UNIT – III

ENERGY EFFICIENT MOTORS

Energy efficient motors, factors affecting efficiency, loss distribution, constructional details, characteristics – variable speed, variable duty cycle systems, motor energy audit.

ENERGY EFFICIENT MOTORS:

Energy efficient motors (EEM) are the ones in which, design improvements are incorporated specifically to increase operating efficiency over motors of standard design (see figure). Design improvements focus on reducing intrinsic motor losses. Improvements include the use of lower-loss silicon steel, a longer core (to increase active material), thicker wires (to reduce resistance),thinner laminations, smaller air gap between stator and rotor, copper instead of aluminum bars in the rotor, superior bearings and a smaller cooling fans, etc.

Energy-efficient motors operate with efficiencies that are typically 4 to 6% higher than the standard motors. In keeping with the stipulations of the BIS, energy- efficient motors are designed to operate without loss in efficiency at loads between 75% and 100% of rated capacity. This may result in major benefits in varying load applications. The power factor is about the same or may be higher than for standard motors. Furthermore energy-efficient motors have lower operating temperatures and levels, greater ability to accelerate higher-inertia loads, and are less affected by supply voltage fluctuations.

Energy efficient motors cover a wide range of ratings and the full load efficiencies are higher by 3 to 7%. The mounting dimensions are also maintained as per IS1232 to enable easy replacement. As a result of the modifications to improve performance, the costs of energy-efficient motors are higher than those of standard motors by about 30%. The higher cost will often be paid back rapidly in saved operating costs, particularly in new applications or end-of-life motor replacements. In cases where existing motors have not reached the end of their useful life, the economics will be less positive.

Because the favorable economics of energy-efficient motors are based o savings in operating costs, there may be certain cases which are economically ill-suited to energy-efficient motors. These include highly intermittent duty or special torque applications such as hoists and cranes, traction drives, punch presses, machine tools and centrifuges.

In addition, energy efficient designs of multi-speed motors are generally not available. Further, energy-efficient motors are not yet available for many special applications, e.g. for flame-proof operation in oil-field or fire pumps or for very low speed applications (below 750 rpm). Also, most energy-efficient motorsproduced today are designed only for continuous duty cycle operation.

Given the tendency of over-sizing on the one hand and ground realities like: voltage, frequency variations, efficacy of rewinding in case of a burnout, on the other hand, benefits of EEMs can be achieved only by careful selection, implementation, operation and maintenance efforts of energy managers. Summaryof energy efficiency improvements in EEMs is given in the following Table.

Energy Efficient Motors

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

Measures adopted for energy efficiency address each loss specifically as under:

FACTORS AFFECTING EFFICIENCY AND LOSS DISTRIBUTION

A fundamental issue that can affect a motor's energy usage is its suitability for the intended application. Motors are designed to operate most efficiently at their nameplate rating. The nameplate rating of the motor is commonly disregarded by motor users! Imagine in a sugar mill, their supply voltage is 480V but the nameplate voltages of motors are 440V, 460V, and 480V. No doubt 50% of their motor inventories were rewound. Selecting the wrong motor for a particular application or operating the motor outside its recommended parameters will decrease the motor's performance, introducing additional losses into the electrical system.

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There are many factors affecting performance of AC motor that will affect its efficiency and will end-up burn motor windings. Restoring motor efficiency after rewound becomes a problem.

As long as nobody is given the responsibility for company-wide electric motor asset management, employees in the production environment will continue to act on an ad hoc basis, maintaining, repairing, and replacing motors in the same way they have in the past. The obvious driver for change usually escapes notice since the losses that are generated by a sub-optimal motor are scattered among different cost centers: energy consumption, material waste, lost revenue, extra working hours, reduced productivity, reduced production quality, et cetera. By assigning an individual — either inside the company or outsourced — to electric motor asset management, electric motors will receive the focus they deserve.

A. Motor Performance

There is a wealth of information about a motor's performance buried in the characteristics of the electrical signals at the motor's terminals. With the motor's nameplate data and these electrical characteristics, it is possible to quantify many energy savings opportunities for a given motor. The fundamental electrical characteristics include the voltage, current, and frequency data for each phase. By collecting data on these fundamental characteristics, monitoring devices can provide additional information needed to maximize energy savings including:

- Voltage variations
- Voltage unbalance
- Motor load (based on current)
- Total harmonic distortion
- Power Factor

B. Voltage Variance

Induction motors are at times operated on circuits of voltage other than those for which the motors are rated. Under such conditions, the performance of the motor will vary from the rating, as shown in Figure 2. The following are some of the operating results caused by small variation of voltage:

- Motor temperature
- Power factor

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- Starting torque
- Slip

From Figure 2, a 10% voltage variation increase motor load by 2.5 – 3.5%, reduce efficiency by 1%, reduce power factor by 10%, and etc.

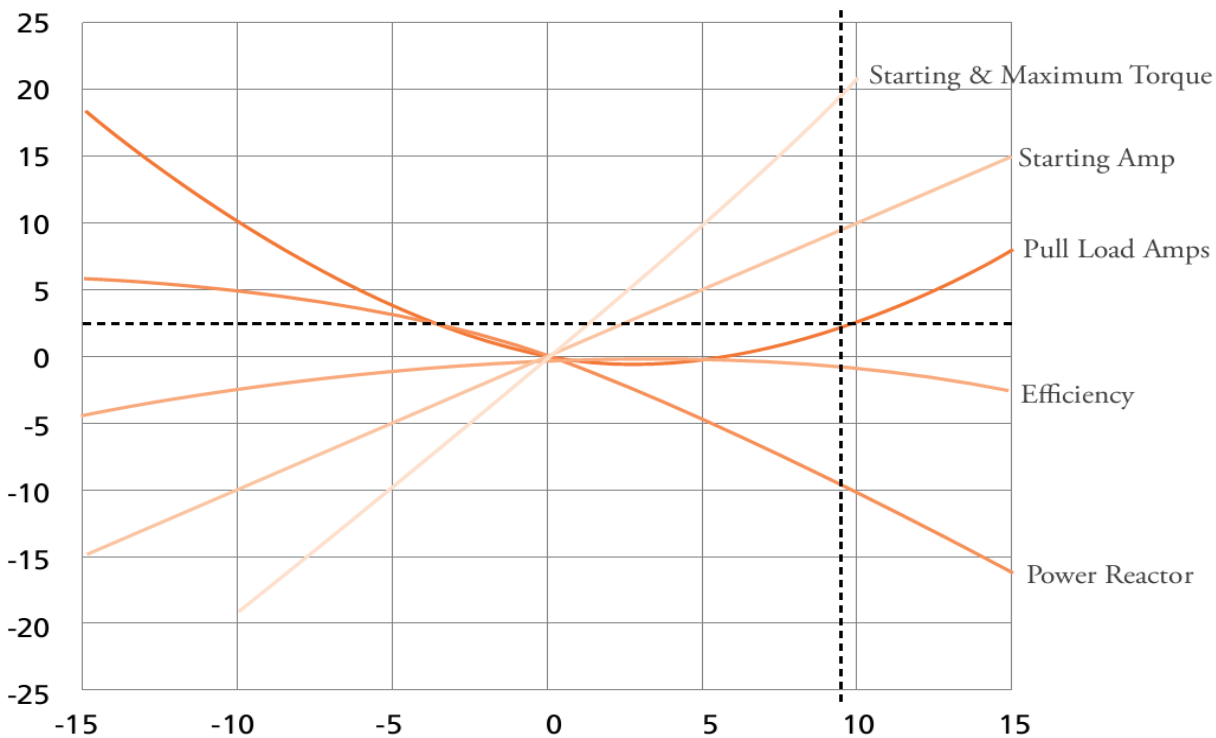

Figure 2 - Effect of Voltage Variations on Induction Motor Character

C. Voltage Unbalance

Voltage unbalance (including single phasing) is both a leading cause of motor failures and a major contributor to energy losses in motors. The subsequent current unbalances that result produce additional losses in the motor. The effect of unbalanced voltages on polyphase induction motors is equivalent to the introduction of a “negative sequence voltage” having a rotation opposite to that occurring with balanced voltages. This negative sequence voltage produces in the air gap a flux rotating against the rotation of the rotor, tending to produce high currents. The unbalance voltage is defined as:

$$\textbf{percent voltage unbalance} = 100 \times \frac{\text{Maximum vlotage deviation from average voltage}}{\text{Average voltage}}$$

The impacts of voltage unbalance are as follows:

- Increase in winding temperatures. The increase in winding temperature causes additional power losses and a significant drop in motor efficiency
- Increase vibrations and noise

D. Motor load

Motor load increases when there are stresses coming from bearing and unusual mechanical loads. 50% of machinery problems, electric motor in particular are caused by excessive load due to unbalance, misalignment, and belt tension. Figure 3, 4, and 5 showed the impact of misalignment to motor load.

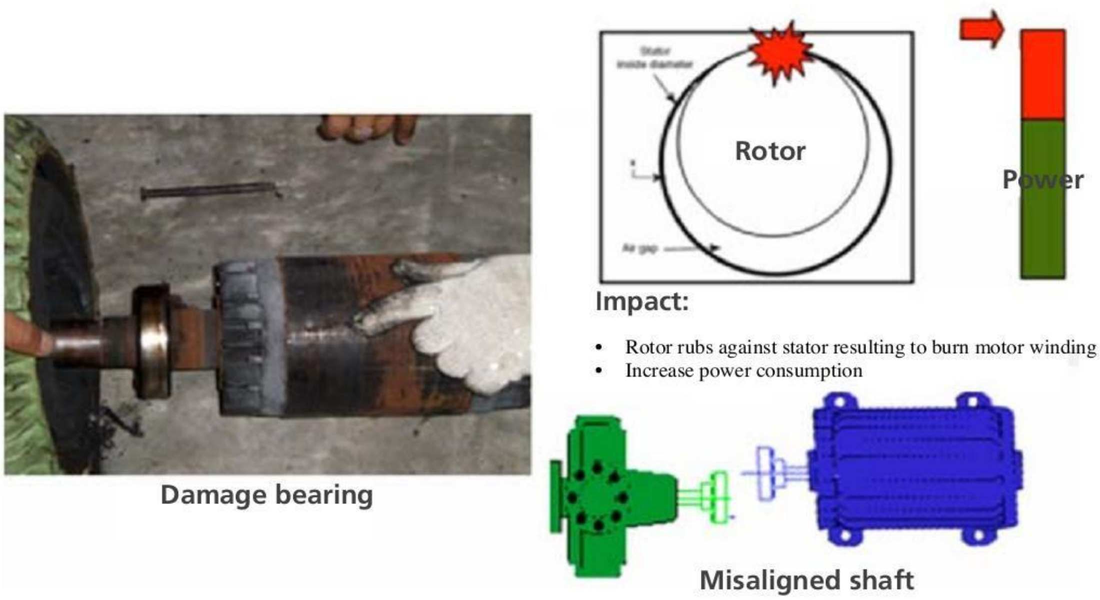

Figure 3 - Impact of misalignment in power consumption

Figure 4 - 97.9 watts is drawn by motor with aligned shaft.
Courtesy of Rotating Equipment Specialists, LLC

Figure 5 - 122.1 watts is drawn by motor with misaligned shaft.
Courtesy of Rotating Equipment Specialists, LLC

Other stresses such as: heat, power supply anomalies, humidity, and contamination work in conjunction with time to degrade components. Motors will survive for several hundred thousand operating hours when these stresses are minimized with the use of technologies to maintain the motor and its drive systems as well as well trained technical personnel.

E. Total Harmonic Distortions

Harmonic distortion is the change in the waveform of the supply voltage from the ideal sinusoidal waveform. It’s caused by the interaction of distorting customer loads with the impedance of the supply network. Its major adverse effects are the heating of transformers, capacitors, induction motors, and the overloading of neutral conductors that are not rated to carry large currents. Therefore, monitoring Total Harmonic Distortion (THD) is very important to utilities.

F. Power Factor

The term power factor is defined as a ratio of the current drawn that produces real work to the total current drawn. Like most aspects of modern electrical systems, power factor is a complex issue intertwined with utility rate structures, economic consideration and system capacities.

Stator and Rotor I^2R Losses

These losses are major losses and typically account for 55% to 60% of the total losses. I^2R losses are heating losses resulting from current passing through stator and rotor conductors. I^2R losses are the function of conductor resistance and the square of current. Resistance of conductor is a function of conductor material, length and cross sectional area. The suitable selection of copper conductor size will reduce the resistance. Reducing the motor current is most readily accomplished by decreasing the magnetizing component of current. This involves lowering the operating flux density and possible shortening of air gap. Rotor I^2R losses are a function of the rotor conductors (usually aluminum) and the rotor slip. Utilization of copper conductors will reduce the winding resistance. Motor operation closer to synchronous speed will also reduce rotor I^2R losses.

Core Losses

Core losses are those found in the stator-rotor magnetic steel and are due tohysteresis effect and eddy current effect during 50 Hz magnetization of the core material. These losses are independent of load and account for 20-25% of the total losses.

The hysteresis losses which are a function of flux density are reduced by utilizing low-loss grade of silicon steel laminations. The reduction of flux density isachieved by suitable increase in the ore length of stator and rotor. Eddy current losses are generated by circulating current within the core steel laminations. Theseare reduced by using thinner laminations.

Friction and Windage Losses

Friction and windage losses result from bearing friction, windage and circulatingair through the motor and account for 8-12% total losses. These losses are independent of load. The reduction in heat generated by stator and rotor losses permits the use of smaller fan. The windage losses also reduce with the diameter of fan leading to reduction in windage losses.

Stray Load-Losses

These losses vary according to square of the load current and are caused by leakage flux induced by load currents in the laminations and account for 4 to 5% oftotal losses. These losses are reduced by careful selection of slot numbers, tooth/slot geometry and air gap.

Constructional Details

The efficiency of energy efficient motors is higher due to the following constructional features:

1. By increasing the amount of copper in the motor (≥60%) which reduces the resistance (Ohmic) loss in the winding & temperature rise. Performance improves because of increased thermal mass.
2. Use of more & thinner laminations of high quality motor steel reduces core losses in the stator and rotor.
3. Narrowing of air gap between stator and rotor increases the intensity of magnetic flux, thereby improving the motor ability to deliver the same torque at reduced power. Increasing the length of stator and rotor increases the net flux linkages in the air gap to the same effect.
4. More complex rotor bar designs enable good starting torque with efficient full speed operation.
5. Improved overall design reduces windage losses and stray load losses.

Applications:

Energy efficient motors hold their efficiency better at part loads enhancing their advantage over standard motors. Economic benefits of installing energy efficient motors can be recognized in

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three situations:

- In a new applications (Plant expansion)
- In lieu of rewinding of failed motors
- Proactive replacement for in-service standard motors

Energy efficient motors are more cost effective than standard motors in the above cases. Efficient of EEMs is 4 – 6 % higher compared to the efficiency of standard motors.

Energy efficiency motors run cooler, and therefore have potentially longer life thantheir standard efficiency counterparts.

Characteristics – variable Speed, Variable Duty Cycle Diagrams

The single most potent source of energy savings in induction motor system lies not in the motor, but rather in the controls that govern its operation. Adjustable speed, intelligent controls and other ways of modifying or controlling motor behavior hold great promise for improving performance and efficiency in drive systems.

Need for using controls

Induction motors are well suited to single speed, constant output applications. However, there are large numbers of motor/ load/ system combinations where single speed operation does not efficiently meet the process requirements, usually due to two common factors.

- Oversized motor: motors are often oversized for their loads causing not only reduced efficiency, but also reduced power factor, and in many cases increased energy consumption in the load because of reduced slip.
- Varying Load: Many applications require modulated output from a motor/load/system.

  These systems are sized to provide the maximum output under the worst operating conditions, but rarely require this much flow (output). The excess energy is wasted, usually by some form of throttling.

Controlling motor speed to load requirements provides many benefits, including increased energy efficiency and improved power factor. Adjustable speed capability can significantly improve productivity of many manufacturing processes by reducing scrap, enabling quality manufacturing during transition times and allowing more control over start up and shut down.

Following are the benefits of VSDs:

- Matching motor and load to output
- Improved process precision
- Improved power factor
- Improved tool life
- Increased production & flexibility
- Faster response
- Extend operating range
- Electrical isolation
- Driving multiple motors
- Throttled load saving (throttling is the most energy inefficient operation)
- Cube-law load savings ($P \infty N^{3)}$

MOTOR ENERGY AUDIT

Five basic concepts of Energy conservation in Drive Power are as follows:

- Drive power is huge- **think big,**
- Motors are part of a system –**think systems,**
- Optimize the applications &process-**deliver service,**
- The further the downstream savings, the higher is the upstream benefits- **start downstream,**
- Pursue integration package of savings opportunities rather than isolatedmeasures because many savings are inter –dependent –**integrate measures.**

Energy Conservation in Electric Motors (load Equipment)

For improving the efficiency use of energy it is important to know the typical load on the motor over its duty cycle. It would be misleading to measure only the current drawn under load and draw conclusion. For example, a typical 25HP motor draws about 60% of its rated full load current when delivering only 45% of its rated output. Hence it is required to measure input power, current, voltage, power factor, frequency, and speed of operation.

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- Collection of nameplate details of motor and load equipment
- Measurement of voltage, current, power, apparent power, power factor,frequency and annual operating hours for major loads.
- Calculation of load factor for major loads.
- Checking for light loads on large motors
- Check if valves are always used for flow control in pumps, fans and blowers.
- Check if flow from pumps, fans and blowers are changing continuously.
- Check if the set discharge pressure is at the lowest permissible limit ofoperation in the compressor.
- Check for proper maintenance of major equipment i.e. cleaning measuringtemperature, dust, vibration, noise, lubrication and coupled condition.

Power Factor Correction at Motor end

As noted earlier, induction motors are characterized by power factors less than unity, leading to lower overall efficiency (and higher overall operating cost) associated with a plant's electrical systems. 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 I^2R losses in cables upstream of the capacitor (andhence reduced energy charges), reduced voltage drop in the cables (leading to improved voltage regulation), and in 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 generation side will improve i.e. the benefits of PF would be only on upstream side.

The size of capacitor required for a particular motor depends upon the no-load reactive KVA (KVAr) drawn by the motor, which can be determined only from no-load testing of the motor. In general, the capacitor is then selected to not exceed 90% of the no-load KVAr of the motor. Higher capacities could result in over-voltages and motor burn-outs. Alternatively, typical power factors of standard motors can provide the basic for conservative estimates of capacitor ratings to use for different size motors. The capacitor rating for power factor correction by direct connection to induction motors is shown in table.

Capacitor rating for power factor correction by Direct Connection ofInduction Motors						
Motor Rating (HP)	Capacitor rating (KVAr) for Motor Speed					
	3000	1500	1000	750	600	500
5	2	2	2	3	3	3
7.5	2	2	3	3	4	4
10	3	3	4	5	5	6
15	3	4	5	7	7	7
20	5	6	7	8	9	10
25	6	7	8	9	9	12
30	7	8	9	10	10	15
40	9	10	12	15	16	20
50	10	12	15	18	20	22
60	12	14	15	20	22	25
75	15	16	20	22	25	30
100	20	22	25	26	32	35
125	25	26	30	32	35	40
150	30	32	35	40	45	50
200	40	45	45	50	55	60
250	45	50	50	60	65	70

From the above, it may be noted that required capacitive kVAr increases with decrease in speed of motor, as the magnetizing current requirement of a low speed motor is more compared to the high speed motor for the same HP. Since a reduction in line current and associated energy efficiency gains are reflected backwards from the point of application of the capacitor, the maximum improves in overall system efficiency is achieved when the capacitor is connected across the motor terminals, as compared to somewhere further upstream in the plant's electrical system. However, economies of scale associated with the cost of capacitors and the associated labor cost will place an economic limit on the lowest desired capacitor size.

Lighting: Good lighting system design and practice, lighting control, lighting energy audit.

GOOD LIGHTING SYSTEM DESIGN AND PRACTICE

Lighting is an essential service in all the industries. The power consumption by the industrial lighting varies between 2 to 10% of the total power depending on the type of industry. In hotels, lighting consumes up to 30% of total electrical energy. Innovation and continuous improvement in the field of lighting has given rise to tremendous energy saving opportunities in this area. Lighting is an area, which provides a major scope to achieve energy efficiency at the design stage, by incorporating modern energy efficient lamps, luminaries and gears, apart from good operational practices.

Basic Terms in Lighting System and Features

A. Lamps

Lamp is equipment, which produces light. The most commonly used lamps are described briefly as follows:

- ***Incandescent lamps:***

Incandescent lamps produce light by means of filament heated to incandescence by the flow of electric current through it. The principal parts of an incandescent lamp, also known as GLS (General Lighting Service) lamp include the filament, the bulb, the fill gas and the cap.

- ***Reflector Lamp:***

Reflector lamps are basically incandescent, provided with a high quality internal mirror, which follows exactly the parabolic shape of lamp. The reflector is resistant to corrosion, thus making the lamp maintenance free and output efficient.

- ***Gas discharge lamps:***

The light from a gas discharge lamp is produced by the excitation of gas contained in either a tabular or elliptical outer bulb. The most commonly used discharge lamps are as follows:

1) Fluorescent tube lamps (FTL)

2) Compact Fluorescent Lamps (CFL)

3) Mercury Vapor Lamps (HPMV)

4) Sodium Vapor Lamps (HPSV)

5) Metal Halide Lamps

B. luminaire:

Luminaire is a device that distributes filters or transforms the light emitted from one or more lamps. The luminaire all the parts necessary for fixing and protecting the lamps, except the lamps themselves. In some cases, luminaires also include the necessary circuit auxiliaries, together with the means for connecting them to the electric supply. The basic physical principles used in optical luminarie are reflection, absorption, transmission and refraction.

C. Control gear:

The gears used in the lighting equipment are as follows:

- ***Ballast:***

The current limiting device, to counter negative resistance characteristics of any discharge lamps. In case of fluorescent lamps, it aids the initial voltage build-up for starting.

- **Igniters:**

These are used for starting high intensity Metal Halide and Sodium vapor lamps.

D. Illuminance:

This is the quotient of the luminous flux incident on a element of the surface at a point of surface containing the point, by the area of that element. The lighting level produced by a lighting installation is usually qualified by the illuminance produced on a specified plane. In most, cases this plane is the major plane of the tasks in the interior and is commonly called the working plane. The illuminance provided by an installation affects both the performance of the tasks and the appearance of the space.

E. Lux (lx):

This is the illuminance produced by a luminous flux of one lux, uniformly distributed over a surface area of one square meter. One lux is equal to one luen per square meter.

F. Luminous Efficacy (Im/W):

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

G. Color Rendering Index (RI):

Is a measure of the degree to which the colors of surfaces illuminated by a given light source confirm to those of the same surfaces under a reference illuminant; suitable allowance having been made for the state of Chromatic adaptation.