| YORK® | SOLUTION AIR HANDLING UNITS<br>AC INDUCTION MOTOR DATA | |
|---|---|---|
| **APPLICATION GUIDE** | Supersedes: Nothing | Form: 102.20-AG15 (507) |

## GENERAL

This guide is designed to highlight fundamental characteristics that apply to the Integral AC Induction type motor. The intent is to provide simplified definitions and helpful facts that will better prepare the Engineer when selecting motors for an application. The Integral AC Induction motor is the standard option for Solution Air Handling Units. It is the dominant motor technology in use today, representing more than 90 percent of installed motor capacity.

### What is an Induction Motor

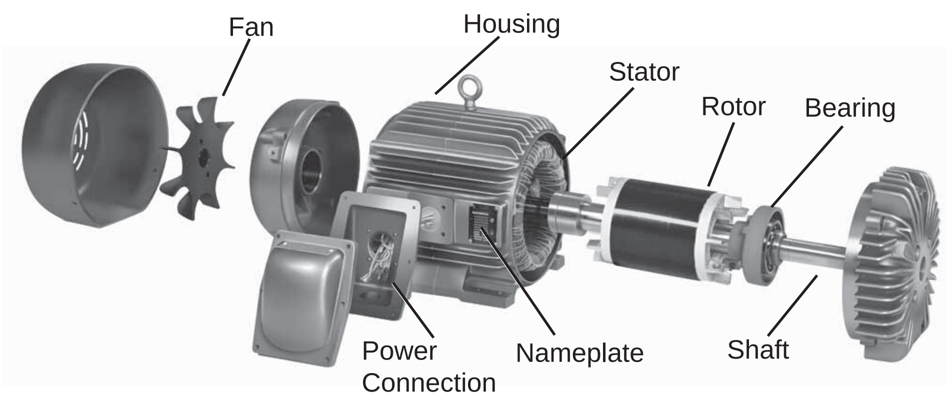
The AC induction motor is a rotating machine that converts electrical power into mechanical power. It is the most common motor design because of simplicity, rugged construction, and low manufacturing cost. AC Induction motors are available in single-phase and polyphase configurations, in sizes ranging from fractions of a horsepower to 100 (+) horsepower. These motors are designed to run at fixed speeds; most commonly 900, 1,200, 1,800, or 3,600 rpm.

This simple machine is made up of two major components;

1. The stator – a stationary or static component consisting of steel laminations (coil windings of wire) mounted on a frame in such a manner that slots are formed on the inside diameter of the assembly.
2. The rotor – a rotating assembly usually including a shaft, fan and rotor core which contains laminations mirroring the stator laminations. The rotor windings are made up of rotor bars passed through the rotor, from one end to the other, around the surface of the rotor. The bars protrude beyond the rotor and are connected together by a shorting ring at each end. The bars are usually made of aluminum, copper, or sometimes brass.

The operation of the motor can be broken down into (5) five simple steps of which will be discussed in more detail through-out the guide:

1. The stator coils when energized allow the magnetizing current to flow creating a revolving magnetic field between two poles.
2. This rotating magnetic field cuts through the rotor and induces a voltage in the rotor laminations which creates its own magnetic field.
3. The rotor magnetic field attempts to line up with the stator magnetic field.
4. The rotor magnetic field trying to line up with the the stator magnetic field causing the rotor to rotate
5. The rotor magnetic field, never catches up, but follows slightly behind.



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### How Does the Induction Motor Work?

Stator

Within the design of the stationary part of the motor, the stator, bundles of magnet wire are wound together in the slots. These bundles are referred too as inductive load coils or windings.

- Inductive loads are electrical devices, generally made of wire, coiled so as to induce a magnetic field and generate mechanical work when energized.
- This field reacts with the rotor conductors, solid bars made of copper or aluminum, to produce a rotating magnetic field.

Windings

The number and alignment of windings create magnetic poles when electrically charged.

- A 2-pole machine has 2 poles (1 North 1 South) arranged around the periphery of the rotor: a 4-pole machine has 4 poles (N-S-N-S); a 6-pole has 6 (N-S-N-S-N-S) and so on.
- A 4-pole design is the most common pole configuration for AC induction motors and is typically found in belted applications such as blowers, fans, air-handling equipment, compressors, commercial garage door openers, and conveyors.

The numbers of poles determine the motor's synchronized speed stated in revolutions per minute (rpm).

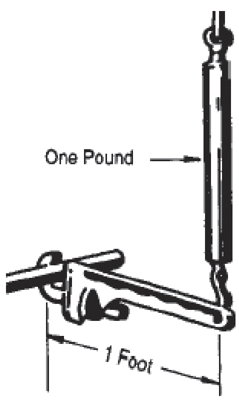
- The speed of the field is fixed by both the frequency of the magnetic currents and the number of poles for which the stator is designed.
- The speed at which the AC induction motor will operate at nameplate rated full load is called 'Full Load Speed'.

The strength of the magnetic field directly controls the available torque in the motor itself. The effectiveness and efficiency of the magnetic field is a key factor in the motors efficiency.

### Electrical Characteristics of an Induction Motor

Torque & Horsepower

Torque and horsepower are motor characteristics used to determine the size of the motor for an application. The difference between the two can easily be explained using a simple image of a pipe and wrench.




Torque is generated when a force is used to begin to spin something. A torque would also be generated if a force was used to stop something from spinning.

- Torque is simply a turning effort, a rotational power or force acting through a radius.
- A common unit of measure used to express torque is called a pound/foot (lb-ft).

It takes one pound (1 lb.) at the end of a one foot (1') wrench to turn the pipe at a steady rate. Therefore, the torque required is one pound times one foot, or 1 lb-ft.

- If the wrench were turned twice as fast, the torque required would remain the same, provided it is turned at a steady rate.

Horsepower takes into account how fast the pipe is turned. Turning the pipe rapidly requires more horsepower than turning it slowly. Adding time and distance to a static force (torque) results in horsepower.

- Horsepower is a measure of the rate at which work is done.
- One horsepower is commonly expressed as 550 lb-ft in 1 sec. or 33,000 lb-ft in 1 min.

(1 Horsepower = 33,000 lb-ft/minute). This would be equal to lifting 1 ton (2,000 lbs.) 16.5 feet, or 1,000 lbs., 33 feet in one minute.

These are just different ways of saying the same thing. Notice these definitions include force (pounds), distance (feet), and time, (minute, second).

The force necessary to produce the rated nameplate motor horsepower at full-load speed is called 'Full Load Torque'.

**Handy Formula every Engineer should know:**

**Full load torque is equal to the rated horsepower times 5252 divided by the full-load speed in RPM.**

1. **Full-load torque (lb-ft) = Horsepower x 5252 / rpm**
2. **Horsepower = torque x rpm / 5252**

***(5252 is the constant when using 'Watts's observation' of one horsepower as 150 pounds of force.)***

Synchronous Speed

Synchronous speed is the momentum at which the magnetic field within the motor is rotating. It is also approximately the speed that the motor will run under no load conditions. Synchronized speed formula is the Number of (HZ) cycles (x) seconds in a minute (x) two (for the positive and negative pulses in the cycle) divided by the number of poles.

For example, a 4 pole motor running on 60 cycles would have a magnetic field speed of 1800 RPM. The no-load speed of the motor shaft would be very close to 1800, probably 1798 or 1799 RPM. The full load speed of the same motor might be 1745 RPM. The difference between the synchronous speed and the full load speed is called the slip RPM of the motor.

**Table 1 –** AC Induction Motor Speed

| # of Poles | 60hz Synchronous Speed | 50hz Synchronous Speed |
|---|---|---|
| 2 | 3600 | 3000 |
| 4 | 1800 | 1500 |
| 6 | 1200 | 1000 |
| 8 | 900 | 750 |
| 10 | 720 | 600 |
| 12 | 600 | 500 |

Slip

Slip is the difference between the speed of the stator magnetic field and the speed of the rotor. Slip RPM is expressed as a percentage of the synchronous speed. It is called percent slip or just “slip”. Most standard motors run with a full load slip of 2% to 5%. The Slip will vary proportionally with the rotor resistance.

**Handy Formula every Engineer should know:**

**Synchronized speed formula = Number of (HZ) cycles (x) seconds in a minute (x) two (for the positive and negative pulses in the cycle) divided by the number of poles.**

***Example:*** **60 hertz with a four pole design:**
**60 x 60 x 2 / 4 = 1800 RPM synchronized speed.**

## Standard Voltages and Frequencies

60 Hertz Frequency

The motor nameplate voltage should be selected according to the available power supply of the distribution system. The correct voltage must be known in order to properly select a motor for a given application.

The nominal 3-phase, 60 cycle (Hz) power system voltages commonly available in the United States for industrial plants are 208, 240, 480 and 600 volts.

- Typically the motors are name-plated for 200, 230, 460 and 575 volts which is a nominal value. (Some specifications still call for 220, 440 or 550 volt motors which were the long-ago accepted nominal standards.)
- The nameplate value of the voltage is set a little lower than the power supply coming from the distribution system. This is to allow for a voltage drop that occurs due to the location of system transformers, substations/load centers, low plant-wide power factors and extended power line runs.

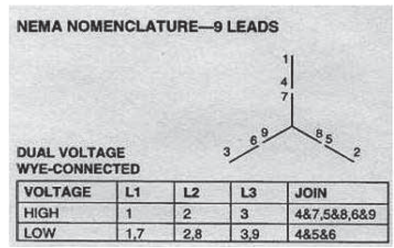
50 Hertz Frequency

Rarely required in the United States and Canada is a nominal 3-phase, 50 cycle (Hz) which is the prevailing frequency in Europe and Asia.

- The preferred 50 Hz motor voltages are 190, 380 and 440 volts. These values cover most nominal system voltages.
- The nominal 3-phase, 50 Hz power system voltages vary from country to country.

NOTES:

- All type distribution system voltages vary from country to country; therefore, motor nameplate voltage should be selected for the country in which it will be operated.
- 3-phase motors may be furnished as dual voltage per the above voltage/frequency. In the USA, the most common three phase, dual voltage AC motor has nine leads at the connection point, and is designed to operate on 240v or 480v power. The voltages are in a ratio of 1:2. Most dual voltage motors have connection diagrams printed somewhere on the motor.




| VOLTAGE | L1 | L2 | L3 | JOIN |
|---|---|---|---|---|
| HIGH | 1 | 2 | 3 | 4&7,5&8,6&9 |
| LOW | 1,7 | 2,8 | 3,9 | 4&5&6 |

## Power-factor

The power-factor is the relationship between outputs; active power and total power.

- It is a measurement of the usable portion of voltage and current applied to the motor to do work.
- It is usually expressed as a percentage.

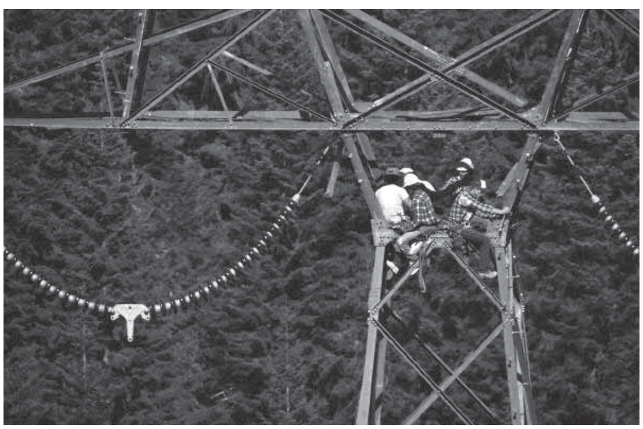
The total power of the motor is referred to as ‘Apparent’ power. The total power of the AC Induction motor is consumed in two different ways; an active (working) power and a reactive (magnetizing) power.

1. ‘Active Power’ (kW)
   a. This is the portion of the total power that actually performs the work.
   b. It is real power that would be read on a watt-meter.
2. ‘Reactive Power’ (kvar)
   a. This is the non-working portion of the total power which returns to the source, the windings, to maintain the magnetic field. It may also be referred to as magnetizing power.
   b. Reactive power must be recouped by the utilities distribution system.

A good example of reactive power can be seen in a motor with no demand placed on it.

- One might expect a motor with no demand to have no-load. Load is the term used to describe work required from a motor. In truth, the no-load current will generally show a value between 25% and 30% of full load current. This is due to the continuous demand for magnetizing current by any induction load.
- To distinguish reactive power from active power, we use the reactive power unit called “VAR” - which stands for Volt-Ampere-Reactive.

The higher the power-factor, the more effectively electrical power is being used and vice versa. When low power-factor is not corrected, the utility must make-up for the magnetizing reactive power. This results in the utility passing higher expenses down the line to the industrial user in the form of power-factor penalties. Utilities will generally look at the facility in its entirety and charge the customer a penalty for a low power-factor facility.



<u>High Power-Factor:</u>

- Minimizes and or eliminates utility power-factor penalties
- Stabilizes voltage levels

<u>Low Power-Factor:</u>

- Poor electrical efficiency
- Increased load on a building’s electrical system

The user can specify a motor with a high power-factor, but such models sometimes have lower efficiency. The ultimate selection should depend in part on whether a facility is subject to power-factor penalty charges. A facility with a significant number of induction motors and a low power-factor can solve the problem with premium-efficiency motors that are properly sized.

Another option in correcting facility low power factor is by adding power factor correction capacitors to the plant distribution system. Correction capacitors work as reactive current generators “providing” needed reactive power (VAR) into the power supply.

- By supplying their own source of reactive power, the industrial user frees the utility from having to supply it, therefore, the total amount of apparent power supplied by the utility will be less.
- Power factor correction capacitors reduce the total current drawn from the distribution system and subsequently increase system capacity by raising the power factor level.
- Power factor correction capacitors are rated in electrical units called “vars”.
- One var is equivalent to one volt-ampere of reactive power.

**Handy Formula every Engineer should know:**

1. **Power Factor (pf) = <u>kW (real power)</u>**
   **kVA (total power)**

2. **kVAR = Square root of (kVA^2 - kW^2)**

## NEMA STANDARDS

NEMA (National Electrical Manufacturers Association) provides a forum for the standardization of electrical equipment, enabling consumers to select from a range of safe, effective, and compatible electrical products. NEMA standards preside over the most important items basic to all motors:

1. Horsepower (HP ratings)
2. RPM (speed)
3. Standard voltages and frequencies
4. Service factors
5. Starting current and torque
6. Frame sizes and dimensions
7. Enclosure types.

NEMA provides the assurance that a motor conforming to the standards will comply with the user's requirements without modification. Motors provided with Solution Air Handlers comply with NEMA.

NEMA Standard MG1-1.16 has defined four standard motor designs using letters A, B, C or D which refer to the shape of the motor torque & speed curve. (Torque & speed characteristics are the effect of rotor resistance variation, maximum torque and the slip at which it occurs)

1. Design A - Normal-torque, normal-starting current motors
2. Design B - Normal-torque, low-starting current motors (most widely used in the Industry)
3. Design C - High-torque, low-starting-current, double-wound-rotor motors
4. Design D - High-torque & High-slip motors, Low starting current & full load speed

These standards permit the user a certain amount of control in the selection of a motor for an application of different work-load demands.

### Frame Sizes and Dimensions

An important achievement by NEMA has been the standardization of motor frame sizes. This simply means that the same horsepower, speed, and enclosure will normally have the same frame size from different motor manufacturers. Thus, a motor from one manufacturer can be replaced with a similar motor from another company provided they are both of the same standard frame size. Solution Motor Characteristics are shown in Table 2 below.

Under the NEMA system, most motor dimensions are standardized and categorized by a frame size number and letter designation.

- 'T' frames being the current standard were introduced in 1964.
- 'T' frame designs are based on utilizing Class B insulation with a temperature rating of 130° C

**Handy Formula every Engineer should know:**

**In fractional horsepower motors the frame sizes are two digits and represent the shaft height of the motor from the bottom of the base in sixteenths (1/16) of an inch.**

- **For example, a 56-frame motor would have a shaft height of 56/16 of an inch, or 3.5 inches.**

**On larger 3-digit frame size motors, 143T through 449T, a slightly different system is used where the first two digits represent the shaft height in quarters (1/4) of an inch.**

- **For example, a 326T frame would have a shaft height of 32 one-quarter inches, or 8 inches.**

**Although no direct inch measurement relates to it, the third digit of three-digit frame sizes, in this case a 6, is an indication of the motor body's length. The longer the motor body, the longer the distance between mounting bolt holes in the base (i.e. greater "F" dimension). For example, a 145T frame has a larger F dimension than does a 143T frame.**

**Table 2 –** Solution Motor Characteristics Table

| HP | Volts | Hertz | Frame | Type | NEMA Design | Insulation Class | Service Factor |
|---|---|---|---|---|---|---|---|
| 1-100 | 200, 230, 460, 575 | 60 | 56T – 404T | Standard EPAct Efficient | B | B & F* | 1.15 |
| | | | | Premium Efficient | B | F | 1.15 |
| 1-100 | 380 | 50 | 143T – 405T | EPAct Efficient | B | B & F* | 1.15 |

*Insulation Class is subject to enclosure, voltage and horsepower.

There are still many "U" frame motors (from 1952 standards) in service that will have to be replaced in the near future.

- When replacing a motor of a different frame type, one important item to remember is that unless the frame you are applying has the same three digits, the base mounting hole spacing dimensions and shaft height dimension will not be the same.

## Insulation

Insulation is a non-conducting material (paper, glass, etc.) which tends to resist the flow of electric current. In a motor the insulation serves two basic functions:

1. Insulation separates the various electrical components from one another.
2. Insulation protects the electrical components from attack of contaminants and other destructive forces.

NEMA has established insulation classes to meet motor temperature requirements found in different operating environments.

- The four insulation classes are identified as A, B, F and H.
- Class F is the most commonly used while Class A is seldom used.

The insulation class in any motor must be able to withstand at least the maximum ambient temperature plus the temperature rise that occurs as a result of continuous full load operation.

- NEMA has standardized on an ambient of 40°C or 104°F for all motor classes.
- Class A has a temperature rating of 105°C (221°F), and each step from A to B, B to F, and F to H involves a 25°C (45°F) jump.

**Table 3 –** Common Insulation Classes

| Insulation Class | Ambient Temperature Range | Hot Spot Temperature |
|---|---|---|
| B | Up to 40°C (104°F) | 130°C (266°F) |
| F | 41°C (105°F) to 65°C (149°F) | 155°C (311°F) |
| H | 66°C (150°F) to 90°C (194°F) | 180°C (356°F) |

**Table 4 –** T-Frame Class B Insulation Life

| Voltage Unbalance | Service Factor 1.15 |
|---|---|
| 0% | 2.27 |
| 1% | 2.10 |
| 2% | 1.58 |
| 3% | 0.98 |
| 4% | 0.51 |

Note:

- Not all parts of the motor windings operate at the same temperature.
- The temperature at the center of the coil is the hottest and is referred to as the "hot spot temperature."
- The hot spot temperature is the basis for establishing the insulation class rating.

Selecting an insulation class higher than necessary to meet this minimum can help extend motor life or make a motor more tolerant of overloads, high ambient temperatures, and other problems that normally shorten motor life.

**Handy Formula every Engineer should know:**

1. **Every 10°C (18°F) increase in operating temperature cuts insulation life by 1/2, conversely, a 10°C decrease doubles insulation life.**
2. **Selecting a one step higher insulation class above requirement provides 25°C of extra temperature capability.**
3. **The better insulation increases the motor's thermal life expectancy by approximately 500%.**

## Efficiency

Efficiency is a measure of how well the electric motor converts the available power supply from the distribution system into useful work. It is the relationship between input power (voltage) and the conversion to mechanical output (current). Efficiency is stamped on the nameplate of most domestically-produced electric motors.

Inherent to the basic design of the electric motor are several losses associated with materials and operation:

- Materials - copper and iron
- Friction and losses associated with spinning the rotor and bearings
- Moving the cooling air through the motor

In a motor designed for energy efficiency the losses are reduced by using better grades of material, more material and better designs to minimize the various items that contribute to the losses in the motor.

***For example:***
10 HP motor - premium efficient designs might have a full load efficiency of 91.7%, meaning that, at full load (10 HP), it converts 91.7% of the energy it receives into useful work. A less efficient motor might have an

efficiency of 82%, which would indicate that it only converts 82% of the power into useful work.

### Service Factor

NEMA Standard MG1-1.42 defines 'service factor' of an AC motor as "...a multiplier which, when applied to the rated horsepower, indicates a permissible horsepower loading which may be carried under the conditions specified for the service factor...". The multiplier indicates how much over the nameplate rating the NEMA designed motor can be driven without overheating. The defined multiplier for NEMA designs A, B, or C standard 3-phase drip-proof, 60 Hz motor is 1.15. When voltage and frequency are maintained at nameplate rated values, the motor may be overloaded up to the horsepower obtained by multiplying the electric motor's nameplate (rated) horsepower by the service factor shown on the nameplate.

- A NEMA designed standard drip-proof 10 HP motor rated with a 1.15 service factor at 40°C ambient could carry a continuous load of 1.15 SF x 10 HP or 11.5 HP.

Generally, electric motor service factors:

- Handle a known overload, which is occasional.
- Provide a factor of safety where the environment or service condition is not well defined, especially for general-purpose electric motors.
- Obtain cooler-than-normal electric motor operation at rated load, thus lengthening insulation life.

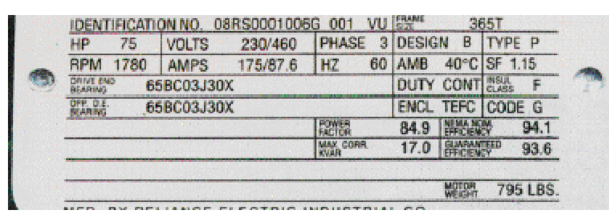
The question often arises whether to use the service factor in motor load calculations. In general, the best answer is that for good motor longevity, service factor should not be used for basic load calculations. By not loading the motor into the service factor, the motor can better withstand adverse conditions that occur. Adverse conditions include higher than normal ambient temperatures, low or high voltage, voltage imbalances, and occasional overload. These conditions are less likely to damage the motor or shorten its life if the motor is not loaded into its service factor in normal operation.

### Nameplate Data

The most important part of any motor is the name-plate. Motor nameplates are provided by virtually all manufacturers to allow users to accurately identify the operating and dimensional characteristics of their motors years after installation. The nameplate is usually a metal plate, secured by a pair of screws or rivets, and is generally located on the side of the motor. Changing motors out becomes a lot easier when you can quickly recognize the key items that describe a motor's size, speed, voltage, physical dimensions, and performance characteristics. All of this information and more is usually available on the motor's nameplate.

Section MG 1-10.40, "Nameplate Marking for Medium Single-Phase and Poly-phase Induction Motors," of the NEMA standard requires that the following minimum amount of information shall be given on all nameplates of single-phase and poly-phase induction motors.

- Manufacturer's type and frame designation
- Horsepower output.
- Time rating.
- Maximum ambient temperature for which motor is designed.
- Insulation system designation.
- RPM at rated load.
- Frequency.
- Number of phases.
- Rated load current.
- Voltage.
- Code letter for locked rotor kVA.
- Design letter for medium motors.
- NEMA nominal efficiency when required by MG 1- 12.55
- Service factor if other than 1.0.
- For motors equipped with thermal protectors, the words "thermally protected" if the motor provides all the protection described in MG 1-12.52.



Check the data given on the plate before making any connections. It is responsible to be able to correctly interpret the information on the nameplate, correctly apply it in the field, and verify conformance to NEMA, *IEC, or other industry standards. A typical nameplate also includes the motor's brand name, and it includes a "Serial No." or other identifying number unique to that motor, that would let the manufacturer trace the motor back through manufacturing. The nameplate also includes the manufacturer's name, and its principal city and state and "Made in U.S.A." if U.S.-made.

** International Electromechanical Commission (IEC) is a European group who develop standards for electrical components. See explanation in the International Standard for Motor discussion.*

### What is EPAct?

The topic of discussion in the motor industry since the federal government's passage of the Energy Policy Act (EPACT) in 1992 is motor efficiency; how completely an electric motor converts electricity into mechanical work. Yesterday, it was mostly a question for the curious. Today, driven first by higher energy costs, then by incentive programs of electric utilities, and most recently by federal legislation in the form of EPAct, which took effect in late 1997, motor efficiency has become an imperative.

- EPAct establishes mandated efficiency standards for general purpose, three-phase AC industrial motors from 1 to 200 horsepower which are manufactured for sale in the United States. In addition, EPAct also establishes new testing procedures and labeling requirements for electric motors. The U.S. Department of Energy (DOE) is responsible for establishing the rules to implement and enforce EPAct.
- EPAct defines "electric motor" to include a: "general purpose, T-frame, single-speed, foot-mounting, poly-phase squirrel cage induction motor of the National Electrical Manufacturers Association ("NEMA") Design A and B, continuous-rated, operating on 230/460 volts and constant 60 hertz line power, as defined in NEMA Standards Publication MG1.

Since EPAct becoming the law of the land, most mandated efficiency levels are generally slightly lower than the "premium efficiency". Nevertheless, we periodically deal with a terminology issue; standard efficient vs. high efficient motor. ***The correct terminology should be Standard EPAct Efficient motor and Premium Efficient motor.***

## NEMA OPTIONS

### Enclosures

The term "enclosure" here means the same as "frame" or "housing." It also refers to the arrangement of the ventilating openings or other means of cooling and the amount of protection provided against the atmosphere in which the motor operates. For proper application, the selection of the correct enclosure to use is quite important in order to meet the particular atmospheric conditions.

NEMA MG 1, the industry standard for motors and generators, contains two methods for rating motor enclosures with regard to their environment:

1. Traditional ODP, TEFC, etc
2. The IEC "IP" system of enclosure ratings.

### Traditional - ODP, TEFC

Open Drip-proof

- Drip-proof motors have open enclosures and are suitable for indoor use and in relatively clean atmospheres. The openings are constructed so that drops of liquid or solid particles falling on the machine at an angle of not greater than 15 degrees from the vertical cannot enter the machine.
- Drip-proof motors have ventilating openings constructed which permit the passage of ambient air over the rotor and windings.

Totally Enclosed

- Totally enclosed motors are suitable for use in humid environments or dusty, contaminated atmospheres.
- Total enclosed motors are designed to prevent the free exchange of air between the inside and outside of the enclosure, but not sufficiently enclosed to be airtight.

TEFC – Totally Enclosed Fan Cooled:

This type includes an external fan mounted on the motor shaft. The fan is enclosed in a fan casing which both protects the fan and directs the air over the motor frame for cooling. The TEFC motor is used in indoor or outdoor duty applications where dust, dirt, mild corrosives, and water are present in modest amounts.

TEAO – Totally Enclosed Air Over:

This type is similar to the TEFC design except that the cooling fan and casing are not provided. This motor is not self-cooling. It should only be used in applications where the fan itself provides sufficient airflow over the motor surface for cooling.

Explosion proof

Explosion proof motors are totally enclosed fan cooled or non-ventilated type, but designed for applications in hazardous atmospheres which contain explosive gases or dusts.

**Induction Motor Options**

Overload Protection

Overload protection should always be provided in the overall system's design for safety. Protectors are generally current and temperature sensitive. Any excessive winding temperature can permanently damage the winding, greatly reducing winding life and can cause complete winding insulation breakdown and failure. As standard most motors have no inherent protector.

Solution motors are protected when a Solution *motor control* is part of the system design.

Starter panels include:

- Individual short circuit and overload protection

Variable Frequency Drive protection circuits include:

- over current
- ground fault
- over voltage
- under voltage
- over temperature
- input power loss of phase

If a specific application requires the motor to have an inherent thermal protection a thermal protector, automatic or manual, can be mounted in the end frame or on a winding, to prevent a motor from getting too hot, causing possible fire or damage to the motor. There are typically (4) four options in protection:

1. Manual (*inherent type*) - A manual overload must be physically reset to restart the motor. This line-interrupting protector has an external button that must be pushed to restore power to the motor.
   - Use where unexpected restarting would be hazardous, as on saws, conveyors, compressors and other machinery
2. Automatic (*inherent type*) - An automatic thermal overload will stop the motor when it is overloaded or overheated and restart it after the motor has cooled down. After the motor cools, this line-interrupting protector automatically restores power. (*not recommended for fans*)
   - It should not be used where unexpected restarting would be hazardous.
3. Thermostats - Thermostats (precision-calibrated resistors) are embedded in the winding and are used in conjunction with (connected-to) the motor starter control circuit to detect high temperatures.
   - Winding thermostats are snap-action, bi-metallic, temperature actuated switches normally installed in the connection end turns of the motor winding. Their purpose is to activate a warning device, or shut down the motor upon excessive winding temperatures. Thermostats are the simplest and least expensive of the protective devices. The basic detector systems in use today are:
     - Temperature Switches
     - Resistance Temperature Detectors (RTD's)
     - Thermistors
     - Thermocouples shutdown thermostats (N.C.).
4. None - None means the motor has no protection.

Note:

1. Never bypass a protector because of nuisance tripping. This is generally an indication of some other problem, such as overloading or lack of proper ventilation.
2. Never replace nor choose an automatic-reset thermal overload protected motor for an application where the driven-load could cause personal injury if the motor should restart unexpectedly. Only manual-reset thermal overloads should be used in such applications.

Multi-Speed Motors

A multi-speed motor configures windings in such a way that varying connections at the starter can change the speed to a predetermined speed. Multi-speed motors can be configured with two sets of windings or one set of windings. The most common multi-speed motor is a two speed, although three and four-speeds are sometimes available. A special characteristic attributed to multi-speed motors is variable torque. The strength of the magnetic field generated by the stator winding directly controls the torque output or torque available in the motor itself. The HP varies as the square of the speed.

Two-Speed, Two-Winding

The two-winding motor is designed in such a manner that it is really two motors wound into one stator. One-winding, when energized provides one speed. The second winding, when energized assumes authority and the motor takes on the speed that is determined by the second winding. The two-speed, two-winding motor can be used to get virtually any combination of normal motor speeds.

- The two different speeds **need not be related** to each other by a 2:1 speed factor.
- The two-speed motor requiring 1750 RPM and 1140 RPM would, of necessity, have to be a two-winding motor.

Two-Speed, One-Winding

The two-speed, one-winding motor is a more straightforward design.

- 2:1 relationship between the low and high speed must exist.
- Two-speed, one-winding motors are of the design that is called consequent pole. These motors are wound for one speed but when the winding is reconnected (physically reconnecting the leads) the number of magnetic poles within the stator is doubled and the motor speed is reduced to one-half of the original speed.

The two-speed, one-winding motor is, by nature, more economical to manufacture compared to a two- speed, two-winding motor. This is because the same winding is used for both speeds and the slots in which the conductors are placed within the motor do not have to be nearly as large as they would have to be to accommodate two separate windings that work independently. The frame size on a two-speed, single winding motor is usually smaller than on an equivalent two-winding motor.

## N.E.C. EXPLOSION PROOF REGULATIONS

The National Fire Protection Association's National Electrical Code categorizes common hazardous atmospheres and locations of both gaseous and particle dust. Since the type and degree of hazard varies widely according to the materials encountered and their presence in hazardous quantities, the following methods of identification are used:

**CLASS –**

Hazardous materials are assigned to three broad categories: gases, dusts, and fibers.

- Class I – A hazardous location in which flammable gases or vapors are present in sufficient quantities to produce an explosive mixture.
- Class II – A hazardous location in which flammable dusts are present in sufficient quantities to produce an explosive mixture.
- Class III – A hazardous location in which ignitable fibers or combustible airborne particles are present in sufficient quantities to produce an explosive mixture. There is no group designation for this class. An example would include cotton and rayon in textile mills.

**GROUP –**

Hazardous materials (gases, dusts, fibers) grouped according to their relative degree of hazard.

Class I

- Group A - Atmospheres containing acetylene.
- Group B - Atmospheres containing hydrogen, fuel, and combustible process gases containing more than 30 percent hydrogen by volume, or gases or vapors of equivalent hazards such as butadiene, ethylene oxide, propylene oxide, and acrolein.

*Caution: Explosion proof equipment is generally not available for Class I, Groups A and B and it is necessary to isolate motors from these hazardous areas.*

- Group C - Atmospheres containing ethyl ether, ethylene, or gases or vapors of equivalent hazard.
- Group D - Atmospheres such as acetone, ammonia, benzene, butane, cyclopropane, ethanol, gasoline, hexane, methane, natural gas, naphtha, propane, or gases or vapors of equivalent hazard.

Class II

- Group E - Atmospheres containing combustible metal dusts including aluminum, magnesium, and their commercial alloys, or other combustible dusts whose particle size, abrasiveness, and conductivity present similar hazards in the use of electrical equipment.
- Group F - Atmospheres containing carbonaceous dusts, including carbon black, charcoal, coal, or coke dusts that have more than 8 percent total entrapped volatiles, or dusts that have been sensitized by other materials so that they present an explosion hazard.
- Group G - Atmospheres containing combustible dusts not included in Group E or F, including flour, grain, wood, plastic, and chemicals.

Caution: The responsibility of specifying the proper rating, temperature and limit for application within a Class, Group, and Division of a hazardous location resides with the end user and the involved regulatory agency. Consult the National Electrical Code for more information on explosion proof regulations.

### Hazardous Location Divisions

- DIVISION I - Location in which ignitable concentrations of flammable or combustible material exist and come in contact with the motor.
- DIVISION II - Location in which ignitable concentrations of flammable or combustible material exist but are contained within closed systems or containers and normally would not come in contact with the motor.

## INTERNATIONAL STANDARD FOR MOTORS

International Electromechanical Commission (IEC) is a European group consisting of multi-national representatives who develop standards for electrical components. Historically, NEMA traditional motor designs have been sold primarily in U.S. markets, while IEC – "IP" motor designs have been sold primarily in the European/global markets. In Europe, much emphasis is placed on small size and efficient use of materials. Size, ruggedness, durability, complexity, perceived quality, and domestic vs. global markets are the primary differences between NEMA and IEC. Despite the perceptions about size and assumptions about complexity, neither the NEMA design nor the IEC design is intrinsically better or safer.

EN 60529 outlines the international classification system for the sealing effectiveness of IEC design enclosures of electrical equipment against the intrusion into the equipment of foreign bodies (i.e. tools, dust, fingers) and moisture. This classification system utilizes the letters "IP" ("Ingress Protection"), to indicate the degree of protection provided by an enclosure against access to hazardous parts, ingress of solid foreign objects, and ingress of water and to give additional information in connection with such protection. Complete details are found in IEC standard 60529, "Degree of Protection Provided by Enclosures (IP Code)," and in NEMA standard MG 1, "Motors and Generators."

### "IP" System

1. IP Ingress Protection Ratings:
   a. "IP" ("Ingress Protection") followed by two or three digits. (A third digit is sometimes used. An "x" is used for one of the digits if there is only one class of protection; i.e. IPX4 which addresses moisture resistance only.)

Example:

IP20 = Protection against solid foreign objects of 12.5 mm in diameter and greater.
IP40 = Protection against solid foreign objects of 1.0 mm in diameter and greater.
IP56 = Dust protected and protected against powerful water jets.
IP65 = Dust-tight and protected against water jets.
IP67 = Dust-tight and protected against the effects of temporary immersion in water.
IP68 = Dust-tight and protected against the effects of continuous immersion in water.
IPXX = When a characteristic numeral is not required to be specified, it is replaced by the letter "X". ("XX" when both numerals are omitted).

### Degrees of Protection - First Digit

The first digit of the IP code indicates the degree that persons are protected against contact with moving parts (other than smooth rotating shafts, etc.) and the degree that equipment is protected against solid foreign bodies (dust protection) intruding into an enclosure.

0. No special protection
1. Protection from a large part of the body such as a hand (but no protection from deliberate access); from solid objects greater than 50mm in diameter.

2. Protection against fingers or other object not greater than 80mm in length and 12mm in diameter.
3. Protection from entry by tools, wires, etc., with a diameter of thickness greater than 1.0mm.
4. Protection from entry by solid objects with a diameter or thickness greater than 1.0mm
5. Protection from the amount of dust that would interfere with the operation of the equipment.
6. Dust tight.

**Degrees of Protection - Second Digit**

The second digit indicates the degree of protection of the equipment inside the enclosure against the harmful entry of various forms of moisture (water protection) e.g. dripping, spraying, submersion, etc.

0. No special protection
1. Protection from dripping water.
2. Protection from vertically dripping water.
3. Protection from sprayed water.
4. Protection from splashed water.
5. Protection from water projected from a nozzle
6. Protection against heavy seas, or powerful jets of water.
7. Protection against immersion.
8. Protection against complete, continuous submersion in water. Submersion depth and time must be specified by the end user. The requirement must be more difficult than IP67.

## METHODS FOR STARTING MOTORS

The current required when starting the motor and load is referred to as 'locked rotor current' (LRC). To overcome the problems associated with current and torque surges, designers have developed different starting methods over the years since most AC motor applications require motor starters.

AC motor starters are intended to start and accelerate motors to normal speed, to ensure continuous operation of motors, and to provide protection against overloads (switch power off if overload occurs).

The different starting methods can be categorized as follows:

**Direct On-Line Starting (Across the Line Start) –** Direct on-line starting is most common up to 10HP or 7.5kW

- In many applications, the smaller induction motors are started with full-line voltage using motor starters. This motor control method starts and accelerates motor to full speed by connecting full line voltage immediately to motor. Essentially the motor is connected directly to the power source via a contactor. This usually the most simple and inexpensive method.

Caution - there is a high inrush current to the motor windings and sudden acceleration of the motor connected load. NEMA design B EPAct motors can draw up to seven times (600% - 700%) full-load operating current and produce approximately two (2) times (200%) full-load starting torque when it is first started up. This high inrush current puts tremendous burden on the power lines and consequently results in high demand charges by power companies. Direct-on line starting is not recommended in most situations.

**Reduced Voltage Starting (RVS) –** reduced voltage starting is advised when high starting current can be damaging to the motor due to excessive heat and/or the high starting torque can be damaging to the load and the transmission mechanisms such as gears, sprockets etc. The typical reason for RVS is due to a weak power distribution system requiring the current to be low on start-up to minimize line voltage drop. Line voltage drops can never be eliminated completely.

Thus RVS is needed for two reasons:

1. To avoid overloading the power distribution system
2. To avoid unnecessary wear and tear on equipment by reducing starting torque.

**Reduced Voltage Starting Techniques**

<u>Part-Winding Start Motor</u>

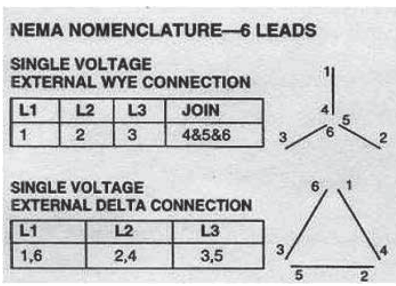
Part-winding start motors are NOT multi-speed motors. The Part Winding motor is a special motor with two separate motor windings. The primary purpose of part-winding is to reduce the initial starting (inrush) current and/or the initial starting torque developed by the motor.

Part-winding is arranged by initially energizing the first set of windings which will start the motor. The motor is not expected to accelerate on the start connection, and may not even turn. The current and torque are approximately 50% of locked rotor condition. After a selected time delay (2 to 3 seconds), power is applied to the second set of windings, which are parallel to the first set, energizing the remainder of this winding in one or more steps similar to a step control. This results in bringing the motor to full-speed.

Application for this method is where the power system has automatic voltage recovery and normal inrush would cause unacceptable voltage dip. Part winding start is typical on larger motors >40HP.

Wye-Delta (Star-Delta) starting

A special motor and starter are required for this wiring and starting method. A Wye-Delta motor is a special motor with both ends of the 3-phase motor windings brought out as leads.




At starting, the winding is temporarily connected in Wye (star) configuration.

- The phase voltage is thus reduced to 1/3 = 0.58 of full-line voltage, which results in starting current and torque of approximately 1/3 of full-voltage starter condition. After a selected time delay, usually several seconds, the windings are switched to Delta configuration, bringing the motor to full-voltage (likened to a cruising gear).
- Starting in Wye connection and running in Delta connection implies a connected load with low inertia. This method of starting is cheap and effective so long as the starting torque is not required to exceed about 50% of full load torque.

Per NEMA MG1 1998-1.76, *"A Wye Start, Delta Run motor is one arranged for starting by connecting to the supply with the primary winding initially connected in wye, then reconnected in delta for running condition." This is accomplished by a special Wye-Delta starter configuration using six leads from the motor and is intended to limit the inrush current required to start the motor.*

Soft starting – Solid State Soft Starter

Solid-state, reduced-voltage (SSRV) soft starters operate by controlling the current delivered to a motor. Controlling the current also controls the torque so that the motor accelerates smoothly. Soft starters ensure smooth, stepless acceleration and deceleration of your AC motors. Solid-state, reduced-voltage (SSRV) soft starters serve to mitigate destructive effects of such very high motor inrush currents and resulting mechanical stresses on connected equipment or system components. However, typical values for motor LRC have risen considerably with the advent of EPAct requirements. Many soft starters are only designed for a maximum start current of 400% and are protected through a thermal limit. This presents a problem for some applications that require high torque start. A soft starter may be considered an alternative to a variable frequency drive since they are cheaper than a drive, but, you must have a good understanding of the limitations of the soft starter.

Variable Frequency Drives

Variable speed drives operate as the most efficient method to control a fan or pump by controlling the voltage and frequency delivered to the motor. This gives control over motor torque, and reduces the current level during starting. Drives can control the speed of the

**Comparison of Wiring Methods for Starting AC Induction Motors**
**% Full Voltage Value**

| | Voltage @ Motor | Line Current | Motor Output Torque |
|---|---|---|---|
| Full Voltage | 100 | 100 | 100 |
| Part-Winding | | | |
| • Low speed motor (1/2-1/2) | 100 | 50 | 50 |
| • High speed motor (1/2-1/2) | 100 | 70 | 50 |
| • High speed motor (2//3-1/3) | 100 | 65 | 42 |
| • Wye start – delta run | 100 | 33 | 33(27) |

**Note:** It is advisable to review the actual reduced voltage starting characteristics with the motor manufacturer.

motor at any time during operation. Although variable speed drives can provide excellent soft start and soft stop functionality, they are much more complex and expensive than soft starters.

## INDUCTION MOTORS USED WITH FREQUENCY CONTROL

Solution air handler motors meet the performance standards for general purpose motors used with frequency control as listed in NEMA Standards Publication MG 1-2006 (Motors and Generators):

- MG 1-2006 Part 30—Application Considerations for General Purpose Motors used with Adjustable - Voltage OR Adjustable - Frequency Controls or Both
- MG 1-2006 Part 31—Definite-Purpose Inverter-Fed Poly-phase Motors

### Inverter Suitable - EPAct Efficient

Properly set-up the Solution Epact motors can be applied on inverters and be expected to perform satisfactorily for torque, temperature, noise and vibration over the entire speed range. Proper motor inverter set-up includes long lead filters which greatly reduce voltage spikes experienced at the motor terminals *(see note at bottom of this paragraph).

- Solution Epact motors (high efficient) are suitable for use at 20:1 variable torque and 4:1 constant torque applications.
- The Solution EPAct 3- phase motors are wound with ISR Spike Resistant wire and can with stand the peak voltages called out by NEMA part 31.

***Long Lead Filter –** AC output load reactors are used on installations requiring long motor lead lengths between 60 – 1000 feet. The output reactor is installed between the inverter and motor to reduce dV/dt and motor peak voltage. The use of an output load reactor also protects the inverter drive from a surge current caused by a rapid change in the load and even from a short circuit. For further information refer to the Air-Mod Application Guide.*

### Inverter Ready - Premium Efficiency

All Solution premium efficient 3-phase motors, both Totally Enclosed Fan Cooled and Open Drip Proof construction, are Inverter Ready per MG 1-2006 Part 31.

- This means the motors in 230, 460 and 575 volts meet NEMA’s corona inception voltage requirements and can withstand peak voltages of up to 1600 volts.
- ISR wire is a standard feature in all motors, 575 volt and under, 1 hp and up. Motors wound with ISR wire are up to 100 times more resistant to transient voltage spikes, high frequencies and short rise time pulse frequently produced by inverters and vector drives. The result is a better motor with longer life, reduced downtime and better overall value.

### Inverter Duty

The inverter-duty motors would need to be special quoted for Solution Air Handlers when required.

- These motors are designed for applications where up to a 1000:1 constant torque speed range is required. Inverter duty motors are also suitable for variable torque applications.
- Inverter Drive Motors are wound with 200 degree C. moisture resistant ISR (Inverter Spike Resistant) magnet wire which dramatically extends the life of the motors. Only a 1.0 service factor is available as standard.

Applications include conveyors, pumps, fans, metal processing, compressors, test stands, and material handling equipment.

## GENERAL APPLICATION CONCERNS

### Voltage & Frequency Variation


From time-to-time the available power supply from the distribution system will vary. Motors in agreement with NEMA standards can be operated successfully at rated load with a variation of (+-) 10% in voltage or (+-) 5% in rated frequency, or a combined variation of 10%.

Variations are expressed as a deviation from motor nameplate values. The allowable 10% voltage variation is based upon the assumption that the horsepower requirement will not exceed the nameplate rating.

- Nameplate-defined parameters for the motor such as power factor, efficiency, torque and current are at rated voltage and frequency
- Application at other than nameplate voltage will likely produce different performance.
- **DO NOT** apply a different voltage than that which is listed on the nameplate.

### Balanced vs. Un-Balanced Voltage

Un-Balanced Voltage is defined as the application of un-equal line voltage.

- When the line voltage applied to a 3-phase induction motor is not equal, a greater percent of unbalanced current will result in the stator windings.
- The use of unstable currents may result in an electrical winding failure over time
- A motor operating with a percentage of unbalanced voltage will experience higher operating temperature
- Input power is wasted in the form of rejected heat; a direct relationship with the motor's efficiency.
- Unbalanced voltage has an effect on the insulation life – See table 4.

Balanced Voltage is defined as equal line voltage.

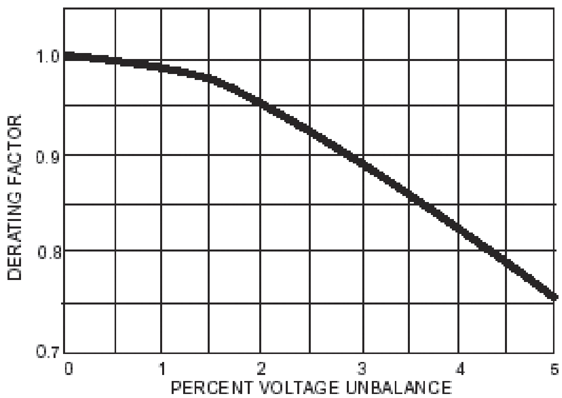
- Balanced voltage will indicate the motor will function as designed.

**General Effect of Voltage and Frequency Variations on Induction Motor Characteristics**

| **Characteristic** | **Voltage** | |
|---|---|---|
| | **110%** | **90%** |
| Starting Torque | Up 21% | Down 19% |
| Maximum Torque | Up 21% | Down 19% |
| Percent Slip | Down 15-20% | Up 20-30% |
| Efficiency | | |
| - Full Load | Down 0-3% | Down 0-2% |
| - 3/4 Load 0 | Down Slightly | Little Change |
| - 1/2 Load | Down 0-5% | Up 0-1% |
| Power Factor | | |
| - Full Load | Down 5-15% | Up 1% - 7% |
| - 3/4 Load | Down 5-15% | Up 2% -7% |
| - 1/2 Load | Down 10-20% | Up 3% -10% |
| Full Load Current | Down Slightly to Up 5% | Up 5-10% |
| Starting Current | Up 10% | Down 10% |
| Full Load - Temperature Rise | Up 10% | Down 10-15% |
| Maximum Overload Capacity | Up 21% | Down 19% |
| Magnetic Noise | Up Slightly | Down Slightly |

| **Characteristic** | **Frequency** | |
|---|---|---|
| | **110%** | **90%** |
| Starting Torque | Down 10% | Up 11% |
| Maximum Torque | Down 10% | Up 11% |
| Percent Slip | Up 10-15% | Down 5-10% |
| Efficiency | | |
| - Full Load | Up Slightly | Down Slightly |
| - 3/4 Load | Up Slightly | Down Slightly |
| - 1/2 Load | Up Slightly | Down Slightly |
| Power Factor | | |
| - Full Load | Up Slightly | Down Slightly |
| - 3/4 Load | Up Slightly | Down Slightly |
| - 1/2 Load | Up Slightly | Down Slightly |
| Full Load Current | Down Slightly | Up Slightly |
| Starting Current | Down 5% | Up 5% |
| Full Load - Temperature Rise | Down Slightly | Up Slightly |
| Maximum Overload Capacity | Down Slightly | Up Slightly |
| Magnetic Noise | Down Slightly | Up Slightly |

Integral HP motor de-rate factor:
If the horsepower de-rate is within the design service factor, then 'no' de-rate is required. However, in the most rigorous applications a motor with unbalanced voltage should have a de-rate factor applied.




Percent Unbalance = $\frac{100 \times \text{Max. Voltage Deviation from Avg. Voltage}}{\text{Avg. Voltage}}$

230 volt Example: With voltages of 220, 215 and 210, the average is 215, and the maximum deviation from average is 5. Therefore, percent unbalance = (100 x 5) ÷ 215 = 2.3%. From the above graph the motor de-rating factor is 0.93. Consequently, if we have a 20 HP, 3-phase motor its output should be de-rated to approximately 18.6 HP to reduce the possibility of damage to the motor.

460 volt Example: With voltages of 450, 445 and 440, the average is 445, and the maximum deviation from average is 5. Therefore, percent unbalance = (100 x 5) ÷ 445 = 1.1%. From the graph above the motor de-rating factor is 0.97. Consequently, if we have a 20 HP, 3-phase motor its output should be de-rated to approximately 19.4 HP to reduce the possibility of damage to the motor.

### Noise

Mechanically rotating electric motors have three basic noise sources:

1. Noise generated through the ventilation system (can be a dominant noise source)
2. Noise as a result of the electromagnetic excitation (largest source of noise, especially in a low-speed system)
3. Mechanical noise from rotating parts; bearings and rings (not normally significant)

Acoustically, the greater disturbing noise generated in electric motors is from the vibration forces which are produced by the interactions between waveforms. Simply speaking there are several waves produced from the electromagnetic machine:

1. Fundamental current waveforms
2. Harmonic (overtone) waveforms due to the slot configurations (air gap or opening between the stator and rotor) of the stator and rotor.
3. Harmonic (overtone) waveforms from excitement through any resonances (vibrations) of the machine

In adjustable speed drives the electromagnetically excited noise can be the largest source of noise, especially in a low-speed application where airflow noise will tend to be of lesser significance. If the forces produced during operation do not excite any resonances then generally the resulting vibration and noise will be less.

- This implies that avoiding the excitation of motor resonance frequencies can be a key factor in a noise control strategy.

For example if a supply voltage frequency is 30Hz and this coincides with a motor resonant frequency, high noise levels associated with this frequency can result. Most inverters offer the capability of keying in "prohibited" frequencies, whereby the inverter will not allow the prohibited frequencies to be used in operation.

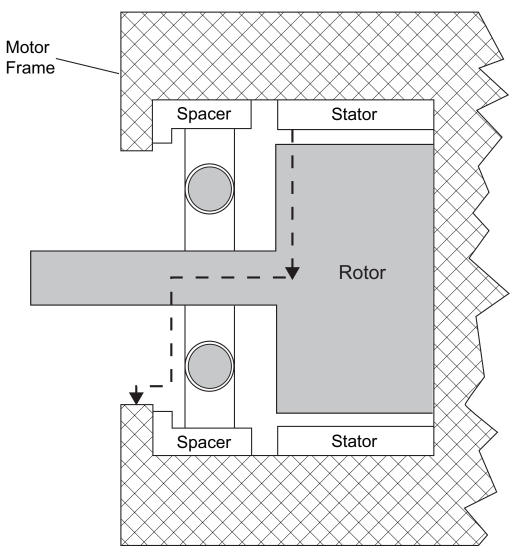
- These frequencies are entered by the site engineer during commissioning, based on the observed noise performance of the particular motor(s) being used.
- This allows a "manual" approach to the avoidance of high levels of noise due to resonance, but has the disadvantage that there will be specific speeds at which the motor will not operate, which may have a serious impact on the motor application.
- If the motor is replaced in the future, due to motor maintenance or failure, the new motor is likely to exhibit different resonant frequencies (especially if the motor is a different type/manufacturer). This would require recalibration/retuning of the inverter.

### Shaft Voltage

Voltage variations (unsteady sine wave) are generated in the rotor of each induction motor by the magnetic field passing through unbalanced or unsynchronized portions of its path. These unsynchronized spots vary according to the size of the motor. Another type of voltage variation is voltage spike. The cause for a voltage spike is a surge current caused by a rapid change in the load or even from a short circuit.

Essentially the rotor builds up a charge and attempts to shed the charge. A very small machine will have very little effect in generating voltage variations in the rotor while the effect is more pronounced in the larger machines.

All voltage variations directly relate to voltage passing through the shaft. Shaft voltage will make a complete circuit, when not insulated, through the motor's bearings and the frame or foundation, allowing current to flow across the bearings. Normally, voltage levels below 0.5V will not cause harmful currents. When the expected or measured shaft voltage is above 0.5V, provisions should be made to open or break the circuit to prevent current flow.




VOLTAGE PATH ( – – – – –)

The normal method is to insulate the motor bearing at the end opposite to the coupling end where the motor is coupled to the driven equipment. And, of course, other connections to the motor shaft at the end opposite the drive coupling must also be insulated to maintain the open circuit.

Applications using a VFD create an additional concern. The increased use of variable frequency drives has resulted in shaft voltages in much smaller motors. It is theorized that the terminal motor voltage supplied by the drive is not balanced or symmetrical in some aspect. As noted above; in standard machines, any break from balanced voltage in the rotor or stator can cause shaft voltages. When using variable frequency drives, there is a concern that some drives may induce a high frequency voltage spike and current that will pass through a conventional insulated bearing. At a high frequency the bearing and insulation will act like a capacitor without the ability to delay or prevent the progress of the high frequency voltage. *(Note: caution is necessary in installations with variable frequency power sources as the transient voltage spikes may reflect into the power supply and cause higher shaft voltages on other, non-variable speed machines on the power system.)*

Harmful results occur when sufficient current passes from the shaft to the bearing and then to a ground which is continuous to the other bearing. When current is broken at the contact surfaces between bearing rolling elements and raceways, arcing results. Thus the bearings are exposed to discharges causing pitting, fluting, excessive noise and catastrophic failure. The localized high temperature and consequent damage, is best described as a rut or groove in the bearing surface and looks like transverse ruts in the bearing raceways. In extreme cases, pits in the shaft journal surface appear. As a result, it may be necessary to add a shaft grounding kit to the motor.

Any one of the following recommendations can be used for protecting bearings from shaft voltages:

1. Install ground brushes on both ends
2. Install in-line filters between the motor and VFD to reduce the problem
3. Shaft Grounding Ring
4. Insulate both shaft journals
5. Insulate both bearing housings

## MISCELLANEOUS FORMULAS

### OHMS Law

Ohms = Volts/Amperes (R = E/I)
Amperes = Volts/Ohms (I = E/R)
Volts = Amperes x Ohms (E = IR)

### Power—A-C Circuits

1 HP = 3/4 KW (more precisely 746 watts)
746 watts = 1 HP

**The following are approximations:**

575 volt 3-phase motor draws 1 amp per HP.
460 volt 3-phase motor draws 1.27 amps per HP
230 volt 3-phase motor draws 2.5 amps per HP
230 volt 1-phase motor draws 5 amps per HP
115 volt 1-phase motor draws 10 amps per HP

**If electricity can be likened to plumbing:**

1. Voltage would resemble water pressure
2. Amps would be the same as gallons-per-second

Watts ÷ Amps = Volts.
Volts x Amps = Watts.
Watts ÷ Volt = Amps.
Volt (V) = a measure of electrical potential.
Watt (W) = a measure of the power an electrical device consumes.
Amp (A) = a measurement of the rate of flow of electrons along a wire.

Current = the rate of flow of electrons through a conductor, measured in Amps
VAC = Volt of Alternating Current.

Kilowatt (kw) = a thousand watts.
A kilowatt hour is the measurement most utilities use to measure electrical consumption. It indicates how many kilowatts are consumed for a full hour.

| | |
|---|---|
| Efficiency = | (746 x Output Horsepower) ÷ (Input Watts) |
| Three-Phase Kilowatts = | (Volts x Amperes x Power Factor x 1.732) ÷ (1000) |
| Three-Phase Volt-Amperes = | (Volts x Amperes x 1.732) |
| Three-Phase Amperes = | (746 x Horsepower) ÷ (1.732 x Volts x Efficiency x Power Factor) |
| Three-Phase Efficiency = | (746 x Horsepower) ÷ (Volts x Amperes x Power Factor x 1.732) |
| Three-Phase Power Factor = | (Input Watts) ÷ (Volts x Amperes x 1.732) |
| Single-Phase Kilowatts = | (Volts x Amperes x Power Factor) ÷ (1000) |
| Single-Phase Amperes = | (746 x Horsepower) ÷ (Volts x Efficiency x Power Factor) |
| Single-Phase Efficiency = | (746 x Horsepower) ÷ (Volts x Amperes x Power Factor) |
| Single-Phase Power Factor = | (Input Watts) ÷ (Volts x Amperes) |
| Horsepower (3 Ph) = | (Volts x Amperes x 1.732 x Efficiency x Power Factor) ÷ (746) |
| Horsepower (1 Ph) = | (Volts x Amperes x Efficiency x Power Factor) ÷ (746) |

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Form 102.20-AG15 (507)
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