a. Exposure to:
    1) Combustible, explosive, abrasive, or conducting dusts
    2) Lint or very dirty operating conditions where the accumulation of dirt may interfere with normal ventilation
    3) Chemical fumes or flammable or explosive gases
    4) Nuclear radiation
    5) Steam, salt-laden air, or oil vapor
    6) Damp or very dry locations, radiant heat, vermin infestation, or atmospheres conducive to the growth of fungus
    7) Abnormal shock, vibration, or mechanical loading from external sources
    8) Abnormal axial or side thrust imposed on the motor shaft
    9) A coupling mass that is greater than 10% of rotor weight and/or has a center of gravity that is beyond the shaft extension
    10) A coupling or coupling/coupling guard combination that could produce a negative pressure at the drive end seal
b. Operation where:
    1) Low noise levels are required
    2) The voltage at the motor terminals is unbalanced by more than 1%
c. Operation at speeds above the highest rated speed
d. Opera
e. Opera
    1) To
    2) Re
    3) Re
f. Belt, g
g. Multi-r

Special consideration must be given to applications where more than one motor is used on the same control. Some of these considerations are:
    1) Possible large variation in load on motors where load sharing of two or more motors is required
    2) Protection of individual motors
    3) Starting or restarting of one or more motors
    4) Interaction between motors due to current perturbations caused by differences in motor loading

31.1.4 Operation in Hazardous (Classified) Locations

WARNING—Motors operated from inverters should not be used in any Division 1 hazardous (classified) locations unless the motor is identified on the nameplate as acceptable for such operation when used in Division 1 hazardous (classified) locations.

For motors to be used in any Division 2 hazardous (classified) locations, the motor manufacturer should be consulted.

Failure to comply with this warning could result in an unsafe installation that could cause damage to property or serious injury or death to personnel, or both.

31.2 Dimensions, Tolerances, and Mounting for Frame Designations

Frame designations for medium definite purpose inverter-fed motors shall be in accordance with Part 4.

31.3 Rating

31.3.1 Basis of Rating

Definite purpose inverter-fed AC induction motors covered by this part shall be rated based on identification of the applicable load points selected from the four load points shown in and defined in Figure 31-1. The base rating shall be defined coincident with point (3) in Figure 31-1 by specifying the motor voltage, speed, and horsepower or torque, at that point.

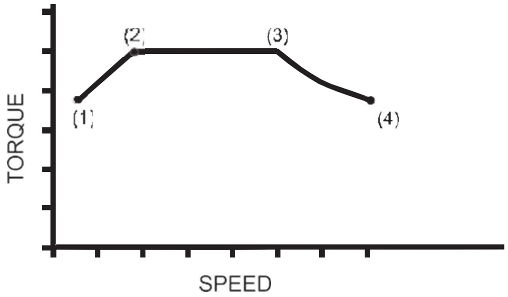

Figure 31-1
Basis of Rating

Notes:

1. Torque at minimum speed based on temperature considerations and voltage boost
2. Lowest speed of the constant torque range based on temperature considerations
3. Base rating point at upper end of constant torque range
4. Maximum operating speed based on constant horsepower and any limitation on rotational speed

When the voltage ratings at reference points 3 and 4 are different, then, unless otherwise specified, the voltage is assumed to reach the maximum value at a frequency between points 3 and 4 per a constant volts-to-hertz relationship equal to the voltage at point 3 divided by the frequency at point 3.

31.3.2 Base Horsepower and Speed Ratings

Preferred horsepower and speed ratings shall be as shown in Table 31-1.

Note: It is not practical to build induction motors of all horsepower ratings at all speeds.

Table 31-1
Preferred Horsepower and Speed Ratings

Output Horsepower					
1/2	10	75	400	1250	4000
3/4	15	100	450	1500	4500
1	20	125	500	1750	5000
1-1/2	25	150	600	2000	-
2	30	200	700	2250	-
3	40	250	800	2500	-
5	50	300	900	3000	-
7-1/2	60	350	1000	3500	-

Speed (RPM)			
300	650	1750	5000
400	850	2500	7000
500	1150	3500	10000

31.3.3 Speed Range

Defined speed ranges illustrated by the points shown in Figure 31-1 are based on the base rating point (3) speed for a given machine.

31.3.3.1 Lowest Speed of Constant Torque Range—Point (2)

The preferred ratio of speed at base rating point (3) to that at point (2) shall be 1, 2, 3, 4, 6, 10, 20, or 100, except where point (2) is zero rpm, in which case the ratio is undefined. Example: expressed as 6 to 1, 6:1.

31.3.3.2 Maximum Operating Speed—Point (4)

The preferred ratio of speed at point (4) to that of base rating point (3) shall be 1, 1-1/2, 2, 2-1/2, 3, or 4.

31.3.3.3 Minimum Speed—Point (1)

The minimum speed may be zero.

Note: It is not practical to build induction motors of all horsepower ratings at all speed ranges or combinations of speed ranges.

31.3.3.4 Other Speed Ranges

Other speed ranges may be specified by agreement between the purchaser and manufacturer.

31.3.4 Voltage

Preferred voltages shall be 115, 230, 460, 575, 2300, 4000, 4600, 6600, and 7200 volts. These voltage ratings apply to the maximum level of the rms fundamental voltage to be applied to the motor over the rated speed range.

Note: It is not practical to build induction motors of all horsepower ratings at all voltages.

31.3.5 Number of Phases

The preferred number of phases is three (3).

31.3.6 Direction of Rotation

a. F1 or F2 arrangement, foot mounted:

   The standard direction of rotation for definite purpose inverter-fed motors having an F1 or F2 arrangement and foot mounting is counterclockwise when phase sequence 1, 2, and 3 of the power from the control is applied to terminals T1, T2, and T3 of the motor, respectively, when facing the end of the motor for which the conduit box is on the right and the feet are down.

b. Other arrangements:

   The standard direction of rotation for definite purpose inverter-fed motors having arrangements other than F1 or F2 is counterclockwise when phase sequence 1, 2, and 3 of the power from the control is applied to terminals T1, T2, and T3 of the motor, respectively, when facing the opposite drive end.

WARNING—The phase sequence of the output power from the control may not be the same as the phase sequence of the power into the control. Direction of rotation should be checked by momentary application of voltage to the motor before connecting the motor to the driven equipment.

31.3.7 Service Factor

A motor covered by this Part 31 shall have a service factor of 1.0.

31.3.8 Duty

31.3.8.1 Variable Speed

The motor is intended for varied operation over a defined load/speed cycle and not for continuous operation at a single or limited number of speeds. Variable speed duty is not applicable if the load/speed cycle is not defined.

The load/speed cycle consists of a defined number of load/speed segments where each load/speed segment is either a discrete operating point of load and speed that is maintained for a specific time duration or an acceleration or deceleration that persists for a defined period of time. The minimum load within a load/speed cycle may have the value zero (no-load or de-energized at rest). A time duration for the complete load/speed cycle that exceeds 24 hours is outside the scope of this standard.

Two specific types of variable speed duty are defined in 31.3.8.1.1 and 31.3.8.1.2.

31.3.8.1.1 Variable Speed Duty for Which Thermal Equilibrium Is Reached at Each Load/Speed Segment

For this type of variable speed duty:

a. the load/speed segment at each discrete operating point is maintained until thermal equilibrium is established[1]

b. each load/speed cycle within a series of load/speed cycles is not necessarily identical[1]

c. each load/speed cycle when integrated over time will return the same relative thermal life expectancy[1,2]

An example of a load/speed cycle appears in Figure 31-2.

31.3.8.1.2 Periodic Duty (Variable Speed Duty for Which Thermal Equilibrium Is Not Reached at Each Load/Speed Segment)

For this type of variable speed duty:

a. the load/speed segment at each discrete operating point is not maintained for a sufficient period of time to establish thermal equilibrium[3]

b. each load/speed cycle is identical[3]

An example of a load/speed cycle appears in Figure 31-3.

31.3.8.2 Continuous

The motor can be operated continuously at any speed within the defined load/speed range.

31.4 Performance

31.4.1 Temperature Rise

31.4.1.1 Maximum Temperature Rise for Variable Speed Duty

The temperature rise of the windings, above the temperature of the cooling medium, at any point in time during the load/speed cycle, shall not exceed the limit for maximum intermittent winding temperature rise given in Table 31-2, when tested with the identified control. The relative equivalent temperature rise T_E for the load/ speed cycle as determined according to 31.4.1.2 shall not exceed the values for T_E given in the table. All temperature rises in the table are based on a maximum ambient temperature of 40°C.

The temperature attained by cores, squirrel-cage windings, and miscellaneous parts shall not injure the insulation of the machine in any respect.

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[1] Consistent with duty type S10 in IEC 60034-1 Edition 13.0

[2] The term “relative thermal life expectancy” is defined in 31.4.1.2

[3] Consistent with duty type S8 in IEC 60034-1 Edition 13.0

Table 31-2
Temperature Rise

Insulation Class	Maximum Intermittent Winding Temperature Rise, Degrees C		Maximum Permissible Value of Relative Equivalent Temperature Rise (T_E), Degrees C	
	Method of Temperature Determination		Method of Temperature Determination	
	Resistance	Embedded Detector	Resistance	Embedded Detector
A	70	80	60	70
B	100	110	80	90
F*	130	140	105	115
H*	155	170	125	140
*Where a Class F or H insulation system is used, special consideration should be given to bearing temperature, lubrication, etc.				

31.4.1.2 Relative Equivalent Temperature Rise for Variable Speed Duty

The rate of thermal aging of the insulation system will be dependent on the value of the temperature and the time duration at the load/speed segments within the load/speed cycle. A thermal life expectancy of the motor operating over the load/speed cycle can be derived in relation to that for the motor operating continuously at a temperature equal to that for the temperature classification of the insulation system.

With reference to Figure 31-2 or Figure 31-3, this relative thermal life expectancy shall be calculated by the following equation:

$$\frac{1}{TL} = \Delta t_1 \times 2^{\frac{\Delta T_1}{K}} + \Delta t_2 \times 2^{\frac{\Delta T_2}{K}} + \ldots + \Delta t_n \times 2^{\frac{\Delta T_n}{K}}$$

Where:

TL = relative thermal life expectancy for the load/speed cycle compared to the thermal life expectancy for continuous operation at the temperature rating of the insulation class

ΔT_1 ... ΔT_n = differences between the average[4] temperature rise of the winding at each of the load/speed segments within the load/speed cycle and the maximum permissible value of relative equivalent temperature rise for the insulation class. For periodic duty (31.3.8.1.2), the load/speed cycle that shall be considered is that which occurs after thermal equilibrium is obtained from one load/speed cycle to the next and the criterion for thermal equilibrium shall be that a straight line drawn between the corresponding points of successive load/speed cycles on a temperature plot has a slope of less than 1°C per 30 minutes.

Δt_1 ... Δt_n = time duration at each load/speed segment expressed as a per unit value of the total time for the load/speed cycle

k = 10°C = difference in temperature rise that results in a shortening of the thermal life expectancy of the insulation system by 50%

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[4] For periodic duty (31.3.8.1.2), integration of the curve of temperature rise vs. time duration for each load/speed segment may be required to determine the average temperature rise.

If a load/speed segment at a particular operating point is maintained for a sufficient time for thermal equilibrium to be reached, then the acceleration or deacceleration load/speed segment immediately preceding it is deemed negligible and can be ignored in the calculation of relative thermal life expectancy.

A relative equivalent temperature rise based on continuous operation at that temperature rise for the load/speed cycle time duration and resulting in the same level of relative thermal life expectancy for the defined load/speed cycle shall be determined as follows:

$$T_E = k\ x\ log_2\left(\frac{1}{TL}\right) + T_R$$

or

$$T_E = k\ x\ 3.322\ x\ log_{10}\left(\frac{1}{TL}\right) + T_R$$

Where:

T_E = relative equivalent temperature rise

T_R = maximum permissible value of relative equivalent temperature rise for insulation class (Figures 31-2 and 31-3; for example, see Table 31-2)

31.4.1.3 Maximum Temperature Rise for Continuous Duty

The maximum temperature rise of the windings, above the temperature of the cooling medium, shall not exceed the values given for relative equivalent temperature rise in Table 31-2.

31.4.1.4 Temperature Rise for Ambients Higher Than 40°C

The temperature rises given in Table 31-2 are based upon a reference ambient temperature of 40°C. However, it is recognized that induction machines may be required to operate in an ambient temperature higher than 40°C. For successful operation of induction machines in ambient temperatures higher than 40°C, the temperature rises of the machines given in Table 31-2 shall be reduced by the number of degrees that the ambient temperature exceeds 40°C. When a higher ambient temperature than 40°C is required, preferred values of ambient temperatures are 50°C, 65°C, 90°C, and 115°C.

31.4.1.5 Temperature Rise for Altitudes Greater Than 3300 Feet (1000 Meters)

For machines that operate under prevailing barometric pressure and that are designed not to exceed the specified temperature rise at altitudes from 3300 feet (1000 meters) to 13200 feet (4000 meters), the temperature rises, as checked by tests at low altitudes, shall be less than those listed in Table 31-2 by 1 percent of the specified temperature rise for each 330 feet (100 meters) of altitude in excess of 3300 feet (1000 meters).

Preferred values of altitude are 3300 feet (1000 meters), 6600 feet (2000 meters), 9900 feet (3000 meters), and 13200 feet (4000 meters).

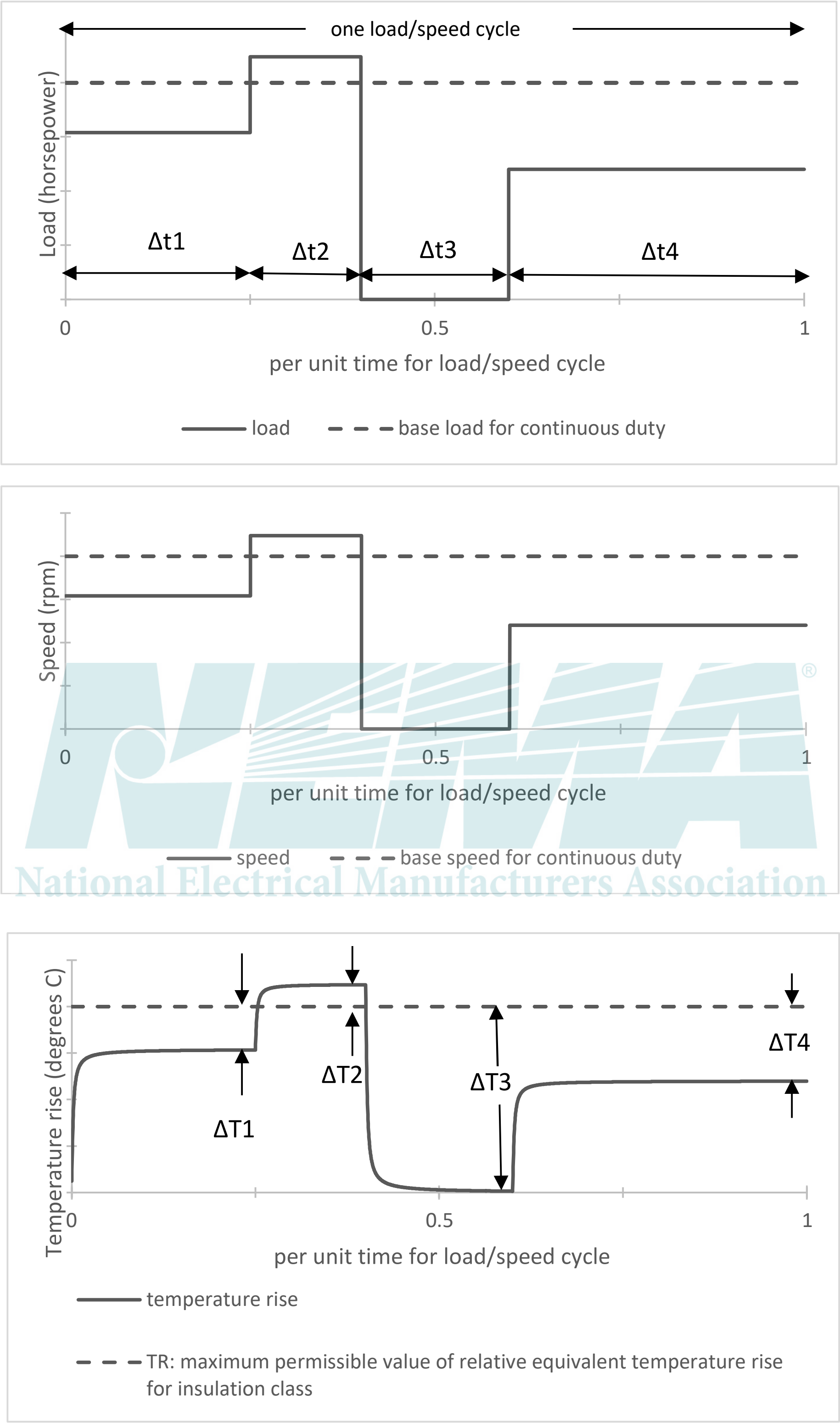

Figure 31-2
Load/Speed Cycle for Variable Speed Duty for Which Thermal Equilibrium Is Reached at Each Load/Speed Segment

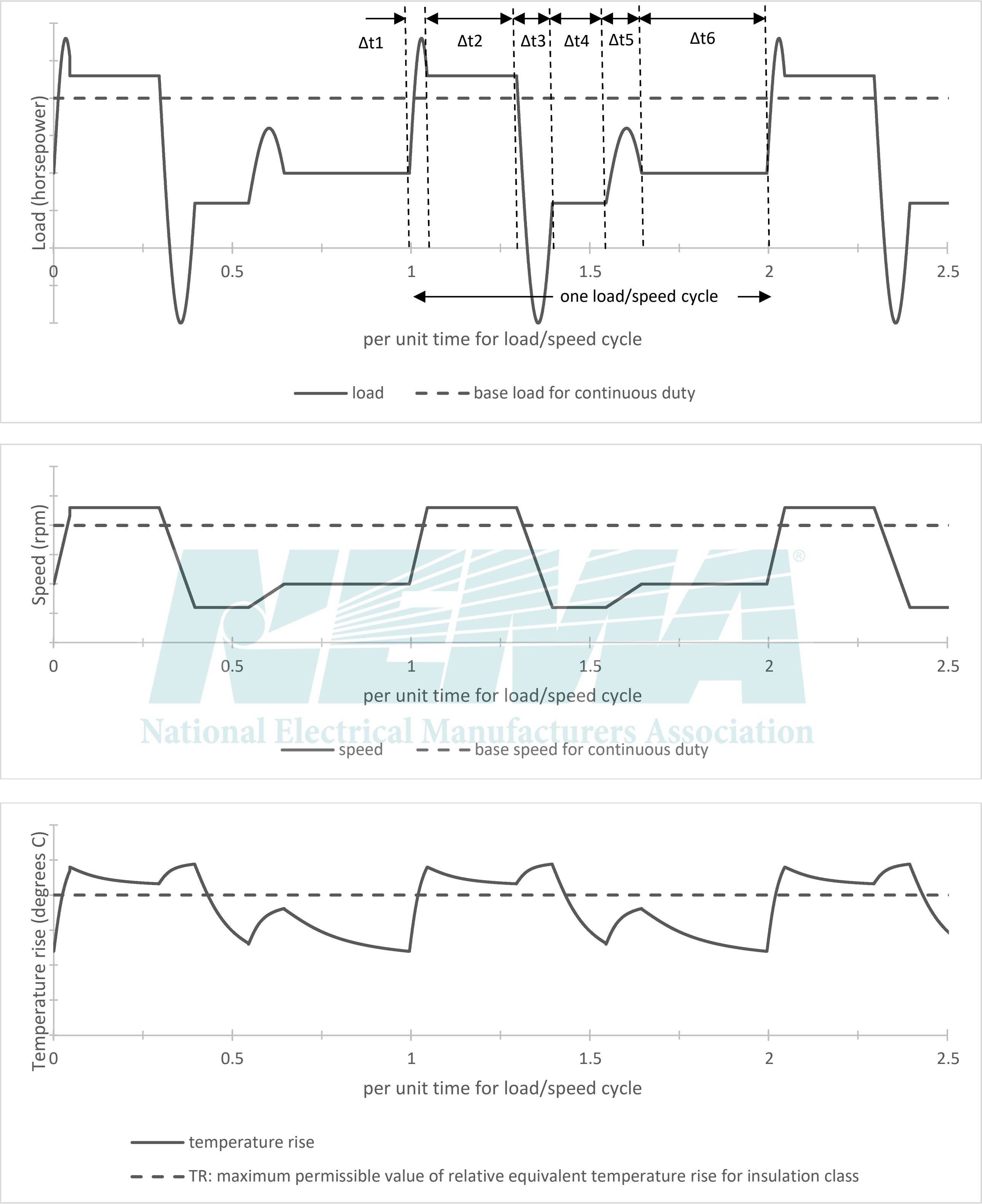

Figure 31-3
Load/Speed Cycle for Periodic Duty (Variable Speed Duty for Which Thermal Equilibrium Is Not Reached at Each Load/Speed Segment)

31.4.1.6 Temperature Rise for Air-Cooled Machines for Ambients Lower Than 40° C But Not Below 0° C*

The temperature rises given in Table 31-2 are based upon a reference ambient temperature of 40°C to cover most general environments. However, it is recognized that air-cooled induction motors may be operated in environments where the ambient temperature of the cooling air will always be less than 40°C. When an air-cooled induction motor is marked with a maximum ambient less than 40°C, then the allowable temperature rises in Table 31-2 shall be increased according to the following:

a. For motors for which the difference between the Reference Temperature and the sum of 40°C and the Temperature Rise Limit given in Table 31-2 is less than or equal to 5°C, then the temperature rises given in Table 31-2 shall be increased by the amount of the difference between 40°C and the lower marked ambient temperature.

b. For motors for which the difference between the Reference Temperature and the sum of 40°C and the Temperature Rise Limit given in Table 31-2 is greater than 5°C, then the temperature rises given in Table 31-2 shall be increased by the amount calculated from the following expression:

$$\text{Increase in Rise} = \{40^\circ\text{C} - \text{Marked Ambient}\}\ \text{X}\ \left\{1 - \frac{\text{Reference Temperature} - (40^\circ\text{C} + \text{Temperature Rise})}{80^\circ\text{C}}\right\}$$

Where:

Class of Insulation System	Reference Temperature, Degrees C
A	120
B	150
F	180
H	205

*Note: This requirement does not include water-cooled machines.

Temperature Rise Limit = Maximum allowable temperature rise according to Table 31-2

For example: An inverter-fed induction motor with a Class F insulation system is marked for use in an ambient with a maximum temperature of 25°C. From the table above the Reference Temperature is 180°C and from Table 31-2 the Temperature Rise Limit is 130°C. The allowable Increase in Rise to be added to the Temperature Rise Limit is then:

$$\text{Increase in Rise} = \{40^\circ\text{C} - 25^\circ\text{C}\}\ \text{X}\ \left\{1 - \frac{180^\circ\text{C} - (40^\circ\text{C} + 130^\circ\text{C})}{80^\circ\text{C}}\right\} = 13^\circ\text{C}$$

The total allowable Temperature Rise by Resistance above a maximum of a 25°C ambient is then equal to the sum of the Temperature Rise Limit from Table 31-2 and the calculated Increase in Rise. For this example, that total is 130°C + 13°C = 143°C.

31.4.2 Torque

31.4.2.1 Breakaway Torque

The motor should be capable of producing a breakaway torque of at least 140% of rated torque requiring not more than 150% rated current when the voltage boost is adjusted to develop rated flux in the motor and when the inverter is able to produce the required minimum fundamental frequencies. For frequencies below 5 hertz, rated flux occurs approximately when:

$$V_{LL} = \sqrt{3} \text{ x } I_L \text{ x } \frac{R_{LL}}{2} + V_{LL\ rated} \text{ x } \frac{f}{f_{rated}}$$

Where:
V_{LL} = line-to-line rms fundamental voltage at the motor terminals
I_L = line current (rms) corresponding to the desired level of breakaway torque
R_{LL} = line-to-line stator winding resistance at operating temperature
f = frequency

The voltage boost should not be adjusted to exceed a value of V_{LL} based on I_L equal to 1.5 times rated full load current to achieve higher breakaway torque without special consideration.

CAUTION—Continued application of boosted motor voltage at low frequencies under no-load conditions will increase motor heating. When voltage boost is required to achieve a breakaway torque greater than 140% of rated torque, the motor should not be operated under voltage boost condition at frequencies less than 10 hertz for more than 1 minute without consulting the manufacturer.

31.4.2.2 Breakdown Torque

The breakdown torque at any frequency within the defined frequency range shall be not less than 150% of the rated torque at that frequency when rated voltage for that frequency is applied.

31.4.3 Operating Limitations

31.4.3.1 Starting Requirements

While definite purpose motors may be capable of being started across-the-line, the level of locked-rotor current at line frequency and voltage may exceed that for general purpose motors. The torque versus speed profile during across-the-line starting of the definite purpose motor also may be different from that of the general purpose motors and may not be suitable for the requirements of the load. For large motors, the stator end-winding support may be inadequate. If across-the-line starting capability is required by the application, these factors should be considered when selecting the motor and controls.

31.4.3.2 Variations from Rated Voltage

The rated motor fundamental line voltage as a function of motor speed is defined at the base rating point and implied at the various operating conditions in 31.3. Definite purpose inverter-fed motors shall operate successfully throughout their defined speed range when the applied fundamental voltage does not vary from the rated value at any operating point by more than ±10%. Performance with this variation will not necessarily be in accordance with operation at the rated voltage.

31.4.3.3 Occasional Excess Current

Definite purpose inverter-fed motors shall be capable of withstanding an occasional excess current for a period of not less than 1 minute when the motor is initially at normal operating temperature. The magnitude of the current and the time in minutes between successive applications of this current are as follows:

Momentary Overload as a Percent of Base Current	Time Interval Between Overloads (minutes)
110	≥ 9
125	≥ 28
150	≥ 60

Repeated overloads may result in operation where winding temperatures are above the maximum values given by 31.4.1.1, which will result in reduced insulation life. If the overload is part of the normal duty cycle, the relative equivalent temperature rise must be calculated per 31.4.1.2 to ensure that the limits in 31.4.1.1 are not exceeded.

31.4.3.4 Power and Coupling Capacitors

The use of power capacitors for power factor correction or surge suppression on the load side of an inverter connected to an induction motor is not recommended. The proper application of such capacitors requires an analysis of the motor, electronic control, and load characteristics as a function of speed to avoid potential overexcitation of the motor, harmonic resonance, and capacitor overvoltage.

The use of coupling capacitors, typically less than 200 pF for partial discharge (PD) detection on the load side of an inverter connected to an induction motor, is generally acceptable. The proper application of such capacitors requires an analysis of the motor, electronic control, and load characteristics as a function of speed. Additional hardware may be required in the terminal box to take PD measurements.

31.4.3.5 Overspeeds

Definite purpose inverter-fed motors shall be so constructed that in an emergency not to exceed 2 minutes, they will withstand, without mechanical damage, overspeeds above the maximum operating speed (see Figure 31-1) in accordance with the following:

Maximum Operating Speed, rpm	Overspeed, Percent of Maximum Operating Speed
3601 and over	15
1801–3600	20
1800 and below	25

31.4.4 Insulation Considerations

31.4.4.1 Leakage Currents

High-frequency harmonics of inverters can cause an increase in the magnitudes of leakage currents in the motor due to a reduction in the capacitive reactance of the winding insulation at higher frequencies. Established and safe grounding practices for the motor frame should therefore be followed.

31.4.4.2 Voltage Spikes

Inverters used to supply adjustable frequency power to induction motors do not produce sinusoidal output voltage waveforms. In addition to lower order harmonics, these waveforms also have superimposed on them steep-fronted, single-amplitude voltage spikes. Turn-to-turn, phase-to-phase, and ground insulation of stator windings are subjected to the resulting dielectric stresses. Suitable precautions should be taken in the design of drive systems to minimize the magnitude of these spikes.

When operated under usual service conditions (31.1.2), where the inverter input nominal voltage does not exceed rated motor voltage, stator winding insulation systems for definite purpose inverter-fed motors with a base rating less than or equal to 600 volts shall be designed to:

1) Operate at the following withstand voltage at the motor terminals:

$$V_{peak} \le 1.1 * 2 * \sqrt{2} * V_{rated} \le 3.1 * V_{rated}$$

Rise time ≥ 0.1 μs
and

2) Operate partial discharge (PD) free at a PD-free voltage[5] at the motor terminals that falls within the following limits:

$$V_{peak} \le 1.1 * 1.5 * \frac{\sqrt[3]{2}}{\pi} * V_{rated} \le 2.23 * V_{rated}$$

Rise time ≥ 0.1 μs

Where: V_{peak} is a single amplitude zero-to-peak line-to-line voltage.

V_{rated} is the rated line-to-line voltage.

CAUTION—When the input voltage to the inverter exceeds the rated voltage, care must be taken in determining the maximum peak voltage (V_{peak}) that will be applied to the motor by the inverter.

Table 31-3
Examples of Minimum Acceptable Single Amplitude Zero-to-Peak Line-to-Line Withstand and PD-Free Voltages Measured at the Motor Terminals for Common Rated Voltages

V_{rated}	$V_{withstand}$ (withstand voltage)	$V_{PD\text{-}free}$ (PD-free voltage)
230	716	513
460	1431	1025
575	1789	1281

See Figure 30-5 for a typical voltage response at the motor terminals for an illustration of V_{peak} and rise time.

To demonstrate the ability to operate PD free at the PD-free voltage, the type test procedure provided in Clause 11 of IEC 60034-18-41 Edition 1 shall be used. This test is intended to be performed on representative samples when the stator winding insulation system is initially qualified and is not intended to be a required routine test for each motor produced. The test voltage can be either an impulse voltage or a 50 Hz or 60 Hz sinusoidal voltage.[6]

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[5] This PD-free voltage is intended to correspond to the upper limit of the Moderate stress category defined in IEC 60034-18-41 Ed. 1.

[6] If the test voltage is sinusoidal, then the turn/turn insulation cannot be evaluated unless testing is done on a special winding with two electrically isolated conductors wound in parallel with only one conductor energized as described in Clause 10.2 of IEC 60034-18-41 Edition 1.0. If the test voltage is an impulse voltage, then both the phase/phase and phase/ground PD tests evaluate the turn/turn insulation. Since the proper impulse test voltage for the turn/turn insulation is that from the phase/ground PD test, ambiguous results are obtained from the type test if PD is not detected on the phase/ground PD test (which demonstrates the ability of the turn/turn and phase/ground insulation to operate PD free at the PD-free voltage), but PD is detected on the phase/phase PD test since it is unknown whether the PD is occurring in the turn/turn insulation (which was already deemed acceptable at the lower test voltage from the phase/ground PD test) or in the phase/phase insulation (which is what the phase/phase PD test is intended to

The peak-to-peak value of the test voltage shall be:

a. For the phase/phase PD test: The zero-to-peak line-to-line PD-free voltage multiplied by 2.5[7]
b. For the phase/ground PD test: The voltage for the phase/phase PD test multiplied by 0.7

Table 31-4
Peak-to-Peak Values of Test Voltage (Sinusoidal or Impulse Voltage with a Fall Time ≥10 µS for the Trailing Edge) for Common Rated Voltages and Their Corresponding Zero-to-Peak Values of PD-Free Voltage

V_{rated}	PD-free voltage, V_{peak}	phase/phase PD test voltage	phase/ground PD test voltage
230	513	1281	897
460	1025	2563	1794
575	1281	3203	2242

Table 31-5
Peak-to-Peak Values of Test Voltage (Impulse with a Fall Time <10 µS for the Trailing Edge) for Common Rated Voltages and Their Corresponding Zero-to-Peak Values of PD-Free Voltage

V_{rated}	PD-free voltage, V_{peak}	phase/phase PD test voltage	phase/ground PD test voltage
230	513	641	448
460	1025	1281	897
575	1281	1602	1121

When operated under usual service conditions (31.1.2), where the inverter input nominal voltage does not exceed rated motor voltage, stator winding insulation systems for definite purpose inverter-fed motors with a base rating above 600 volts shall be designed to operate under the following limits at the motor terminals:

$$V_{peak} \leq 2.25 \left|\frac{\sqrt{2}}{\sqrt{3}}\right| V_{rated} \leq 2.04 * V_{rated}$$

Rise time ≥ 1 µS

Where:

V_{peak} is a single amplitude zero-to-peak line-to-line voltage
V_{rated} is the rated line-to-line voltage

CAUTION—When the input voltage to the inverter exceeds the rated voltage, care must be taken in determining the maximum peak voltage (V_{peak}) that will be applied to the motor by the inverter.

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evaluate). To avoid this ambiguity, a test impulse voltage with a longer than specified rise time can be used for the phase/phase PD test so that the turn/turn insulation is not evaluated a second time as is stated in Clause 11.3b) of IEC 60034-18-41 Edition 1.0. If such a test impulse voltage is not available, then the phase/phase PD test results can be disregarded if this ambiguity is present.

[7] If the test voltage is an impulse voltage with a fall time of less than 10 µs for the trailing edge, then the peak-to-peak value of the test voltage for the phase/phase PD test shall be equal to the zero-to-peak line-to-line PD-free voltage multiplied by 1.25.

31.4.4.3 Shaft Voltages and Bearing Insulation

Shaft voltages can result in the flow of destructive currents through motor bearings, manifesting themselves through pitting of the bearings, scoring of the shaft, and eventual bearing failure. In larger frame size motors, usually 500 frame and larger, these voltages may be present under sinusoidal operation and are caused by magnetic dissymmetries in the construction of these motors. This results in the generation of a shaft end-to-end voltage. The current path in this case is from the motor frame through a bearing to the motor shaft, down the shaft, and through the other bearing back to the motor frame. This type of current can be interrupted by insulating one of the bearings. If the shaft voltage is larger than 300 millivolts peak when tested per IEEE 112, bearing insulation should be utilized.

More recently, for some inverter types and application methods, potentially destructive bearing currents have occasionally occurred in induction motors of all sizes. However, the root cause of the current is different. These drives can be generators of a common mode voltage that shifts the three-phase winding neutral potentials significantly from ground. This common mode voltage oscillates at high frequency and is capacitively coupled to the rotor. This results in peak pulses as high as 10-40 volts from shaft to ground. The current path could be through either or both bearings to ground. Interruption of this current therefore requires insulating both bearings. Alternately, to address the concerns of bearing currents, the drive topology can be changed, filters can be added, improved grounding of the system can be used, or shaft grounding brushes can be used. It should be noted that insulating the motor bearings will not prevent the damage of other shaft connected equipment. (For further guidance, refer to NEMA application guide ICS 16). At this time, there has been no conclusive study that has served to quantify the relationship of peak voltage from inverter operation to bearing life or failure. There is also no standard method for measuring this voltage. Because of this, the potential for problems cannot consistently be determined in advance of motor installation.

31.4.4.4 Neutral Shift

When inverters are applied to motors, the motor windings can be exposed to higher than normal line-to-ground voltages due to the neutral shift effect. Neutral shift is the voltage difference between the source neutral and the motor neutral. Its magnitude is a function of the total system design and, in the case of some types of current, source inverters can be as high as 2.3 per unit ($1 \text{ pu} = \sqrt{2}/\sqrt{3}V_{LL}$), resulting in motor line-to-ground voltages of up to 3.3 per unit, or 3.3 times the crest of the nominal sinusoidal line-to-ground voltage. In the case of a typical voltage source inverter, the magnitude of the line-to-ground voltage can be as high as $\sqrt{3}$ times the crest of the nominal sinusoidal line-to-ground voltage.

The magnitude of the neutral voltage can be reduced if the inverter is connected to an ungrounded power source, or, if this is not possible, by isolating it from the source ground by using an isolation transformer by using separate reactors in both the positive and the negative direct current link, or by connecting the motor neutral to the ground through a relatively low impedance. Proper selection of the method to reduce motor line-to-ground voltage should be coordinated with the system designer.

31.4.5 Resonances, Sound, Vibration

31.4.5.1 General

The motor and the driven equipment (system) have natural resonant frequencies in the lateral, axial, and torsional modes. When an inverter is applied to the motor, the system is excited by a spectrum of harmonics coming from the inverter. This can affect the sound level, vibration level, and torsional response of the system. The system integrator should take these effects into consideration to ensure successful system performance.

31.4.5.2 Sound and Vibration

Machine sound and vibration are influenced by the following parameters:

a. Electromagnetic design
b. Type of inverter
c. Resonance of frame structure and enclosure
d. Integrity, mass, and configuration of the base mounting structure
e. Reflection of sound and vibration originating in or at the load and shaft coupling
f. Windage

It is recognized that it is a goal that motors applied on inverter type supply systems for variable speed service should be designed and applied to optimize the reduction of sound and vibration in accordance with the precepts explained above. However, since many of these influencing factors are outside of the motor itself, it is not possible to address all sound and vibration concerns through the design of the motor alone.

31.4.5.3 Torsional Considerations

When an induction motor is operated from an inverter, torque ripple at various frequencies may exist over the operating speed range. Consideration should be given to identifying the frequency and amplitude of these torques and determining the possible effect upon the motor and the driven equipment. It is of particular importance that the equipment not be operated longer than momentarily at a speed where a resonant condition exists between the torsional system and the electrical system (i.e., the motor electrical torque). For example, if the inverter is of the six-step type, then a sixth harmonic torque ripple is created that would vary from 36 to 360 Hz when the motor is operated over the frequency range of 6 to 60 Hz. At low speeds, such torque ripple may be apparent as observable oscillations of the shaft speed or as torque and speed pulsations (usually termed “cogging”). It is also possible that some speeds within the operating range may correspond to the natural mechanical frequencies of the load or support structure, and operation other than momentarily should be avoided at those speeds.

31.4.6 Bearing Lubrication at Low and High Speeds

Successful operation of the bearings depends on their ability to function within acceptable temperatures. Above a certain operating speed, depending on the design, size, and load, the losses in an oil-lubricated sleeve bearing may increase to a point that the temperature exceeds the permissible limits with self-lubrication. Below a certain speed, self-lubrication may not be adequate and may result in abnormal wear or high temperature or both. In either case, forced lubrication will be required.

Grease-lubricated antifriction bearings do not have similar problems at low speeds. Maximum operating speed for these bearings is limited because of temperature considerations and is a function of the bearing design, its size, the load, and other considerations.

The maximum and minimum operating speeds should be taken into consideration in the selection of the bearing and lubrication systems for motors covered by this part.

31.5 Nameplate Marking

31.5.1 Variable Torque Applications

The following minimum information necessary to characterize the motor for variable torque applications in which the maximum operating speed does not exceed the speed corresponding to the base rating point

(3) defined in Figure 31-1 shall be given on all nameplates. All performance data is to be based on a sine wave power supply. For some examples of additional information that may be included on the nameplate, see 1.70.2.

a. Manufacturer's name, serial number or date code, type, frame, and enclosure
b. The following data corresponding to base rating point (3) defined in Figure 31-1
  1) Horsepower
  2) Voltage
  3) Current
  4) Speed—rpm
  5) Frequency
c. Number of phases
d. Ambient temperature—degrees C
e. Insulation class
f. Duty rating

31.5.2 Other Applications

For applications other than variable torque, the appropriate items selected from the following list should be given in addition to that stated in 31.5.1.

a. The following data corresponding to base rating points (1), (2), or (4) defined in Figure 31-1
  1) Horsepower
  2) Voltage
  3) Current
  4) Speed—rpm
  5) Frequency
  6) Torque
b. Equivalent circuit parameters for R1, R2, X1, X2, Xm (see 1.60.6) in ohms per phase (Wye equivalent) at 25°C for the base rating. For reconnectable winding multi-voltage motors, the parameters are to be based on the higher voltage connection.
c. Rotor Wk^2

31.6 Tests

31.6.1 Test Method

The method of testing definite purpose inverter-fed motors shall be in accordance with IEEE 112.

31.6.2 Routine Tests

a. Measurement of winding resistance.
b. No-load readings of current, power, and speed at base rating voltage and frequency (point (3) of Figure 31-1) using sinusoidal voltage. For motors with the base rating at other than 60 Hz, these readings shall be permitted to be taken at 60 Hz at the appropriate voltage for 60 Hz.
c. High-potential test in accordance with 3.1, 12.3, or 20.17.

31.6.3 Performance Tests

Performance tests, when required, shall be conducted on a sinusoidal power supply unless otherwise specified by mutual agreement between the manufacturer and the user.

31.7 Accessory Mounting

When provided, a Type FC face for the mounting of tachometers, resolvers, encoders, or similar accessories on the end opposite the drive end of definite purpose inverter-fed motors shall be per 4.4.5 based on FAK dimensions of 4.50 or 8.50 in.

Care should be used in the selection of the accessory coupling to ensure it is able to accommodate any misalignment likely to be encountered in the assembly. If the driven accessory is a tachometer, resolver, or encoder, it also may be necessary to ensure that the coupling has adequate torsional stiffness for the desired response, resolution, and stability in the intended application.

If the motor has an insulated bearing or similar means to guard against bearing currents (see 31.4.4.3), it may be necessary to provide an insulated coupling or other means to prevent such shaft potentials from being applied to connected accessories.

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