# Lecture 3. Energy Efficient Electrical Services Part 2

## 3.1 Electric Motors

Induction motors are widely used in many applications. Pumps, fans, compressors, escalators and lifts are all powered by motors of one type or another. Induction motors are therefore essential to the operation of most modern buildings. Furthermore, electric motors are often the most costly items of plant to run in many office buildings. It is therefore well worth understanding how induction motors use electrical energy and investigating possible energy-conservation measures.

All induction motors have inherent inefficiencies. These energy losses include:

- Iron losses which are associated with the magnetic field created by the motor. They are voltage related and therefore constant for any given motor and independent of load.
- Copper losses (or $I^2R$ losses) which are created by the resistance of the copper wires in the motor. The greater the resistance of the coil, the more heat is generated and the greater the power loss. These losses are proportional to the square of the load current.
- Friction losses which are constant for a given speed and independent of load.

These losses can be divided into those which vary with motor load and those which are constant whatever the load. When a motor is running at full load, the split between the two is about 70% and 30% respectively. Under part load this split changes; at low load the current drawn is small and the $I^2R$ losses are low.

Consequently, the iron losses predominate and since they result from the consumption of reactive current, the power factor is correspondingly low. Even at full load, induction motors exhibit a relatively poor power factor, typically around 0.8.

## 3.2 Motor Sizing

Correct sizing of electric motors is critical to their efficient operation, since oversized motors tend to exhibit poor power factors and lower efficiencies. Depending on size and speed, a typical standard motor may have a full load efficiency between 55% and 95%. Generally, the lower the speed, the lower the efficiency and the lower the power factor.

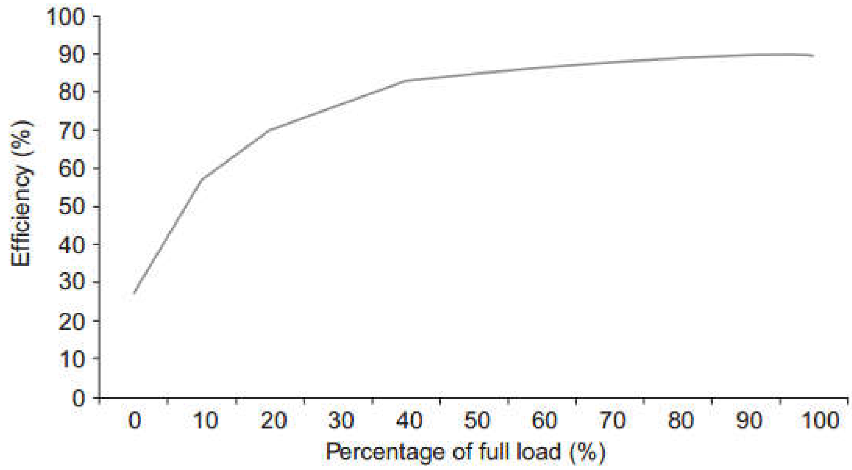


Fig.3.1 Relationship between motor loading and efficiency

Typically motors exhibit efficiencies which are reasonably constant down to approximately 75% full load. Thereafter they may lose approximately 5% down to 50% of full load, after which the efficiency falls rapidly (as shown in Figure 3.1).

It can be seen from the performance curve in Figure 3.1 that it is possible to oversize a motor by up to 25% without seriously affecting its efficiency, provided that a motor is run at a relatively constant load. If the load fluctuates and rarely achieves 75% full load, then both the efficiency and the power factor of the motor will be adversely affected.

In fact the power factor tends to fall off more rapidly than the efficiency under part load conditions. Therefore, if motors are oversized, the need for power factor correction becomes greater. Oversizing of motors also increases the capital cost of the switchgear and wiring which serves the motor.

### 3.3 Variable Speed Drives (VSD)

Most induction motors used in buildings are fitted to fans or pumps. The traditional approach to pipework and ductwork systems has been to oversize pumps and fans at the design stage, and then to use commissioning valves and dampers to control the flow rate by increasing the system resistance. While mechanical constrictions are able to control the flow rate delivered by fans and pumps (see Figure 3.2), the constriction itself increases the system resistance and results in increased energy loss. This situation is highly undesirable and is one of the main reasons why the energy consumption associated with fans and pumps is so high in so many buildings.

An alternative approach to the use of valves and dampers is to control the flow rate by reducing the speed of the fan or pump motor.

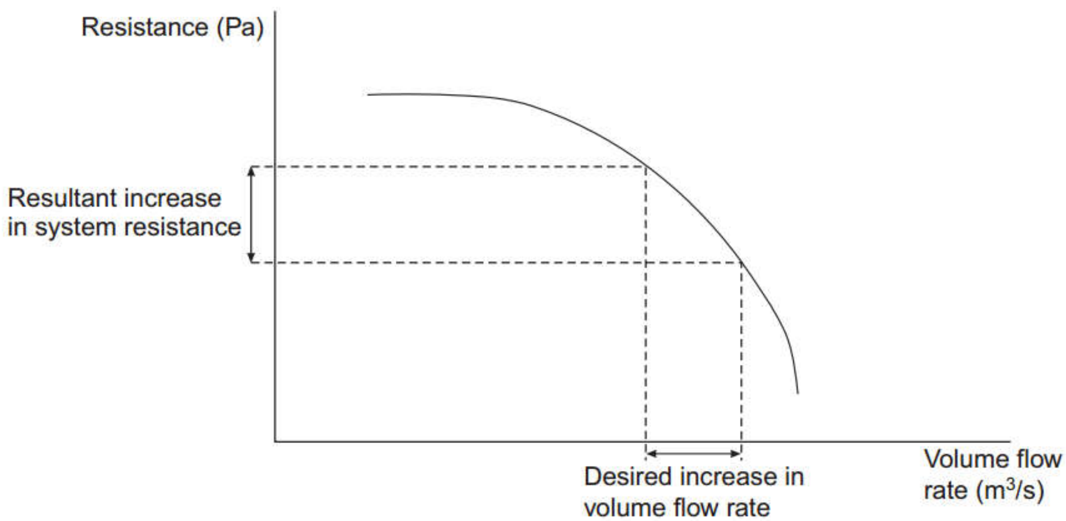


Figure 3.2. Impact of a volume control damper on system resistance.

***Example 3.1.***

It is proposed to use a forward-curved centrifugal fan in a mechanical ventilation system. The fan is required to deliver a volume flow rate of 1.8 $m^3/s$ and the estimated system resistance is 500 Pa. However, the proposed fan delivers 2.06 $m^3/s$ against a resistance of 500 Pa while running at a speed of 1440 rpm. Determine the fan power input, if:

a) A volume control damper is used to achieve a volume flow rate of 1.8 m3/s by increasing the total system resistance to 750 Pa.
b) The fan speed is reduced in order to deliver 1.8 $m^3/s$.

***Solution***

a) Fan air power input:

$$W = V \times P_t$$

Where $v$ is the air volume flow rate ($m^3/s$), and $Pt$ is the total system resistance (Pa).Let $W_1$ be the fan power when delivering 2.06 $m^3/s$ against a resistance of 500 Pa, and $W_2$ be the fan power when delivering 1.8 $m^3/s$ against a resistance of 750 Pa.

$$W_1 = 2.06 \times 500 = 1030W$$

And

$$W_2 = 1.8 \times 750 = 1350W$$

Thus,

$$Increase\ in\ power\ consumption = \frac{1350 - 1030}{1030} \times 100 = 31.1\%$$

b) The fan laws state that:

$$V \propto N$$

And

$$W \propto N^3$$

Where $v$ is the air volume flow rate ($m^3/s$), $N$ is the fan speed (rpm), and $W$ is the fan air power input (W).

Let $N_1$ be the fan speed when delivering 2.06 $m^3/s$ against a resistance of 500 Pa, $N_3$ be the fan speed when delivering 1.8 $m^3/s$, and $W_3$ be the fan power when delivering 1.8 $m^3/s$.

$$N_3 = 1440 \times \frac{1.8}{2.06} = 1258.3rpm$$

$$W_3 = 1030 \times \frac{1.8^3}{2.06^3} = 687.2W$$

Therefore

Reduction in power consumption ($W_3$ compared with $W_1$)

$$= \frac{1030 - 687}{1030} \times 100 = 33.3\%$$

However

Reduction in power consumption ($W_3$ compared with $W_2$)

$$= \frac{1350 - 687}{1350} \times 100 = 49.1\%$$

It can be seen from Example 3.1 that:

- The use of volume control dampers to regulate air flow significantly increases fan energy consumption. The precise magnitude of this increase will depend on the characteristics of the particular fan selected.
- Reducing the fan speed to regulate the air flow rate always results in fan energy savings.

The fan power savings which can be achieved through reducing fan speeds are considerable, especially when compared with the fan power increase which results from using volume control dampers. As a result there are great advantages to be gained, if fan and pump speeds can be controlled.

The energy savings achieved in **Example 3.1** are indicative of the type of savings which can be achieved through the use of VSDs on fans and pumps. In most applications the potential for saving energy through the use of VSDs on pumps, fans and compressors is considerable. Most designers overestimate system resistances with the result that most pumps and fans are theoretically oversized before the actual fan or pump selection is undertaken. During the selection process, the cautious designer is unlikely to find a fan, or pump, which matches the theoretical 'calculated' specification and thus a larger one is selected which is sure to perform the required task. This strategy protects the system designer and ensures that he/she does not negligently undersize the fans or pumps.

Unfortunately, it also ensures that the system is greatly oversized and that during the commissioning process, volume control dampers and dampers will have to be used to reduce the volume flow rate. Consequently, both the capital and future operating costs of the system are greatly increased. By using VSDs it is possible to ensure that even if fans and pumps are oversized, energy consumption will not be greatly increased. This makes the installation of VSDs one of the most cost-effective energy efficiency measures that can be taken. It has been estimated that for VSDs payback periods of less than 2 years are the norm.

In addition to the energy savings gained through using VSDs on constant flow systems, even greater savings can be made by employing VSDs on variable volume flow systems. When the load profiles and duty cycles of heating, air-conditioning and ventilation systems are examined in detail, it is found that most regularly operate well below their intended design specification. The main reason for this is that system designers are overcautious at the design stage. As a result, over-large constant volume flow rate, variable temperature systems are designed. While this approach works in practice, it means that pump and fan running costs are constant and high, no matter what the operating load. An alternative approach is to keep the temperature constant and vary the flow rate, so that pump and fan running costs reduce as the operating load reduces. The classic system which adopts this approach is the variable air volume (VAV) air conditioning system, for which VSDs are ideally suited.

### 3.4. Principles of VSD Operation

Modern electronic VSD systems adjust the mains alternating current to regulate motor speed. Various electronic VSD systems are available. One of the most popular types is the *variable frequency drive*, which achieves speed control by varying the voltage and frequency output. Such drives regulate the voltage to the motor in proportion to the output frequency in order to ensure that the ratio of voltage to frequency remains relatively constant. Changes in motor speed are achieved by modulating the voltage and frequency to the motor. **Figure 3.3** shows the basic components in a *variable frequency drive* VSD system.

Variable frequency drive systems comprise two main components, a rectifier and an inverter. The rectifier converts standard alternating current (ac) (e.g. 240 V and 50 Hz) to an adjustable direct current (dc), which is then fed to the inverter. The inverter comprises electronic switches which turn the dc power on and off to produce a pulsed ac power output. This can then be controlled to produce the required frequency and voltage. The switching characteristics of the inverter are modified by a regulator, so that the output frequency can be controlled.

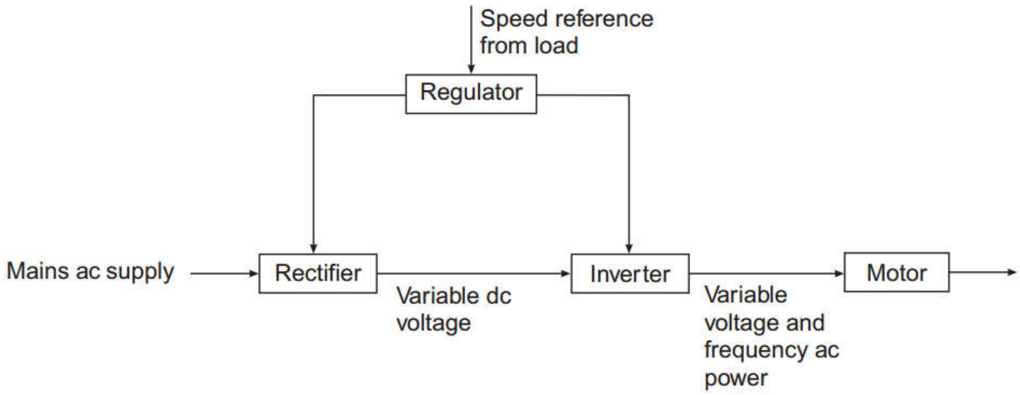


Fig 3.3 Components of a variable speed drive

The inverter is the critical part of a VSD system. One type of inverter currently in use is the pulse width modulated (PWM) inverter, which receives a fixed dc voltage from the rectifier and adjusts the output voltage and frequency. The PWM inverter produces a current waveform which approximates to the pure sine wave of mains ac supply.

### 3.5. Lighting Energy Consumption

The energy consumed by electric lighting in most building types is considerable. Although in many buildings the energy consumed by the heating system is often greater than that consumed by lighting, the energy costs associated with lighting are often considerably greater than those associated with the heating. It is possible to achieve considerable energy cost savings through the careful design and maintenance of lighting schemes.

#### 3.5.1 Daylighting.

Daylight can make a substantial contribution to the lighting of buildings by reducing reliance on artificial lighting.

The major factors affecting the daylighting of an interior are the depth of the room, the size and location of windows, the glazing system and any external obstructions. These factors usually depend on decisions made at the initial design stage. Through appropriate planning at an early stage it is possible to produce a building which is energy efficient as well as having a pleasing internal appearance. Glazing can, however, impose severe constraints on the form and operation of a building. If poor design decisions are made concerning fenestration it is possible to create a building in which the occupants are uncomfortable, and in which energy consumption is high. Glazing should therefore be treated with care.

### 3.5.2. Lighting Definitions and Design.

A discussion of the subject of lighting design is beyond the scope of this lecture.

A full lecture on the subject can be downloaded here;

https://www.benardmakaa.com/wp-content/uploads/2021/05/Lecture-6-Light-and-Lighting-Design-BT.pdf

Download the lecture/PDF and go through it. We shall discuss it briefly. For those who will end up working in the electrical building services or installations sector (consulting or contracting), this lecture is very important.

In brief, the performance of an artificial lighting scheme is influenced by:

- The efficacy of the lamps (i.e. the light output per watt of electrical power consumed).
- The luminaire performance.
- The layout of the luminaire fittings.
- The surface reflectance of the decor and furnishing.
- The maintenance standards.

All these factors have to be allowed for when designing any lighting scheme. One method which is frequently used and which considers all these factors is the lumen design method. The lumen method enables regular lighting schemes to be designed quickly and easily, and so is particularly popular as a design method.

### 3.5.3. Energy Efficient Lighting

The main factors which influence the energy consumption of lighting schemes are:

- ➢ The light output per watt of electrical power consumed (i.e. lamp efficacy).
- ➢ Luminaire performance.
- ➢ The number of luminaires and their location.
- ➢ The reflectance of internal room surfaces.
- ➢ Maintenance and procedure standards.

- Duration of operation.
- The switching and control techniques used.

### 3.5.4 Lighting Controls

The appropriate use of lighting controls can result in substantial energy savings. These savings arise principally from better utilization of available daylight and from switching off electric lighting when a space is unoccupied. Therefore, when designing a lighting control strategy for any given application, it is important to understand the occupancy pattern in the space, since this will heavily influence the potential for energy savings.

There are four basic methods by which lighting installations can be controlled:

- Time-based control.
- Daylight-linked control.
- Occupancy-linked control.
- Localized switching.

Time signals may come from local solid-state switches or be derived from building management systems. These signals switch the lights on and off at set times. It is important to include local override so that lighting can be restored if the occupants need it.

Photoelectric cells can be used either simply to switch lighting on and off, or for dimming. They may be mounted either externally or internally. However, it is important to incorporate time delays into the control system to avoid repeated rapid switching caused, for example, by fast moving clouds. By using an internally mounted photoelectric dimming control system, it is possible to ensure that the sum of daylight and electric lighting always reaches the design level by sensing the total light in the controlled area and adjusting the output of the electric lighting accordingly. If daylight alone is able to meet the design requirements, then the electric lighting can be turned off. The energy saving potential of dimming control is greater than a simple photoelectric switching system. Dimming control is also more likely to be acceptable to room occupants.

Occupancy -linked control can be achieved using infrared, acoustic, ultrasonic or microwave sensors, which detect either movement or noise in room spaces. These sensors switch lighting on when occupancy is detected, and off again after a set time period, when no occupancy movement is detected. They are designed to override manual switches and to prevent a situation where lighting is left on in unoccupied spaces. With this type of system it is important to incorporate a built-in time delay, since occupants often remain still or quiet for short periods and do not appreciate being plunged into darkness if not constantly moving around.

Localized switching should be used in applications which contain large spaces. Local switches give individual occupants control over their visual environment and also facilitate energy savings. By using localized switching it is possible to turn off artificial lighting in specific areas, while still operating it in other areas where it is required, a situation which is impossible if the lighting for an entire space is controlled from a single switch.

### 3.5.5 Maintenance

With the passage of time, luminaires and room surfaces get dirty, and lamp output decreases. Lamps also fail and need replacing. Consequently, the performance of all lighting installations decreases with time. It is therefore necessary to carry out regular maintenance in order to ensure that an installation is running efficiently. Simple cleaning of lamps and luminaires can substantially improve lighting performance.

Therefore, at the design stage maintenance requirements should always be considered. Luminaires should be easily accessible for cleaning and lamp replacement. Bulk replacement of lamps should be planned, so that they are replaced at the end of their useful life, before light output deteriorates to an unacceptable level. The cleaning of lamps and luminaires should be planned on a similar basis. In order to minimize disruption to staff, planned cleaning and lamp replacement can take place during holiday periods.

**Supplementary material on the subject of lighting:**

How to achieve energy efficient buildings:

https://www.eeekenya.com/how-to-achieve-energy-efficient-buildings/

CFLs vs. LEDs: Blow by Blow Comparison:

https://www.eeekenya.com/cfls-vs-leds-blow-by-blow-comparison/

Consider Doing Led Retrofits.

https://www.eeekenya.com/consider-doing-led-retrofits/

What to consider when buying LED lighting fittings:

https://www.eeekenya.com/what-to-consider-when-buying-led-lighting-fittings/

Street lighting design guide:

https://www.eeekenya.com/street-lighting-design-guide/