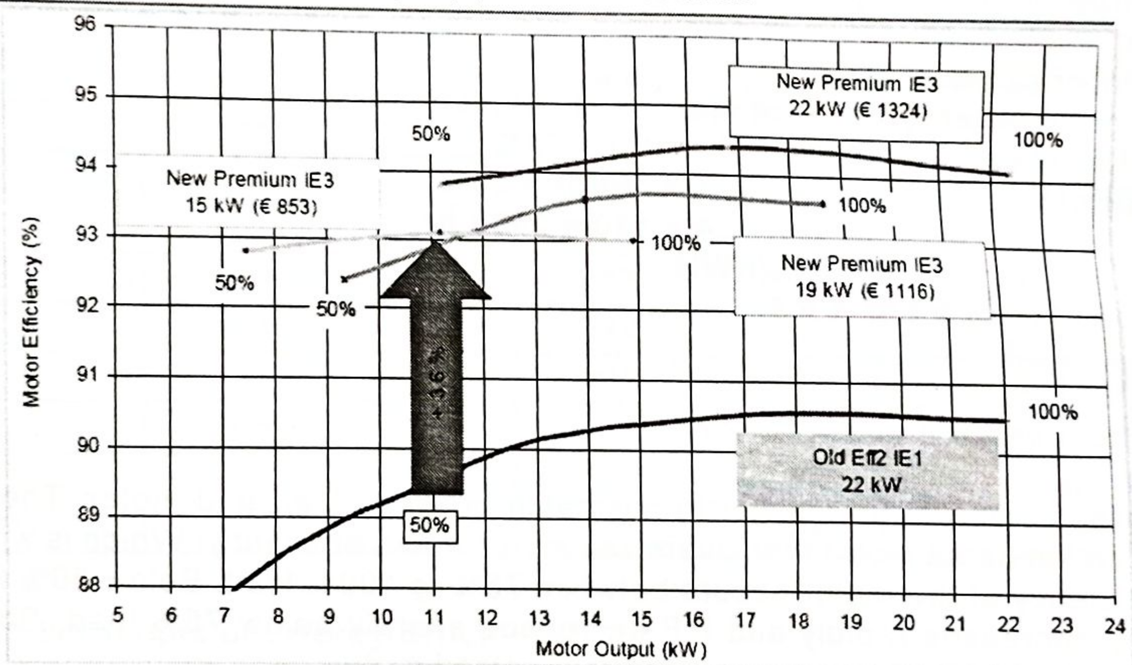
Major losses occur in motor due to mismatch between load and motor. There is misconception about motor that Oversized motor works efficiently! Which is wrong. Peak efficiency of the motor occurs between 75% to 100% load. Below 50% load, efficiency decreases rapidly and P.F decreases sharply below 75% load. So you must replace the oversized motor with proper sized motor.

Partial-load efficiency of IE3 and IE1 motors (4-pole)



3.10.1 Comparison of Efficiency at Full Load and at Partial Load.

Figure 38: Example of how downsizing can pay for a more-efficient motor



Source: A+B International, 2007.

3.11 Make the Motor System Efficient instead of Only Motor.

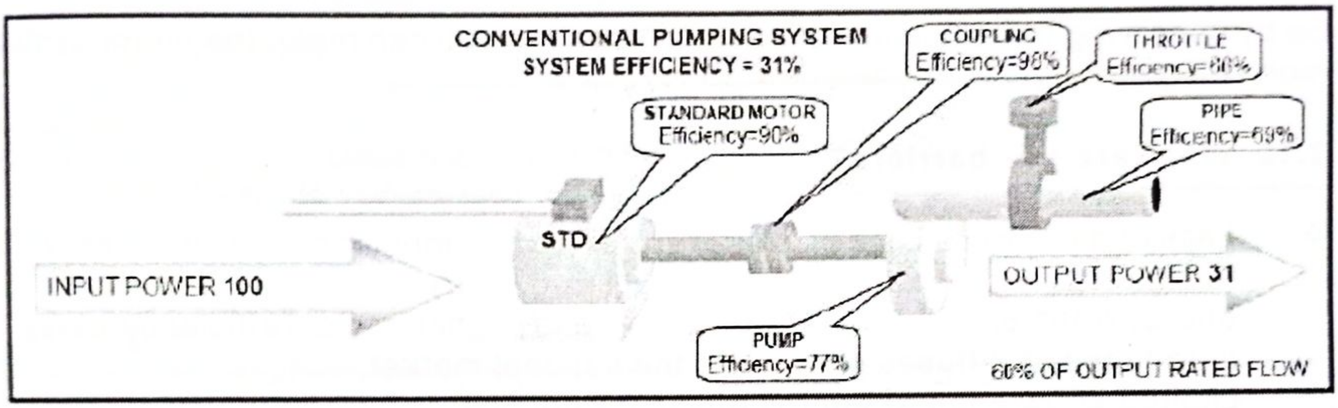
The three major routes to achieving these savings are:

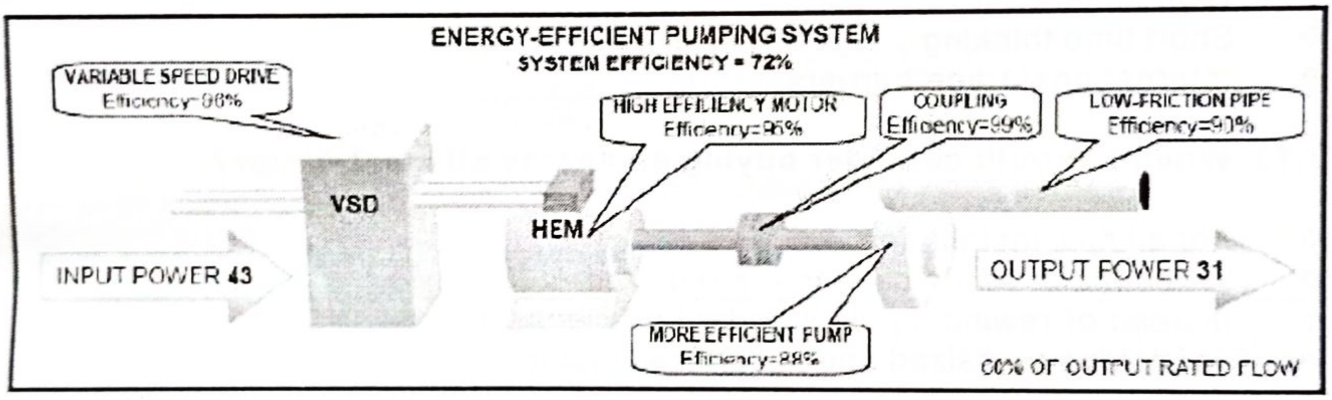
- Use of properly sized and energy?efficient motors.
- Use of adjustable?speed drives (ASDs)2, where appropriate, to match motor speed and torque to the system mechanical load requirements. This makes it possible to replace inefficient throttling devices and, in some cases with "direct?drive", to avoid wasteful mechanical transmissions and gears.

- Optimization of the complete system, including correctly sized motor, pipes and ducts, efficient gears and transmissions, and efficient end?use equipment (fans, pumps, compressors, traction, and industrial handling and processing systems) to deliver the required energy service with minimal energy losses.

Motor System includes Electric motor, VFD, Cooling fan, Gear, Transmission belt. Some energy losses occur in motor itself but energy losses are greater in rest of mechanical system to which motor is coupled.

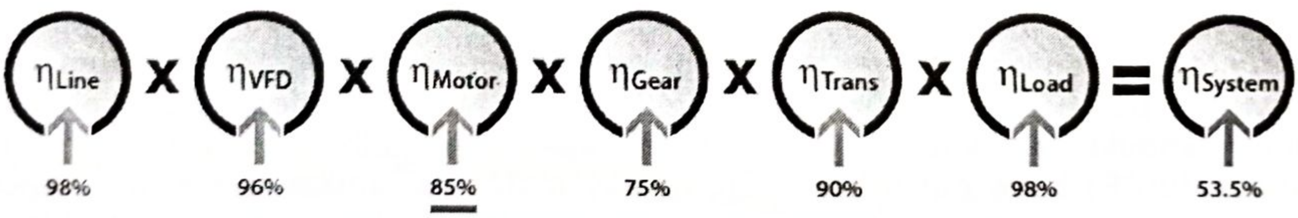
3.11.1 Motor System





Source: De Keulenaer H. et al. 2004

10-year-old motor



Note that the efficiency of all components are multiplied together to find the system efficiency.

Brand new, premium-efficient motor

Note although you have improved the efficiency of motor but still system efficiency is very low due to low efficiency gear system that are still wasting energy. To improve system efficiency you must improve the efficiency of each component involved

So by improving the efficiency of each component, you can make the motor system more efficient.

3.12 What are the barriers?

- Lack of awareness Lack of awareness among motor purchasers of the potential for energy and cost savings by using more efficient motors within energy?efficient EMDS. When a new and higher motor?efficiency class is introduced, it diffuses slowly into the national market.
- Limited knowledge of energy efficiency options
- High initial cost
- Short time thinking
- International trade barriers

3.13 When I should consider buying an energy efficient motor?

- For all new installation
- When major modifications are required
- Instead of rewinding old standard efficiency motor
- To replace oversized and undersized motor

3.14 Either I should rewind a failed motor?

Although failed motors can usually be rewound, it is often worthwhile to replace a damaged motor with a new energy-efficient model to save energy and improve reliability. When calculating operating costs for rewound motors, deduct one efficiency point for motors exceeding 40 hp and two points for smaller motors. Motors should be rewound only at reliable repair shops that use low temperature (under 700°F) bake out ovens, high quality materials, and a quality assurance program Ask the repair shop to conduct a core loss or loop test as part of their rewind procedures.

Different problems that occur during rewinding are

- If winding wire is of smaller diameter, increases I^2R losses
- Decrease in turn in stator winding reduces winding resistance so
  - Increases stator current
  - Increases the magnetic field
  - Increases starting current by 23%

- During rewinding due to overheating stator insulation damages that increases the core losses

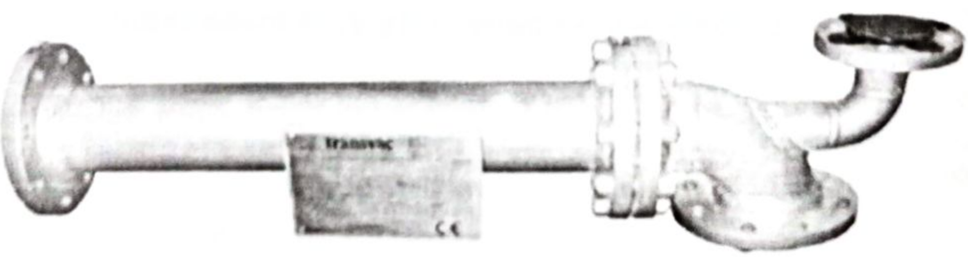
So rewind only if you have qualified rewinding shop

3.15 Proposed timetable for implementation MEPS

Table 38: Proposed timetable for implementation of recommendations

Recommendations	Phase 1 In 2011	Phase 2 2012-15	Phase 3 2016-20	Phase 4 2021-25	Phase 5 2026-30
Regulatory policy measures					
Implementation of motor MEPS.	COMMENCE	COMPLETED			
Regulatory measures for packaged integrated motor-driven energy end-uses.	COMMENCE	COMPLETED			
Development of international test procedures for other electric motor types.	COMMENCE	CONTINUE	COMPLETED		
Development of international test procedures for other electric motor system components.		COMMENCE	COMPLETED		
Regulatory measures for gears and transmissions.		COMMENCE	COMPLETED		
Non-regulatory policy measures					

4. THERMOCOMPRESSOR



4.1 Back ground

Steam is a common source of heat in sugar industry. Therefore it is imperative that sugar industry focus on steam utilization and take action to minimize or optimize the use of steam. One way is to maximize the use of LP steam. The sugar industry has many processes and system that uses both live and exhaust steam. Some of the systems that are live steam user can be totally or partially replace with exhaust steam.

One such live steam user in a sugar mill is adjoining distillery but most of the sugar industry reduces the pressure of live steam through pressure reducing valve, for use in distillery which is highly inefficient method. If somehow we are able to use exhaust steam in distillery, there will be a great saving of energy. One such method of reducing the use of live steam is the use of Thermocompressor. Thermocompressor increases the pressure and temperature of LP steam by mixing it with HP steam through the principle of energy conversion. The resultant LP steam can be used in any other process such as distillery. This modification can result in minimizing the use of MP steam consumption by effectively utilizing the heat or energy of exhaust steam.

4.2 Case study

A 4000TCD sugar industry in india (Maharashtra) uses a back pressure turbine that produces exhaust of at rate 6300Kg/h at 0.4 Kg/cm2 .there was no processes in sugar industry that could utilize this exhaust steam of 0.4Kg/cm2the distillery required 10TPH steam at 1.5 Kg/cm2. this requirement could be met either by a new boiler or by reducing the live steam pressure through pressure reducing valve which is not a good system.

The turbines exhaust steam, instead of vented out into atmosphere, could be converted into MP steam through Thermocompressor and used to meet the steam requirement of distillery. Thermocompressor was installed that increases the pressure and temperature of exhaust steam and the resultant LP steam saved is given to steam turbine that produces additional power

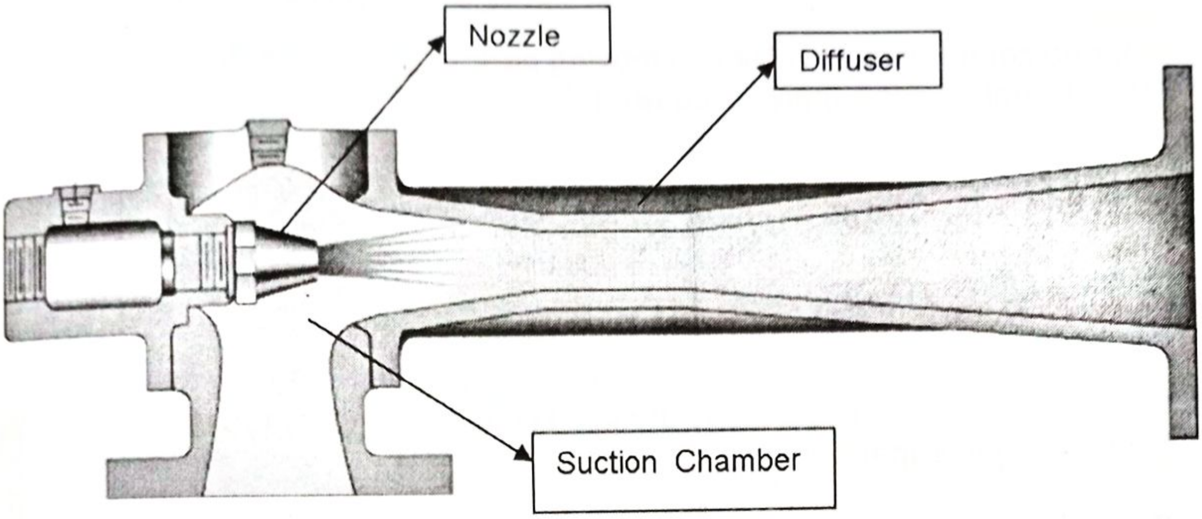
4.2.1 Implementation and methodology

Motive steam	3700 Kg/h	at 20 Kg/cm^2
Suction steam	6300 Kg/h	at 0.4 Kg/cm^2
Discharge steam	10000 Kg/h	at 1.5 Kg/cm^2

4.3 Construction of Thermocompressor

Thermocompressor essentially consist of three main parts.

- Nozzle
- Suction chamber
- Diffuser



4.4 Working Principle of Thermocompressor

- Motive steam (High pressure steam) enters through converging-diverging nozzle.
- Low pressure steam(suction steam) enters through suction inlet
- High pressure steam mixes with low pressure steam in suction chamber
- The resultant steam mixture enters the diffuser where its velocity reduces and its kinetic energy is converted into pressure energy.
- The resultant steam called discharge steam is then used in process. Discharge steam pressure is between the pressure of motive and LP suction steam.

4.5 Applications of Thermocompressor

1. Thermocompressor can be used to compress or boost the vapours by mixing HP steam with vapours
2. Low pressure steam from turbine exhaust can be boosted for reuse in the distillery
3. It can also be used to recover the flash steam.

4.5.1 Thermocompressor in Sugar Industry

4.5.2 Thermocompressor With Back Pressure Turbine

4.6 Things to be considered before installing

- Thermocompressor is a useful but delicate apparatus and can give the desired steam economy in sugar mills under following conditions.
- The exhaust of turbine must necessarily be 15-20% short of steam requirement of the process.
- The live steam feed to Thermocompressor is regulated to suit the variation in exhaust.
- The apparatus is designed taking into account the correct temperature and pressure of vapours to be compressed.

4.7 Advantages of Thermocompressor

- Thermo compressor involves no moving part.
- No external power supply is required
- Require very little maintenance
- Easy installation
- Low capital and installation cost
- Longer useful operating lives
- Suitable for hazard areas
- Reduces overall steam consumption
- It can improve the thermal efficiency of a factory by 1-3%
- Vapour recovery from last stage of multi stage evaporator results in substantial cost saving in sugar plant

4.8 Energy Saving and Pay Back Calculation

Example 1:

- Exhaust steam flow rate = 10,000 lb/hr of steam at near atmospheric pressure [0.3 psig, 212.9°F, 1,150.7 (Btu/lb)].
- Wasted steam can be converted into useful low-pressure process steam by boosting its pressure to 15.3 psig (250.3°F, 1,164.1 Btu/lb).
- Saturated motive steam at a pressure of 200 psig is available (387°F, 1,199.7 Btu/lb).
- For a required compression ratio of 2:1 ,1.1 lb of high-pressure motive steam per lb of low-pressure suction steam is required. The thermo compressor requires 11,000 lb/hr of 200-psig steam to produce a discharge of 21,000 lb/hr of 15.3-psig intermediate-pressure steam. Elimination of steam venting saves:
- Energy Savings = Vent Flow Rate (lb/hr) x Enthalpy of the Vented Steam less the Enthalpy of Makeup Water (Btu/lb)
- = 10,000 lb/hour x (1,150.7 - 77) Btu/lb x (MMBtu/106 Btu) = 10.7 MMBtu/hr
- Annual MMBtu saved = 94,000 MMBtu
- Natural gas fuel priced per MMBtu = Rs.10.00/MMBtu boiler efficiency = 80%
- Annual Savings = 94,000 MMBtu/yr x Rs.10.00/MMBtu/0.80 = Rs.11,75,000

Example 2:

- Steam vent into atmosphere = 300KG/hr at 0.5 barg
- It is required to compress this steam to 3 barg using motive steam of 9 barg.
- Cost of steam per Kg = Rs. 1.5
- Operating hours = 2880 hr
- Annual saving = 300 x 2880 x 1.5
  = Rs. 1,296,000
- Estimated investment = Rs. 3,00,000
- Pay back = 91000/144000 = 3 months

5. Biogas plant:

5.1 Introduction:

Fossil fuel includes oil, gas and coal. Fossil fuel resources are depleting so dramatically that we can not relay on them in future and even it is also possible that in near future these resources may exhaust. Fossil fuel can not fulfill our future demands so we should focus our attention on other energy resources that are more reliable and environment friendly such as biogas plant.

Biogas energy is a very good alternative of fossil fuel that reduces global warming and green house gases. Biogas is clean environment friendly fuel that can be obtained by anaerobic digestion of animal residues, domestic and farm waste, abundantly available in countryside.

5.2 Construction of biogas plant

5.2.1 Types of gasholder or Dome

There are two types of gasholder.

1. Moveable gasholder
2. Fixed dome gasholder

5.3 Biogas Generation Process

Hydrolysis

↓

Acidogenesis

↓

Methanogenesis

↓

Acetogenesis

5.4 Properties of Biogas at 0°C and 1 atm pressure

CH4 Content:	65-70%
CO2Content:	30-35%
H2S Content:	1,000ppm
Flame speed:	25cm/s
A/F Ratio (Theoretical):	6.19m3a/m3g
Combustion Temp:	650o C
Specific Heat (Cp):	1.6 kJ/m3o C
Density (p):	1.15 kg/m3

5.5 1 Cubic meter of Biogas Heat Replacement Value

LPG	0.46Kilogram
Gasoline	0.67Litre
Diesel	0.60Litre
HeatingOil	0.55Litre
Firewood	1.50Kilogram
Electricity	1.20KW-h

5.6 UTILIZATION OF BIOGAS

- Cooking: Biogas can be used in a specially designed burner for cooking purpose. A biogas plant of 2 cubic metres capacity is sufficient for providing cooking fuel needs of a family of about five persons.
- Lighting: Biogas is used in silk mantle lamps for lighting purpose. The requirement of gas for powering a 100 candle lamp (60 W) is 0.13 cubic metre per hour.
- Power Generation: Biogas can be used to operate a dual fuel engine to replace up to 80 % of diesel-oil. Diesel engines have been modified to run 100 per cent on biogas. Petrol and CNG engines can also be modified easily to use biogas.
- Transport Fuel: After removal of CO2, H2S and water vapor, biogas can be converted to natural gas quality for use in vehicles.

5.7 Is biogas safe?

Biogas is not poisonous. The only danger is from explosion if it is mixed with air and lit by fire. However, it only explodes if mixed with air or oxygen with a lighted match or fire very close by. For example, you shouldn't ever lean into the tank with a lighted match! If you have a biogas leak in the house, and have good ventilation (windows, fresh air blowing through the house), it should not pose much danger of explosion although you would lose your stored biogas. This is why good maintenance is important.

5.8 Advantages OF BIOGAS

- Short payback priod
- Reduces pollution by replacing fossil fuel.
- Biogas produces excellent fertilizers for use on the farms
- Biogas can help in the fight against global wrming
- Biogas reduces green house gases

5.9 Energy Saving and Pay Back Calculation

Average dung produced by a cow	= 5Kg/day
Average dung produced by 1000 cows	= 5000Kg/day
1 Kg of dung produces biogas	= 0.06510 m3/day
5000 Kg of dung produces biogas	= 0.06510x5000 m3 =325.5 m3/day
1m3 of biogas produces	= 24.48MJ/day
325.5m3 of biogas produces	= 24.48 x 325.5MJ = 7968.5MJ
As 1KWh = 3.6 x 106J	= 3.6MJ
So 7968.5MJ = 2213.5KWh	= 2.2MWh
Hence MWh produced in one day	= 2.2MWh = 2213.5 KWh

Annual saving = Rs. 8 x 2213.5 x 365 = Rs. 64, 63,330

Investment = 10, 00,000

Pay back period = 5, 00,000/64, 63,330 = 2 months

CONCLUSION:

There are main two purposes of energy conservative technologies. One is to save environment from hazard gases and second is to save energy. Experience obtained from different parts of the world and energy auditing programmes show that by installing above mentioned technologies we can save a large amount of energy and can contribute positively towards environment. Many studies around the world have identified Energy conservative technologies as an attractive low-cost option to generate power. Energy conservative technologies have long term advantages. Any new technology diffuses very slowly in the industry but they don't have apparent advantages but experience of such technologies in different industries can help us to explore the advantages of such technologies and our sugar industry is the example of it that adopt these technologies and save energy and of course lot of money. Many developing countries are moving towards energy efficient technologies because if you install a low price inefficient technology it will remain round about for 20 year so your plant will run inefficiently for 20 years.

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