

BEYOND

SMART CITIES

CERTIFIED INDUSTRIAL ENERGY PROFESSIONAL

CIEP TRAINING PROGRAM

FOR INDUSTRIAL ENERGY SPECIALISTS

KRISHNAJI PAWAR, LEED AP BD+C, GSAS CGP, ISO 14001:2015, GCP

ENERGY SPECIALIST CURRICULUM

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ELECTRIC MOTORS AND DRIVES - 2

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LEARNING OBJECTIVES

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Motor Speed Control Systems

Factors Affecting Energy Efficiency & Minimising Motor Losses in Operation

Electric Motor Management Drives

Variable Speed Drive Alternatives Performance

Rewinding and motor replacement issues, Energy saving opportunities with energy efficient motors.

Compressed Air Management & Gas Systems

FACTORS AFFECTING ENERGY EFFICIENCY & MINIMISING MOTOR LOSSES IN OPERATION



✓Power Supply Quality

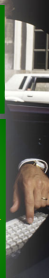
✓Motor performance is affected considerably by the quality of input power, that is the actual volts and frequency available at motor terminals vis-a-vis rated values as well as voltage and frequency variations and voltage unbalance across the three phases. Motors in India must comply with standards set by the Bureau of Indian Standards (BIS) for tolerance to variations in input power quality.

Motor Loading

Measuring Load
% Loading of the motor can be estimated by the following relation:
 $\% \text{ loading} = \frac{\text{Input power drawn by the motor (kW)}}{\text{Name plate full load kW rating / name plate full load motor efficiency}}$
or
 $\% \text{ loading} = \frac{\text{Input power drawn by the motor (kW)}}{\sqrt{3} \times \text{kV} \times \text{I Cos}\phi}$

- Never assume power factor
- Loading should not be estimated as the ratio of currents.

✓The BIS standards specify that a motor should be capable of delivering its rated output with a voltage variation of +/- 6 % and frequency variation of +/- 3 %. Fluctuations much larger than these are quite common in utility-supplied electricity in India. Voltage fluctuations can have detrimental impacts on motor performance.



FACTORS AFFECTING ENERGY EFFICIENCY & MINIMISING MOTOR LOSSES IN OPERATION



Reducing Under-loading

✓Probably the most common practice contributing to sub-optimal motor efficiency is that of under-loading. Under loading results in lower efficiency and power factor, and higher than necessary first cost for the motor and related control equipment. Under-loading is common for several reasons.

Sizing to Variable Load

✓Industrial motors frequently operate under varying load conditions due to process requirements. A common practice in cases where such variable-loads are found is to select a motor based on the highest anticipated load. In many instances, an alternative approach is typically less costly, more efficient, and provides equally satisfactory operation. With this approach, the optimum rating for the motor is selected on the basis of the load duration curve for the particular application.



FACTORS AFFECTING ENERGY EFFICIENCY & MINIMISING MOTOR LOSSES IN OPERATION



Power Factor Correction

✓As noted earlier, induction motors are characterised by power factors less than unity, leading to lower overall efficiency (and higher overall operating cost) associated with a plant's electrical system. Capacitors connected in parallel (shunted) with the motor are typically used to improve the power factor.

✓The impacts of PF correction include reduced kVA demand (and hence reduced utility demand charges), reduced I²R losses in cables upstream of the capacitor (and hence reduced energy charges), reduced voltage drop in the cables (leading to improved voltage regulation), and an increase in the overall efficiency of the plant electrical system.

✓It should be noted that PF capacitor improves power factor from the point of installation back to the generating side. It means that, if a PF capacitor is installed at the starter terminals of the motor, it won't improve the operating PF of the motor, but the PF from starter terminals to the power generating side will improve.



FACTORS AFFECTING ENERGY EFFICIENCY & MINIMISING MOTOR LOSSES IN OPERATION



Maintenance

✓ Inadequate maintenance of motors can significantly increase losses and lead to unreliable operation. For example, improper lubrication can cause increased friction in both the motor and associated drive transmission equipment. Resistance losses in the motor, which rise with temperature, would increase. Providing adequate ventilation and keeping motor cooling ducts clean can help dissipate heat to reduce excessive losses. The life of the insulation in the motor would also be longer : for every 10°C increase in motor operating temperature over the recommended peak, the time before rewinding would be needed is estimated to be halved



FACTORS AFFECTING ENERGY EFFICIENCY & MINIMISING MOTOR LOSSES IN OPERATION



A checklist of good maintenance practices to help insure proper motor operation would include:

- ✓ Inspecting motors regularly for wear in bearings and housings (to reduce frictional losses) and for dirt/dust in motor ventilating ducts (to ensure proper heat dissipation).
- ✓ Checking load conditions to ensure that the motor is not over or under loaded. A change in motor load from the last test indicates a change in the driven load, the cause of which should be understood.
- ✓ Lubricating appropriately. Manufacturers generally give recommendations for how and when to lubricate their motors. Inadequate lubrication can cause problems, as noted above. Over- lubrication can also create problems, e.g. excess oil or grease from the motor bearings can enter the motor and saturate the motor insulation, causing premature failure or creating a fire risk.
- ✓ Checking periodically for proper alignment of the motor and the driven equipment. Improper alignment can cause shafts and bearings to wear quickly, resulting in damage to both the motor and the driven equipment.
- ✓ Ensuring that supply wiring and terminal box are properly sized and installed. Inspect regularly the connections at the motor and starter to be sure that they are clean and tight.



FACTORS AFFECTING ENERGY EFFICIENCY & MINIMISING MOTOR LOSSES IN OPERATION



Age

✓ Most motor cores in India are manufactured from silicon steel or decarbonized cold rolled steel, the electrical properties of which do not change measurably with age. However, poor maintenance (inadequate lubrication of bearings, insufficient cleaning of air cooling passages, etc.) can cause a deterioration in motor efficiency over time. Ambient conditions can also have a detrimental effect on motor performance. For example, excessively high temperatures, high dust loading, corrosive atmosphere, and humidity can impair insulation properties; mechanical stresses due to load cycling can lead to misalignment. However, with adequate care, motor performance can be maintained



SPEED CONTROL OF AC INDUCTION MOTORS

✓Traditionally, DC motors have been employed when variable speed capability was desired. By controlling the armature (rotor) voltage and field current of a separately excited DC motor, a wide range of output speeds can be obtained.

✓DC motors are available in a wide range of sizes, but their use is generally restricted to a few low speed, low-to-medium power applications like machine tools and rolling mills because of problems with mechanical commutation at large sizes. Also, they are restricted for use only in clean, non-hazardous areas because of the risk of sparking at the brushes. DC motors are also expensive relative to AC motors.

✓Because of the limitations of DC systems, AC motors are increasingly the focus for variable speed applications. Both AC synchronous and induction motors are suitable for variable speed control. Induction motors are generally more popular, however, because of their ruggedness and lower maintenance requirements. AC induction motors are inexpensive (half or less of the cost of a DC motor) and also provide a high power to weight ratio (about twice that of a DC motor).

MOTOR SPEED CONTROL SYSTEMS

✓Multi-speed motors Motors can be wound such that two speeds, in the ratio of 2:1, can be obtained. Motors can also be wound with two separate windings, each giving 2 operating speeds, for a total of four speeds. Multi-speed motors can be designed for applications involving constant torque, variable torque, or for constant output power. Multi speed motors are suitable for applications, which require limited speed control (two or four fixed speeds instead of continuously variable speed), in which cases they tend to be very economical. They have lower efficiency than single-speed motors

✓Adjustable Frequency AC Drives:

Adjustable frequency drives are also commonly called inverters. They are available in a range of kW rating from fractional to 750 kW. They are designed to operate standard induction motors. This allows them to be easily added to an existing system. The inverters are often sold separately because the motor may already be in place. If necessary, a motor can be included with the drive or supplied separately.

MOTOR SPEED CONTROL SYSTEMS +

✓Direct Current Drives (DC) :

The DC drive technology is the oldest form of electrical speed control. The drive system consists of a DC motor and a controller. The motor is constructed with armature and field windings. Both of these windings require a DC excitation for motor operation. Usually the field winding is excited with a constant level voltage from the controller.

✓Wound Rotor AC Motor Drives (Slip Ring Induction Motors):

Wound rotor motor drives use a specially constructed motor to accomplish speed control. The motor rotor is constructed with windings which are brought out of the motor through slip rings on the motor shaft. These windings are connected to a controller which places variable resistors in series with the windings. The torque performance of the motor can be controlled using these variable resistors. Wound rotor motors are most common in the range of 300 HP and above.

ELECTRIC MOTOR MANAGEMENT DRIVES



- ✓ Motors are fixed speed devices likely running between NLRPM and FLRPM
- ✓ Other speeds on the driven end have to be engineered (which will affect the load on the motor)
- ✓ Because of the “fan” laws (pumping or blowing) centrifugal devices are desired applications for varying LPS of air or water



CENTRIFUGAL FAN AND PUMP LAWS



✓ Flow and Speed

$$\frac{LPS_{new}}{LPS_{old}} = \frac{RPM_{new}}{RPM_{old}}$$

✓ Pressure (Head) and Speed

$$\frac{P_{new}}{P_{old}} = \frac{[RPM_{new}]^2}{[RPM_{old}]^2} = \frac{[LPS_{new}]^2}{[LPS_{old}]^2}$$

✓ Power and Speed

$$\frac{kW_{new}}{kW_{old}} = \frac{[LPS_{new}]^3}{[LPS_{old}]^3}$$



ELECTRIC MOTOR MANAGEMENT FAN LAWS EXAMPLE



- ✓ A 30 kW centrifugal blower is on a forced draft cooling tower. It is basin temperature controlled but conversion to a variable speed drive is being considered. When the blower is running at ½ speed, what is the impact on the LPS of air flow, and what is the new kW requirement?
- ✓ New LPS is _____ old LPS
- ✓ New kW requirement is:
- ✓ These type savings are why variable speed drives are so popular today

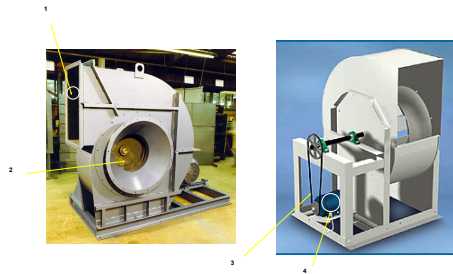


ELECTRIC MOTORS VARIABLE VOLUME OPTIONS

- ✓ Outlet damper control (see sketch, location 1)
- ✓ Inlet vane control (see sketch, location 2)
- ✓ Magnetic clutching (see sketch, location 3)
 - Eddy current clutch
 - Permanent magnetic clutch
- ✓ Variable Frequency Drives (see sketch, location 4)
- ✓ Hydraulic drives, variable sheaves, etc.



ELECTRIC MOTORS VARIABLE VOLUME OPTIONS SKETCH

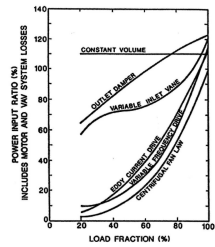
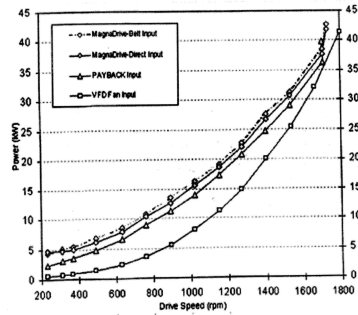


VARIABLE SPEED DRIVE ALTERNATIVES PERFORMANCE

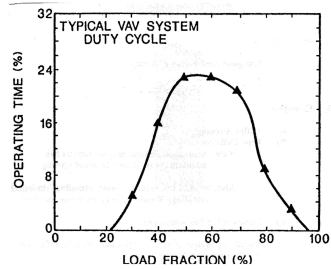
- ✓ The next page shows performance expectations from an older EPRI report
- ✓ The page after that shows performance from a more recent PNL test
- ✓ The third page shows an “average” VAV loading profile. It can be used as a default loading if better figures are not available. Quick Fan from DoE presents another default possibility.



TYPICAL POWER CONSUMPTION OF VARIOUS CONTROL SYSTEMS



VFD: DEFAULT LOADING PROFILE



ELECTRIC MOTOR MANAGEMENT SELECTION OF BEST OPTION

Outlet damper control

- ✓ Simple and effective
- ✓ Not efficient, infrequently used
- ✓ Great candidate for conversion to others

Inlet vane control

- ✓ Simple and effective
- ✓ More efficient than outlet damper, but significantly less than other options, fairly frequently used
- ✓ Great candidate for conversion to others

ELECTRIC MOTOR MANAGEMENT SELECTION OF BEST OPTION

Variable Frequency Drive (VFD)

- ✓ Probably most efficient
- ✓ Competitive cost
- ✓ Harmonic concerns (input and output)
 - Worst drives are old 6 pulse drives, where most intense harmonics are the 5th and 7th.
 - In general, worst harmonics are $n (\pm 1)$, where n is the number of pulses.
 - And, higher order harmonics are less intense than lower order ones.
- ✓ Remote (clean area) installation
- ✓ Multiple motors may be connected to one drive providing higher savings, but sizing is critical
- ✓ Motors and load must be agreeable to VFDs

VARIABLE FREQUENCY DRIVE EXAMPLE

✓ A large 50 HP (37 KW) blower with inlet vane control drives a VAV system operating 6500 hours per year. Energy costs \$0.04/kWh. What is the total savings per year for removing the inlet vane control and replacing it with a VFD?

- ✓ Assume the performance figures in slide 9 apply
- ✓ Assume the loading figures in slide 11 apply.
- ✓ Construct an Excel spread sheet to do the calculations (will be done for you on next page)

VARIABLE FREQUENCY DRIVE EXAMPLE

Profit Improvement With Variable Frequency Drives

1 Load Ratio	2 Power Input Ratio (Old)	3 Power Input Ratio (VFD)	4 Duty Cycle Fraction	5 kWh Saved	6 Dollar Savings
0.20	0.57	0.09	0.00	0	0
0.30	0.67	0.11	0.0*	6786	271
0.40	0.71	0.14	0.16	22103	894
0.50	0.72	0.20	0.23	28985	1159
0.60	0.75	0.29	0.23	25641	1026
0.70	0.80	0.43	0.20	17934	717
0.80	0.88	0.62	0.09	5671	227
0.90	0.99	0.85	0.03	1018	41
1.00	1.20	1.16	0.01	97	4

Total Annual Electricity Savings 108,235 kWh
Total Annual Dollar Savings \$4,329

VARIABLE FREQUENCY DRIVE EXAMPLE

✓ Calculation for 50% load row in Spread Sheet:
 $(50\text{HP})(0.746\text{kW/HP})(0.72-0.20)(0.23)(6500\text{hr/yr})(\$0.04/\text{kWh})$
= \$1159

Spread Sheet repeats this for all rows

ELECTRIC MOTOR MANAGEMENT SELECTION OF BEST OPTION

- ✓ Magnetic clutches (permanent magnet or eddy current)
 - Bulky and heavy on motor shaft
 - No harmonics
 - Close to same savings as VFDs, but less

\$\$\$\$

- ✓ Choose the technology that your staff understands and likes to use
- ✓ You probably don't want to mix technologies in a given facility (WCT opinion)
- ✓ Most efficient is VFD followed closely by magnetic clutching followed (way back) by inlet vane and outlet damper controls
- ✓ Concentrate on centrifugal devices, not axial or reciprocating devices
 - Chilled water pumps, cooling water pumps, etc.
 - Blowers on cooling towers or VAV (variable-air-volume) HVAC units
- ✓ For cooling towers, work on air side as opposed to water side
 - Larger motors
 - Doesn't affect operation as much (freeze protection, biological control, etc.)
 - Multiple cell towers may be a good candidate for one drive on multiple motors

ELECTRIC MOTOR MANAGEMENT OTHER DRIVES

- ✓ Variable sheaves
 - Very closely approach fan laws
 - Repeatability and maintenance often a problem
 - Many lock blades and install VFDs
- ✓ Hydraulics
 - Effective
 - Expensive
 - Not often used as discussed here

ELECTRIC MOTOR MANAGEMENT AXIAL AND RECIPROCATING

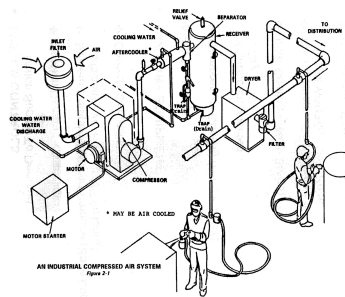
- ✓ Centrifugal laws do not apply
- ✓ More difficult to predict savings
- ✓ If linear, no "real energy savings" over present on/off operation (certainly improved soft start operations and perhaps control)
- ✓ Obviously, savings if converting from constant volume to variable volume

\$\$\$ VARIABLE SPEED DRIVE APPLICATIONS

- ✓ Any large centrifugal blower or pump that runs a lot!
 - ➔ Constant volume? Convert to var. volume
 - ➔ Variable volume with inlet or outlet control
- ✓ Chilled water pumps, large campus
- ✓ Cooling water pumps
- ✓ VAVs using inlet vane
- ✓ Forced draft (blower) cooling towers

COMPRESSED AIR MANAGEMENT

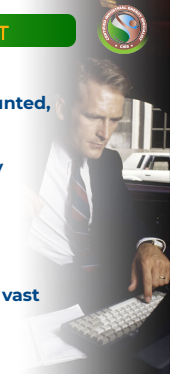
- ✓ Most expensive utility for many companies
- ✓ Large cost reduction potential (20 to 30% common)
 - ✓ Management
 - ➔ Demand side
 - ➔ Supply side
 - ✓ Each 75 KW (100 HP) compressor costs approximately \$25,000 per year to operate
 - ✓ Try it: 8000 hours/year, \$80/kW-yr, \$0.05/kWh, running at 70% load.
 - ✓ Typical first cost is \$30,000 to \$50,000



AIR SYSTEM COMPONENTS MGMT

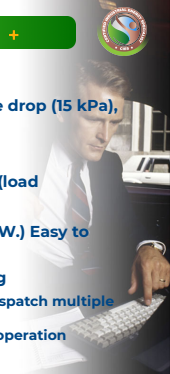
✓ Air Compressors

- ➔ Screw: convenient, fairly efficient, skid mounted, most popular (75 KW or so)
- ➔ Reciprocating: usually large, expensive, very efficient, part load well, often two stage
- ➔ Centrifugal: usually quite large, modulates efficiently down to a point (surge), often VFD
- ➔ Others: other type exist but these cover the vast majority



AIR SYSTEM COMPONENTS MGMT +

- ✓ Intake air should be as cool and dry as possible
- ✓ Intake air filter should be large with low pressure drop (15 kPa), changed frequently
- ✓ Multi stage with interstage cooling helps
- ✓ Drivers can be electric motor (most), gas engine (load management or hybrid), or steam
- ✓ Significant waste heat available (250,000 kJ/75 KW.) Easy to recover on packaged screw air cooled machines.
- ✓ Sequencers: For multiple compressor dispatching
 - ➔ Use a remote (not in compressors) PID control loop to dispatch multiple compressors
 - ➔ Dramatically reduces control differential and smoothes operation
 - ➔ Can be extremely cost effective



AIR SYSTEM COMPONENTS MGMT +

- ✓ After coolers: Air leaves a compressor at approximately 100% RH.
 - ➔ Cooling removes significant moisture; must be trapped and drained (exhausted)
 - ➔ Air cooled or water cooled and they are quite cost effective; save energy in dryer and provide dryer air.
 - ➔ Water cooled more effective but water should be used elsewhere or reused through small cooling tower



AIR SYSTEM COMPONENTS MGMT +



- ✓ **Receivers:** storage devices to smooth demand on compressor
 - ➔ Further cooling removes more water (traps)
 - ➔ Can significantly reduce demand fluctuation on compressor controls
 - ➔ 4 to 8 litres of storage per LPS of compressed air flow (but this varies a great deal)
 - ➔ Located before dryer (wet), after dryer (dry), throughout plant, and at large loads



AIR SYSTEM COMPONENTS MGMT +



- ✓ **Dryers:** Further reduce dew point to avoid moisture in plant equipment
 - ➔ Refrigerated: cools air to about 4 C and reheats by precooling incoming air. Thus, dew point around 4 C. Not dry enough for many plants.
 - ➔ Desiccant: chemically removes moisture by saturating media which must be dried before reusing. Usually two stacks. Expensive but dew point around -23 C.
 - ➔ Deliquescent: similar to desiccant but wet material is removed and replaced.



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AIR SYSTEM COMPONENTS MGMT +

- ✓ Distribution lines: get air where needed and provide further storage
 - ➔ Large lines are good for systems operating full time (often 10 cm)
 - ➔ All lines should be "looped" so air comes at any need from two directions
- ✓ Traps and drains: traps and drains located throughout system to remove moisture. Can be a large source of air leaks.
- ✓ Supply side: should be managed first
 - ➔ Air leaks: large cost (see diagram), often 20% or more of capacity goes to leaks (artificial demand). Air leak detection and repair is extremely cost effective.
 - ➔ Air motors: great torque properties, small handprint, will not spark, but VERY ENERGY INEFFICIENT (7 - 9 kW air vs. 1 kW electric common)

AIR SYSTEM COMPONENTS MGMT +

- ✓ Pressure supplied: proper level critical
 - ➔ Approximately 1% energy savings for each 15 kPa drop (increase) in air pressure
 - ➔ Productivity cost can greatly exceed energy savings so be careful
 - ➔ Distribution drop should not be more than about 10% (600 kPa at tank to supply 550 kPa to tool) so receivers, better looping, etc. may enable pressure to be dropped without affecting tool

COMPRESSED GAS SYSTEMS

- ✓ Gas systems fall into three categories
 - ➔ Compressed air systems, compressed on site
 - ➔ Compressed gas systems, with high pressure storage
 - ➔ Liquid storage
- ✓ Most systems with pressures greater than 100 kPa have one thing in common: leaks.
- ✓ Compressed air system leaks result in more compressor energy and expense.
- ✓ Leaks in other systems result in loss of purchased gas.

COMPRESSED GAS

AIRMaster+

- Software tool sponsored by US Department of Energy
- Estimates potential savings from selected energy efficiency measures and calculates paybacks
 - ★ Reduce air leaks
 - ★ Improve use efficiency
 - ★ Reduce air pressure
 - ★ Use unloading controls
 - ★ Adjust set points
 - ★ Reduce operating time
 - ★ Add receiver volume





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