PDHonline Course E437 (4 PDH)

Voltage Frequencies & Levels Variations and Foreign Electrical Systems

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CHAPTER 1
INTRODUCTION

1-1. Purpose.

This course provides guidance required to identify the voltage and frequency standards of various foreign countries for both medium and low voltage systems. It also identifies the classes of equipment that are sensitive to voltage and frequency differences. Foreign countries around the world use different electrical standards for voltage and frequency than those of the United States. Some electrical equipment will operate properly at an electrical frequency of either 50 or 60 Hz. Equipment designed for 60 Hz that will not operate properly at 50 Hz is termed “50 Hz sensitive,” and equipment designed for 50 Hz that will not operate properly at 60 Hz is termed “60 Hz sensitive.”

1-2. Scope.

This course identifies the classes of electrical equipment that are sensitive to frequency and voltage variations. Appendix B covers identification of various low and medium voltage levels, along with the system frequencies, used by countries around the world. Derating factors are discussed and developed for the six generic types of equipment in chapter 3. Appendix C summarizes the derating factors presented in chapter 3 for different voltage and frequency environments.

1-3. References.

Appendix A contains a list of publications referenced in this course.

CHAPTER 2

EQUIPMENT SENSITIVE TO FREQUENCY AND VOLTAGE LEVELS

2- 1. Theoretical overview.

Equipment sensitive to frequency and or voltage is designed to operate within certain tolerances. Most equipment is sensitive to large changes in the supply voltage level because more current will flow through a device when the voltage level of the supply is increased (the current through the device is equal to the voltage across the device divided by the impedance of the device). When a larger current flows, the heat dissipated in the device increases (the heat dissipated by the device is proportional to the square of the current). Thus, doubling the voltage will typically double the current, resulting in the device dissipating four times the heat. Most devices cannot tolerate this amount of heat and cannot operate reliably with a supply voltage level more than 10 percent or so higher than their rated voltage.

a. An additional complication arises in the case of devices that use magnetic coupling. Since most electrical equipment depends on a magnetic field as the medium for transferring and converting energy, the following paragraphs discuss a basic transformer to explain how the magnetic circuit depends on the frequency and amplitude of the applied voltage.

b. A transformer enables electrical energy to be transferred with high efficiency from one voltage level to another at the same frequency. Consider a simplified view of a transformer with a sinusoidal voltage source, v, applied to the primary circuit and the secondary circuit open, as shown in figure 2-1. The operation of the transformer depends on several natural laws including the following:

(1) A sinusoidal, time-varying flux, Φ, linking a conducting circuit produces a voltage, e, in the circuit proportional to dv/dt (i.e., Faraday's law of induction).

(2) The algebraic sum of the Voltages around any closed path in a circuit is zero (i.e., Kirchhoff's voltage law).

(3) The voltage, v, in a circuit induced by a changing flux is always in the direction in which current would have to flow to oppose the changing flux (i.e., Lenz's law).

c. When the sinusoidal voltage, v, is impressed onto the primary electrical winding of N1 turns, it is expected that a sinusoidal current, I, will begin to flow in the circuit, which in turn will produce a sinusoidally varying flux, Φ. For simplicity, it is assumed that all of the flux set up by the primary circuit lies within the transformer's iron core and it therefore links with all the turns of both windings. If the flux at any instant is represented by the equation:

$\Phi = \Phi_m \sin 2\pi f t$

where:
Φ_m = the maximum value of the flux
f = the frequency
t = time,

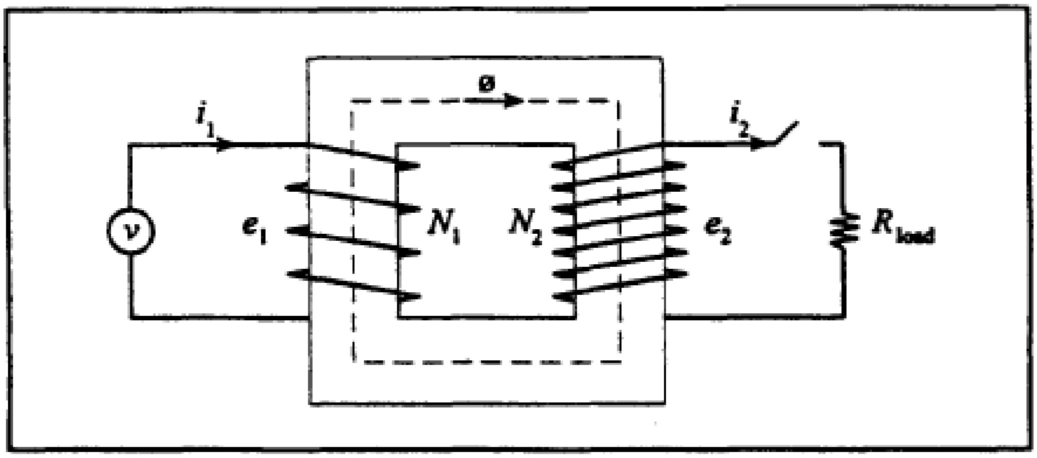

Figure 2-1 Simplified two-winding transformer

it follows from Faraday's law (i.e., $e = N\, d\Phi/dt$) that the instantaneous voltage e_1 induced in the primary winding is:

$e_1 = 2\pi f N_1 \Phi_m \cos 2\pi f t$

The polarity of e_1 will be according to Lenz's law, and hence will be in opposition to the impressed voltage, v (figure 2-l). The root mean square (rms) value of e_1 is:

$E_1 = (2\pi/\sqrt{2})\, f N_1 \Phi_m = 4.44 f N_1 \Phi_m$

d. Remembering Kirchhoff's voltage law, and assuming that the winding resistance is relatively small, E, must be approximately equal to V, where V represents the rms value of the applied voltage. One important result from this equation is that the value of the maximum flux, Φ_m, is determined by the applied voltage. In other words, for a given transformer, the maximum value of the flux is determined by the amplitude and frequency of the voltage applied to the primary winding. The same flux that caused E_t in the primary winding will also induce a voltage across the terminals of the secondary winding. Thus, the only difference in the rms values of the two voltages will come from the difference in the number of turns. if the secondary winding has N_2 turns, the secondary voltage can be written as:

$E_2 = 4.44 f N_2 \Phi_m$

Dividing Equation 3 by Equation 4 gives the familiar relationship:

$E_1/E_2=N_1/N_2$

e. Consider next when the transformer is loaded with a resister R_{Load} by closing the switch in the secondary circuit. If the core flux is in the direction indicated (with the flux increasing), then by Lenz's law, the polarity of E_2 will be such that current It will flow in the secondary winding in attempt to decrease the core flux. The amount of secondary current that will flow will depend on the value of R_{Load} (that is, $I_2 = E_2 / R_{Load}$), and the power delivered to the load will equal $E_2 * I_2$. It is important to understand the mechanism by which the power is transferred from the primary circuit to the load. Consider a situation when current is suddenly allowed to flow in the secondary winding by closing the switch. As mentioned previously, the action of this current will be to decrease the core flux. Decreasing the core flux would lower the value of E_1, which would be in violation of Kirchhoff's voltage law (KVL). Since KVL must be satisfied, more current must flow in the primary winding. The steady-state result is that the primary current will increase to the value sufficient to neutralize the demagnetizing action of the secondary current. It is important to realize that the resultant flux in the core remains the same regardless of the loading on the transformer. If the level of core flux were to vary with load, then E_l and E_2 would also vary, which is contrary to what is observed in practice.

f. An iron core is used in transformers because it provides a good path for magnetic flux and directs the flux so it predominantly links all of the turns in each winding. However, the core has its limitations and can carry only so much flux before it becomes saturated. Core saturation occurs when all of the magnetic domains of the iron align, resulting in a condition in which no further increase in flux density over that of air can be obtained. Consider the magnetizing curve in figure 2-2, showing flux versus magnetizing current, where the magnetizing current i_m, is the steady-state component of current required to establish flux level in the iron core of the transformer. It is typical for a transformer, or any other magnetic circuit, to be designed for operation close to the "knee" of this curve (i.e., Φ_{max}) to use as much of the iron core as possible. Beyond Φ_{max}, the iron saturates and it becomes extremely difficult to increase the flux level. The curve implies that forcing the iron core into saturation can result in a significant increase in the value of magnetizing current, and hence, can cause the windings to become overloaded and the transformer to overheat.

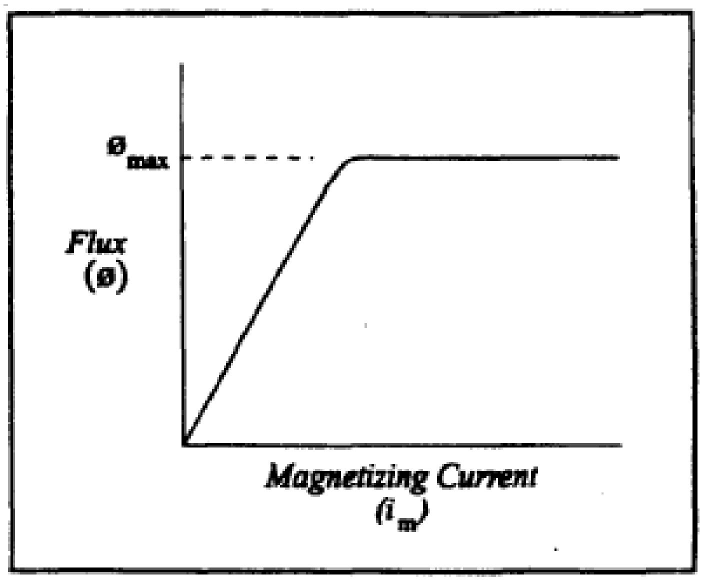

Figure 2-2. Magnetization curve for the transformer's iron core

g. This course is concerned primarily with equipment sensitive to 50 Hz and voltage levels since the equipment will be used overseas where voltage frequencies and levels typically ore different from those in the United States. This equipment could be listed by item, but a more useful format results when it is divided into classes and subclasses of equipment from which manufacturers for specific pieces of equipment can be easily selected. Following this format, listed below are the brood classes of equipment sensitive to 50 Hz and building voltage levels. Each section contains specific classes and sub classes of equipment. Additionally, each section describes why the equipment is sensitive to voltage frequency and or level. Equipment that does not readily fit into any other category is listed in paragraph 2-8.

2- 2. Heating, ventilation, and air-conditioning (HVAC).

HVAC equipment includes boilers, furnaces, water chillers, humidifiers, fans, compressors, evaporators, and related equipment. Certain issues must be considered when using HVAC equipment in 50 Hz and alternate voltage environments, including the motor speed and step-down transformers for power supplies.

a. The objective of on HVAC system is to provide the necessary heating and cooling to a building according to the design specifications. Typically, alternating current (AC) motors are used in HVAC systems to drive fans, pumps, and compressors. When 60 Hz motor is run off a 50 Hz supply, the shaft speed of the motor is reduced by 5/6 since the motor speed is directly related to the frequency of the applied voltage. This speed will affect all direct-drive applications. For example, a pump that is directly coupled to the motor shaft will transfer less fluid over time if the shaft speed is reduced. Consequently, direct-drive HVAC applications must be derated to account for the reduced motor speed. However, for driven equipment that is tied to the motor through adjustable pulleys, the speed of the driven device con be increased to the necessary level.

b. Regardless of how the driven equipment is coupled to the motor, the 60 Hz motor must still operate within its rating in the 50 Hz environment. For the motor to deliver the some mechanical power at a lower speed, it must deliver more torque since output power equals torque times the shaft speed. If the motor delivers more torque, more current will flow in the motor and on overloaded condition may result. Hence, a 60 Hz motor may have to be derated to handle the extra current flow.

c. Another concern with operating a 60 Hz motor with a 50 Hz voltage source is with saturating the iron core of the motor. Like the transformer, the maximum value of flux in the core depends directly on the amplitude of the applied voltage and inversely on the frequency. Assuming that the some voltage level is applied to the 60 Hz motor in the 50 Hz environment, the reduction in frequency to 50 Hz would require an increase in core flux of 20 percent (that is, 6/5 of its 60 Hz level). If the iron core of the motor is unable to provide the extra flux, the core will saturate, and a significant increase in the stator currents can result, causing the motor to overheat.

d. Step-down transformers typically are needed to transform local voltage levels to the levels the equipment is designed for. In most cases, the equipment contains some sort of step-down transformer that typically has to be changed to convert the higher input voltage to the some output voltage. In cases where no step-down transformer is in the equipment, one must be added to avoid burning out components by subjecting them to a higher supply voltage. Determining the need for a step-down transformer and adding it to the equipment is easily accomplished, and is discussed further in chapter 3. Equipment that cannot be purchased with the precise specifications needed must be purchased in U.S. specifications and then denoted as described in chapter 3.

2-3. Electrical distribution and protection.

Electrical distribution equipment includes transformers, panelboards and switchboards, generators, transfer switches, capacitors, and related equipment. Electrical protection devices include fuses, circuit breakers, relays, reclosers, and contactors. The devices have different sensitivities to supply voltage and frequency, and are discussed below.

a. *Electrical distribution.* As mentioned earlier, transformers are sensitive to the frequency and amplitude of the supply voltage. Using a 60 Hz transformer in a 50 Hz electrical environment can cause the core of the transformer to saturate, overheating the transformer. Other than the potential problem with saturation, the transformer should be fully capable of supplying the nameplate rated load. Most transformers are available in 50 Hz or 50/60 Hz configurations, so saturation should not be a problem.

(1) Panelboards, switchboards, and load centers are generally not sensitive to supply frequency, except when protective devices such as circuit breakers are included in them. These items can be acquired readily in a wide variety of voltage ratings; therefore, supply voltage does not pose a problem.

(2) General output voltage can be increased or decreased by using on appropriate transformer. However, since generators are typically used to supply backup power when the utility power source fails, and or are used in addition to the utility power source, it is necessary for the generator to provide o 50 Hz voltage source to match the utility supply. Therefore the user must purchase a generator configured for 50 Hz operation.

(3) Automatic source transfer switches are sensitive to supply voltage frequency and amplitude because they are electronically controlled and hove power supplies that expect to operate on 60 Hz and rated voltage. Once again, supply voltage level is not a problem since transformers are available to adapt voltage levels. Supply frequency, however, may be a problem depending on the type of power supply the electronics use.

(4) Related equipment includes meter centers, and sockets or receptacles. Meter centers are sensitive to voltage level and frequency. Consequently, using a 60 Hz meter center in a 50 Hz environment may result in inaccurate readings. However, meters are readily available in a variety of voltage levels and 50 Hz configurations.

(5) Sockets or receptacles are needed when foreign consumer products are to be used with the power system. Receptacles are configured for different voltage levels, and these configurations vary in different countries. It is important that the standard receptacle style for a given voltage be used to avoid confusing the user and creating a potential safety hazard.

(6) Capacitors are used in on electrical distribution system to adjust the power factor or phase angle between the voltage and current waveforms. It is desirable to

have a phase angle close to zero, or a power factor close to one so that most of the power transferred to the load is real power. Real power is the only part of the total kilovolt-amperes transferred that can do work. The balance is called reactive power and cannot do any useful work. The operation of a capacitor depends on the supply frequency, since a capacitor’s impedance, X_c, is related to the capacitance and frequency of the current passing through it by the equation $X_c = 1/(j2\pi f\,C)$, where C is the capacitance in farads and j equals the square root of -1.

b. *Electrical protection.* Electrical protection devices vary in their sensitivity to supply frequency. All protection devices are available in a wide range of voltage ratings so the level of the supply voltage is not a concern. The main concern with protection devices is the change in response time from 60 Hz to 50 Hz. These devices are coordinated to protect the distribution system from faults (shorts or spikes) but are connected so they do not trip when anticipated voltage spikes (that is, motor starting) occur. The power system design engineer must be sure to use the proper trip curves for the environment when coordinating protective devices. Trip curves for 50 Hz are readily available from vendors. The only device designed differently for 50 Hz and 60 Hz is the circuit breaker.

2-4. Medium voltage distribution equipment: 50 Hz to 60Hz.

In this section medium voltage transformers, switchgear and associated auxiliary devices will be examined with respect to frequency and voltage changes.

a. *Medium voltage distribution transformers.* Distribution transformers are key components in any electric power distribution system. It is important that they are properly matched to their environment. Issues related to operating a 60 Hz transformer from a 50 Hz power source were discussed earlier in this course. The emphasis here will be on discussing issues concerning operating 50 Hz transformers in a 60 Hz environment.

(1) An important parameter to consider when operating a transformer, or other iron core based devices, is the ratio of amplitude to frequency of the applied voltage. The ratio obtained using the nameplate rated voltage and frequency should be compared with the ratio available at the proposed site. If the ratio is less than or equal to that obtained using the nameplate quantities, magnetic saturation will not be a problem at the new site. Any time the ratio is higher than nameplate, the manufacturer should be contacted to ensure that the transformer has enough reserve available to accommodate the increase in operating magnetic flux density.

(2) For example, consider a transformer that is brought over from Germany where it was used on a 10 kV, 50 Hz distribution system. It was determined that the electrical insulation system of the transformer was rated for 15 kV. It is desired to use the transformer on 13.8 kV, 60 Hz system. Considering the magnetic circuit, the volts-per-hertz ratio of the 50 Hz transformer is 200 (i.e., 10 kV/50 Hz). On the new supply the ration would be increased to 230 (that is, 13.8 kV/60 Hz), requiring

a higher magnetic flux density in the iron core. This increase could potentially saturate the iron core and overheat the transformer. Alternatively, this transformer could be used on a 7.2 kV/60 Hz system (120 volts-per-hertz ratio), where saturation would not be a problem.

(3) A few words should be mentioned concerning iron core loss in transformers. The two primary components of core loss are eddy-current loss and hysteresis loss. Eddy-current loss is the term used to describe the power loss associated with circulating currents that are found to exist in closed paths within the body of an iron material and cause undesirable heat production. Hysteresis loss represents the power loss associated with aligning and realigning the magnetic domains of iron in accordance with the changing magnetic flux. Both components are dependent on the frequency, as shown in the following equations:

$$P_{\text{eddy-current}} = K_e f^2 B_m^2 \tau^2 v$$

$$P_{\text{hysteresis}} = K_h f B_m^2 v$$

where,
K = constant value dependent upon material
f = frequency of variation of flux
B = maximum flux density
v = total volume of the material
τ= lamination thickness.

(4) It should be noted that, even though frequency increases when using 50 Hz transformers on a 60 Hz- based system, the voltage-to-frequency ratio will typically be lower, and hence, the maximum flux densities B will be lower. The result is that core-losses will generally not increase as a result of the higher frequency used.

(5) Other key parameters are voltage and current. To maintain insulation system integrity, rated voltage and/or current for the transformer should not be exceeded. A transformer can be operated on lower than rated voltage; however, its current rating must not be violated. Also, the secondary voltage must be matched to the proper voltage levels.

(6) In addition to having an iron core, windings, and insulation system, distribution transformers may include tap changers and auxiliary devices. Auxiliary devices might include fans, current transformers, pressure relief devices, and lighting arresters. Once again, attention should be focused on devices that use a magnetic field for transferring or converting energy, such as instrument transformers and small motor drives. Even if the voltage-to-frequency ratio is found to be lower, manufacturers should be contacted to make sure that all linear and rotating drive mechanisms will develop adequate force and torque to function properly.

b. *Medium voltage switchgear*. Switchgear is a general term covering switching and interrupting devices alone, or their combination with other associated control, metering, protective, and regulating equipment. Common switchgear components include the power bus, power circuit breaker, instrument transformers, control power transformer, meters, control switches, protective relays and ventilation equipment. The ratings of switchgear assemblies are designations of the operational limits under specific conditions of ambient temperature, altitude, frequency, duty cycle, etc. For example, the performance of some 50 Hz magnetic type circuit breakers may be altered slightly when operated on a 60 Hz power system. Switchgear manufacturers should always be consulted to identify the frequency response of circuit breakers and all auxiliary devices.

2-5. Safety and security equipment.

Safety and security equipment includes fire detection systems, burglar alarm systems, doorbells, and surveillance systems. This equipment typically operates on low voltage, either alternating current (AC) or direct current (DC), generated initially by a power supply. Acquiring the proper power supply to convert from the supply voltage to the low voltage that these systems expect (typically 6 to 12 VAC or VDC) is the key to proper operation of these systems in foreign environments. Power supplies of 50 Hz/120 VAC usually are available from vendors of these systems, and a transformer can be used to step a 240 VAC supply down to a 120 VAC foreign environment. Therefore, derating is not necessary for these items, although a transformer may be needed to step high voltage supply levels down to 120 VAC for the power supplied to these systems. Most vendors of safety and security equipment can configure their equipment to 50 Hz and a variety of voltage levels.

2-6. Communication equipment.

Communication equipment encompasses public address systems and sound systems, both of which operate on a low-voltage DC supply generated by a power supply. Power supplies are available to operate on 50 Hz and 240 V supply voltages. In cases where only 120/50 Hz supplies are available, a step-down transformer can be used to step a 240 V supply down to 120 V. The vendors contacted in this study have stated that they provide 50 Hz power supplies.

2-7. Lighting.

Lighting can be divided into incandescent, fluorescent, and high intensity discharge (HID) categories. Incandescent lighting is not frequency-sensitive, whereas fluorescent and HID lights are started by a ballast that is sensitive to voltage level and frequency. All types of lighting are sensitive to the supply voltage level and cannot be derated for voltage. For example, subjecting a 120 V incandescent lamp to a 240 V source will result in the lamp burning twice as hot, causing rapid lamp failure. Subjecting the iron core ballast use in many HID and fluorescent fixtures to twice its rated voltage will saturate the ballast and will subject the fixture to much more than its rated current. As with transformers and motors, 60 Hz iron-core ballasts can also be saturated when operated at 50 Hz. At first thought, frequency dependence may not be as much of a problem with electronic ballasts since, in most cases, the AC voltage source is first converted back to a high frequency AC source, and therefore, the voltage source that is actually impressed across the lamp is decoupled from the 60 Hz AC source. However, the power supply used to power the electronics in these ballasts must be capable of 50 Hz operation.

2-8. Other electrical equipment.

Other electrical equipment includes motors, motor starters, computer power supplies, and clocks.

a. Typically, motor starters are sensitive to both supply voltage level and frequency. The most commonly used motor starters consists of a coil, thermal overloads, and a set of contactors (contacts). The thermal overloads, which are essentially circuit breakers, and the contactors are rated to handle a certain amount of current. Since at 50 Hz, a motor of a given horsepower rating will draw more current than an identically-rated motor would draw at 60 Hz, the thermal overloads and the contactors must be sized accordingly.

b. Computer power supplies include voltage regulators, isolation transformers, transient voltage suppressor transformers, computer regulator transformers, and power conditioning transformers. Computer power supplies are sensitive to both frequency and voltage level.

c. Clocks are sensitive to supply frequency and voltage. Clocks rely on the frequency of the supply voltage to keep correct time, so a clock designed for 60 Hz will not keep correct time at 50 Hz. The motor that runs the clock is also sensitive to supply voltage level. Therefore, a clock must either be purchased configured for the supply voltage level, or a transformer must be used to convert the supply voltage level to the clock’s rated voltage level. Clocks cannot be derated for frequency, and therefore clocks designed for 50 Hz must be purchased.

CHAPTER 3

EQUIPMENT DERATING

3-1. Derating under 50 Hz conditions.

Derating factors for 50 Hz operation are developed differently for different types of equipment. Derating factors for HVAC, electrical distribution and protection, safety and security equipment, communication equipment, lighting, and other electrical equipment are discussed below.

3-2. Heating, ventilating, and air conditioning (HVAC) for derating.

The frequency of the supply voltage affects two types of components in HVAC systems: motors and controls. From the discussion in paragraph 2-2, for the same mechanical load and voltage level, a 60 Hz motor will draw 20 percent more current when supplied from a 50 Hz voltage source. This assumes the iron core of the motor does not saturate. Therefore, a 60 Hz motor would have to be capable of handling the increase in current level. However, as was also mentioned in the previous chapter, saturation can be a serious problem when running a 60 Hz motor off a supply frequency of 50 Hz. Developing a derating factor to account for saturation is not possible, since the motor designs vary from vendor to vendor, and hence, the degree of saturation that would occur, if any, would be impossible to predict. Consequently, it is recommended that no horsepower derating be performed, and a 50 Hz motor be purchased.

a. However, if the vendor can guarantee the user that a given 60 Hz motor would not saturate at 50 Hz, then the motor would need only to be derated to handle the 20 percent increase in current level. The amount of horsepower derating required would depend on the motor’s mechanical load, service factor, and thermal limit. The service factor is a measure of how much the motor can be overloaded continuously without exceeding safe temperature limits. The thermal limit is the minimum speed at which an AC motor can be operated with rated amperes, without exceeding safe temperature rise. The thermal limit is important because the motor’s ability to cool itself will be reduced at lower speeds unless, of course, some sort of auxiliary cooling is used. In most cases, however, the minimum shaft speed necessary to exceed the thermal limit is much lower than 1500 revolutions per minute (RPM, for example, for a 4-pole motor), so 50 Hz operation should not be a problem, although the vendor should be contacted for verification. A 60 Hz motor with a 1.20 service factor can be operated safely while overloaded continuously by 20 percent. The same motor can be operated safely with a rated mechanical load and a 50 Hz power supply with no horsepower derating, assuming saturation is not an issue, the thermal limit of the motor is not exceeded, and the same voltage amplitude is applied. However, a 60 Hz motor, with a 1.0 service factor, driving a rated mechanical load would have to be derated for horse power by 20 percent, since it is not capable of handling greater than the rated current. In summary, the user should find out the service factor and thermal limit of the motor to determine the amount of horsepower derating required, and to ensure that the 20 percent increase in current level in the motor does not exceed the motor’s rating (again, assuming saturation is not a concern).

b. Another issue to be considered when purchasing HVAC equipment for a 50 Hz environment is that the motor’s shaft will spin 5/6 as fast as it would with a 60 Hz supply. For a 4-pole motor, the shaft will rotate at roughly 1500 RPM when run off a 50 Hz supply, whereas with a 60 Hz voltage source it will rotate at about1800 RPM. Consequently, equipment that is directly coupled to the shaft of the motor will rotate at 5/6 the speed it would in a 60 Hz environment. Hence, direct drive equipment must be derated to account for the change in speed. In cases where the equipment is indirectly coupled to the motor shaft, through the use of adjustable pulleys for example, the reduction in shaft speed is not as much of a problem since the required speed of rotation can be obtained through the proper adjustment or selection of the pulleys.

c. Additionally, electronic HVAC controls that contain their own power supply may be 50 Hz sensitive. Most of the vendors contacted stated that this typically is not a problem because most controls are frequency-sensitive. If the control are 50 Hz sensitive, they must be purchased in a 50 Hz configuration. The HVAC vendor must be consulted on a case-by case basis to determine if the controls can be used in 50 Hz environments.

3-3. Electrical distribution and protection.

In general, a 60 Hz transformer should not be used with a 50 Hz voltage source because of the potential saturation problem. As with motors, a derating factor cannot be developed to account for saturation because of the many different transformer designs on the market. It is recommended that a 50 Hz transformer be purchased for use with a 50 Hz voltage source. However, if a 60 Hz transformer vendor can ensure that a transformer will not saturate when operated at 50 Hz, the transformer should be fully capable of safely supplying its nameplate rated load (that is, no horsepower derating is required). In terms of the transformer’s equivalent impedance, sometimes used for power system studies (for example, short-circuit and load-flow analysis), the 60 Hz value should be decreased by 5/6 factor to account for the reduction in system frequency.

a. Power factor capacitors rated at 60 Hz must also be derated to 50 Hz. Capacitors do not consume any real power, but they do consume reactive power. The rating given to power factor capacitors is given in units of kilovolt-amperes reactive (KVAR), which indicates the amount of reactive power the capacitor, will consume at the rated frequency. As mentioned in chapter 2, the capacitor’s impedance, X, is inversely related to frequency. If the frequency drops from 60 to 50 Hz, the impedance will increase to 6/5 of its 50 Hz value. Since the KVAR rating equals V^2/Xc, if X, at 50 Hz increases to 6/5 of its 60 Hz rating, the KVAR rating will decrease to 5/6 of its 60 Hz rating when the capacitor is used in a 50 Hz environment. Therefore, a 60 Hz-rated capacitor must have the KVAR rating multiplied by 5/6 to yield its 50 Hz KVAR rating.

b. Other electrical protection and distribution equipment either cannot or should not be derated. Electrical protection devices are generally able to be used at either 50 Hz or 60 Hz, but a different trip curve needs to be used by the power system designer for 50 Hz. These 50 Hz trip curves are readily available from vendors of this equipment, so no derating is necessary. The only exception is that some circuit breakers are designed differently at 50 Hz and 60 Hz.

c. Voltage, current, and power meters can be derated, but this practice is not recommended. A meter should display the true value it is supposed to measure to ensure that the readings are interpreted correctly and that no dangerous situations result. Meters, therefore, should not be derated. Automatic transfer switches use power supplies that may or may not be frequency-sensitive. Vendors must be contacted regarding 50 Hz configuration of these devices. Electrical generators must be purchased already configured to provide a 50 Hz voltage source.

3-4. Safety and security equipment for derating.

Safety and security equipment operate on a low voltage AC or DC source that is generated by a power supply. Some power supplies are sensitive to frequency; others are not. In either case, derating is not necessary since power supplies sensitive to frequency cannot be derated, and power supplies insensitive to frequency do not need to be derated. In cases where the power supplies are sensitive to 50 Hz, vendors are able to ship the equipment with a 50 Hz compatible power supply.

3-5. Communication equipment for derating.

Communication equipment operates on a low-voltage DC supply and does not need to be derated for frequency. Vendors will either ship the units with frequency- insensitive power supplies, or they will configure the units for 50 Hz operation before shipping.

3-6. Lighting for derating.

Incandescent lighting is not frequency-sensitive since this type of lighting consists of a resistive element (the filament), which is not frequency-sensitive. Fluorescent and high intensity discharge (HID) lighting, on the other hand, use a ballast to generate the proper lamp voltage and to limit the current flowing through the lamp. These ballasts are sensitive to frequency. Because of the numerous ballast designs and styles on the market, and the potential saturation problem, a simple derating factor cannot be developed and it is recommended that a vendor supplying 50 Hz-rated ballasts be located.

3-7. Other electrical equipment for derating.

Other electrical equipment consists of motors, motor starters, computer power supplies, and clocks. Motor derating was mentioned earlier in the HVAC section of this chapter. Motor starters are sensitive to frequency as well, but indirectly so. Since a 60 Hz motor will draw 20 percent more current when operated off a 50 Hz voltage source, assuming the same voltage amplitude is applied and there is no saturation problem, the motor starter current rating must be derated by 20 percent to account for the increase in current. Clocks and computer supply equipment are sensitive to frequency and cannot be derated. Clocks rely on the frequency of the supply to keep correct time, so a 60 Hz clock will not keep correct time at 50 Hz. Although derating factors could be developed for clocks, they would be meaningless. Computer power supply equipment cannot be derated due to the way the equipment is constructed.

3-8. Derating under alternate voltage conditions.

As appendix B shows, standard single phase voltages around the world are either in the range of 100-127 VAC or 220-240 VAC. Voltage variations within about 10 percent of an equipment's rated voltage are acceptable, so derating for voltage will only be necessary when a piece of equipment rated for U.S. voltage (approximately 120 VAC) needs to be operated in an environment using 220-240 VAC. This would be a doubling of rated voltage. None of the equipment sensitive to voltage level is capable of surviving this increase without rapid failure. Thus, no derating factors for voltage level are offered. Instead, it is recommended that transformers be used to step the higher voltage level down to a voltage level in the range of 100-127 VAC, which U.S. equipment can tolerate. It has been found, however, that most vendors of voltage-sensitive equipment are able to configure the equipment for 220-240 VAC and corresponding three phase voltage levels.

3-9. Recommendations.

Derating factors were discussed and developed for the six generic types of equipment. Appendix C, which summarizes the discussion of derating factors presented in this chapter, is useful in identifying derating factors quickly and easily. Although this chapter presents derating factors for equipment, it is recommended that, whenever a piece of equipment is to be derated, the vendor be contacted to discuss the derating. It is always preferable to locate a vendor that will supply the equipment with the desired ratings before derating is attempted. The majority of vendors contacted are able to supply equipment rated at 50 Hz and a variety of voltage levels, so derating should be necessary in only a few cases.

3-10. Summary.

Appendix B can be used to rapidly identify the standard frequency and voltage levels in other countries. In cases where cities within a country differ in their electrical standards, the cities are listed separately. For countries in which all cities have the same electrical standards, typically only the capital city is listed. In these cases, assume that all cities in the country have the same electrical standards.

CHAPTER 4

EFFECTS OF VOLTAGE AND FREQUENCY VARIATIONS ON INDUCTION MOTOR PERFORMANCE

4-1. Over and Under Voltage

Three phase and single phase induction motors within NEMA standards are designed to give satisfactory performance on a line voltage up to 10% above or below the rated value. Beyond this range there is some depreciation of certain performance characteristics. The table shown below demonstrates how the performance is affected by a condition of over or under-voltage with rated frequency held constant.

Voltage	Starting and Maximum Torque	Synchro-nous Speed	% Slip	Full Load Speed	Full Load Efficiency	Full Load Power Factor	Full Load Current	Locked Rotor Current	Temp. Rise Full Load	Max. Overload Capacity	Magnetic Noise
120% Voltage	Increase 43%	No Change	Decrease 30%	Increase 1.5%	Small Increase	Decrease 5 to 15 Points	Decrease 11%	Increase 25%	Decrease 5 to 6 °C	Increase 44%	Notice-able Increase
110% Voltage	Increase 22%	No Change	Decrease 17%	Increase 1%	Increase ½ to 1 Points	Decrease 3 Points	Decrease 7%	Increase 10 to 12%	Decrease 3 to 4 °C	Increase 21%	Increase Slightly
Rated Voltage	Rated Performance Values										
90% Voltage	Decrease 1%	No Change	Increase 23%	Decrease 1.5%	Decrease 2 Points	Increase 1 Point	Increase 11%	Decrease 10 to 12%	Increase 6 to 7 °C	Decrease 19%	Decrease Slightly

Table 4-1. Effects of Voltage Variations on Induction Motor Characteristics

It will be noted from above table that the voltage affects the performance qualities in the following manner:

1. The starting or locked rotor torque varies as the square of the applied voltage.
2. The maximum or breakdown torque varies as the square of the applied voltage.
3. The starting or locked rotor current varies directly as the applied voltage.
4. The overload capacity or maximum developed horsepower varies as the square of the applied voltage. This does not mean that the motor can carry this overload continuously without overheating.
5. There is no change in the synchronous speed with a change in voltage.
6. For most standard motors the slip RPM will decrease as the square of the voltage on an overvoltage power supply and conversely will increase as the square of voltage on an undervolatge supply.

It should be noted that the difference between the temperature rise at rated voltage and the temperature rise at over or undervolatge is difficult to generalize as it depends on the type of enclosure, the distribution of losses within the machine and other factors.

Generally totally enclosed, totally enclosed fan cooled or explosion-proof motors will heat up faster than open motors.

4-2. High or Low Frequency

Motors built in accordance with NEMA standards are designed to operate successfully at rated load and rated voltage with a variation in frequency up to 5% above or below the rated frequency. The table shown below demonstrates how the performance is affected by a condition of over or under-frequency with rated voltage held constant.

Frequency	Starting and Maximum Torque	Synchro-nous Speed	% Slip	Full Load Speed	Full Load Efficiency	Full Load Power Factor	Full Load Current	Locked Rotor Current	Temp. Rise Full Load	Max. Overload Capacity	Magnetic Noise
105% Frequency	Decrease 10%	Increase 5%	No Change	Increase 5%	Slight Increase	Slight Increase	Decrease Slightly	Decrease 5-6%	Decrease Slightly	Decrease Slightly	Decrease Slightly
Rated Frequency	Rated Performance Values										
95% Frequency	Increase 11%	Decrease 5%	No Change	Decrease 5%	Slight Decrease	Slight Decrease	Increase Slightly	Increase 5 to 6%	Increase Slightly	Increase Slightly	Increase Slightly

Table 4-2. Effects of Frequency Variations on Induction Motor Characteristics

It will be noted from above table that the frequency affects the performance qualities in the following manner:

1. The starting torque and maximum torque vary inversely as the square of frequency. In other words, the torque will increase as the square of the decrease in frequency and vice versa.
2. The synchronous speed will vary directly the frequency; that is a 50 cycle motor will have 5/6 the synchronous speed of a 60 cycle motor.
3. The locked rotor current will vary inversely as the frequency.

4-3. Both Voltage and Frequency Variations

We have seen how both voltage (with frequency held constant) and frequency (with voltage held constant) affect motor performance. We will examine now how a combination of the two influences operation.

To keep the magnetics flux densities in a motor at the same value for which the motor has been deigned, the voltage and frequency should vary directly with each other; that is, if the voltage is reduced, the frequency should also be reduced. Many 440 volt, 60 cycle motors have been operated at 400 volts, 50 cycles and some at 380 volts, 50 cycles. This is possible because 50 cycle standard motors are usually built in the same frame size as 60 cycle motors for NEMA ratings, although at some increase in temperature rise.

Any increase in temperature rise reduces insulation life. In general, each 10 °C increase in temperature halves the insulation life expectancy. An open motor with its 40 °C rating can usually take more voltage and frequency variations than an enclosed fan cooled motor with its 55 °C rating. Thus considerable caution must be exercised by the user in permitting motors to be used on other than nameplate conditions.

The variation in induction motor performance with variation in voltage and frequency is shown in table 4-3 below.

Voltage-Frequency	Starting and Maximum Torque	Full Load Torque	Synchro-nous Speed	Full Load Efficiency	Full Load Power Factor	Full Load Current	Locked Rotor Current	Heating	Magnetic Noise
440-60	100%	100%	100%			100%	100%	100%	
380-50	100%	120%	83%	Decrease 2 Points	Decrease 1 Point	130%	100%	145%	No Change
400-50	110%	120%	83%	Decrease 1 Point	Decrease 1 Point	120%	105%	135%	Slight Increase
420-50	121%	120%	83%	Decrease 2 Points	Decrease 2 Points	117%	110%	130%	Increase

Table 4-3. Effects of Voltage and Frequency Variations on Induction Motor Characteristics

The above data is, of course, approximate and does not include effects of saturation. The heating figures are very approximate and are included merely to give some idea of the magnitude of temperature increase.

4-4. Unbalanced Voltages

We will now examine the operation of Polyphase squirrel cage induction motor on systems having unbalanced voltages. The problem could be tackled by modeling the induction motor utilizing mathematical techniques, but for a specific situation is rather long and tedious. Certain general relations, however, can be concluded from the work that has already been done.

The theoretically exact definition of voltage unbalance is rather involved. However, within the range of limits which are satisfactory for successful motor operation, the following definition gives results which are fairly accurate.

"The percentage voltage unbalance may be defined as 100 times the sum of deviation of the three voltages from the average without regard to sign, divided by twice the average voltage."

This can be illustrated by the following example of 220 volt system. If the voltages between lines of an unbalanced system are 216, 223, and 227 volts, the percentage unbalance is calculated as follows:

$$\frac{(222-216)+(223-222)+(227-222)}{2\times 222}\times 100 = 2.70\%$$

The effect of voltage unbalance on the following will now taken up individually.

Current

In general a small voltage unbalance on any type of induction motor results in a considerably greater current unbalance. For a given voltage variation the current variation is greatest at no load and decreases loading with the least effect being exhibited under locked conditions. This phenomenon is conveniently shown in the following graph. The band indicates the spread is likely to be encountered.

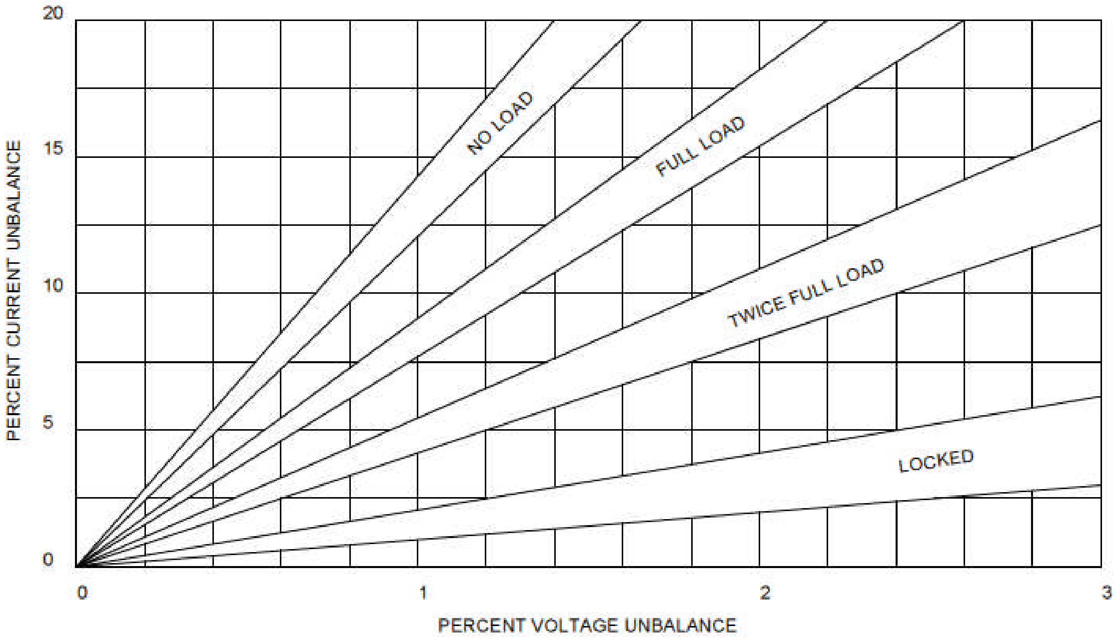

Figure 4-1. Percent Current vs. Voltage Unbalance

Torque

Voltage unbalance within tolerable limits does not affect induction motor torques appreciably either at locked or at breakdown.

The locked rotor torque, however, actually is reduced as the square of the voltage unbalance; that is:

$$\frac{Locked\ Rotor\ Unbalance}{Locked\ Torque\ Balance} = 1 - (\frac{\%\,Voltage\ Unbalance}{100})^2$$

Hence, for a 30% voltage unbalance there is 9% reduction in locked torque. The reduction in the breakdown torque is even more noticeable, and a voltage unbalance of 30% may amount to as much as a 15 to 20% reduction in the breakdown torque. Of course, a 30% voltage unbalance is entirely unacceptable.

Speed

When the voltage unbalance is kept within tolerable limits, the speed is not affected appreciably. The tendency, however, is to slightly decrease the speed.

Temperature Rise

Temperature rise is increased greatly by a small voltage unbalance. No hard or fast rules can be given, but the percent increase in temperature rise is usually about twice the square of the percent voltage unbalance; that is:

$$\frac{Temp.\ Rise\ on\ Unbal.System}{Temp.\ Rise\ on\ Bal.System} = 1 + \frac{2\ (\%\,Volt\ Unbal.)^2}{100}$$

For example assuming 2.7% voltage unbalance, we can calculate the percent increase in temperature rise as follows:

$$\frac{Temp.\ Rise\ on\ Unbal.}{Temp.\ Rise\ on\ Bal.} = 1 + \frac{2\ (2.7)^2}{100} = 1.15$$

Hence, a 2.7% voltage unbalance results in a 15% increase in temperature rise.

On an unbalanced system the largest permissible load can be approximated by dividing the rated load by the ratio found above. For the case of 2.7% voltage unbalance the maximum permissible load amounts to 1/1.15=0.87 of the motor rating.

Overload Protection

The large current unbalance corresponding to a small voltage unbalance introduces a serious problem in selecting the proper overload protection devices. In order to adequately protect the motor under unbalanced voltage conditions, complete information on individual line currents should be referred to the control manufacturer for their recommendation as to the type and size of overcurrent relay heater coils to be supplied.

Single Phase Operation

A common cause for the failure of a polyphase induction motor is due to single phase operation. When inspecting a winding, it can easily be detected if a motor had been single-phased. During the normal operation of the motor; each phase of the motor carries the same normal and equal amount of current. When single phasing happens the remaining two phases carry more current than their ratings. This condition will cause the temperature on the remaining two phases to increase as the square of the current. Within a short period of operation, this will cause the insulation on the remaining phases to completely roast out.

APPENDIX A
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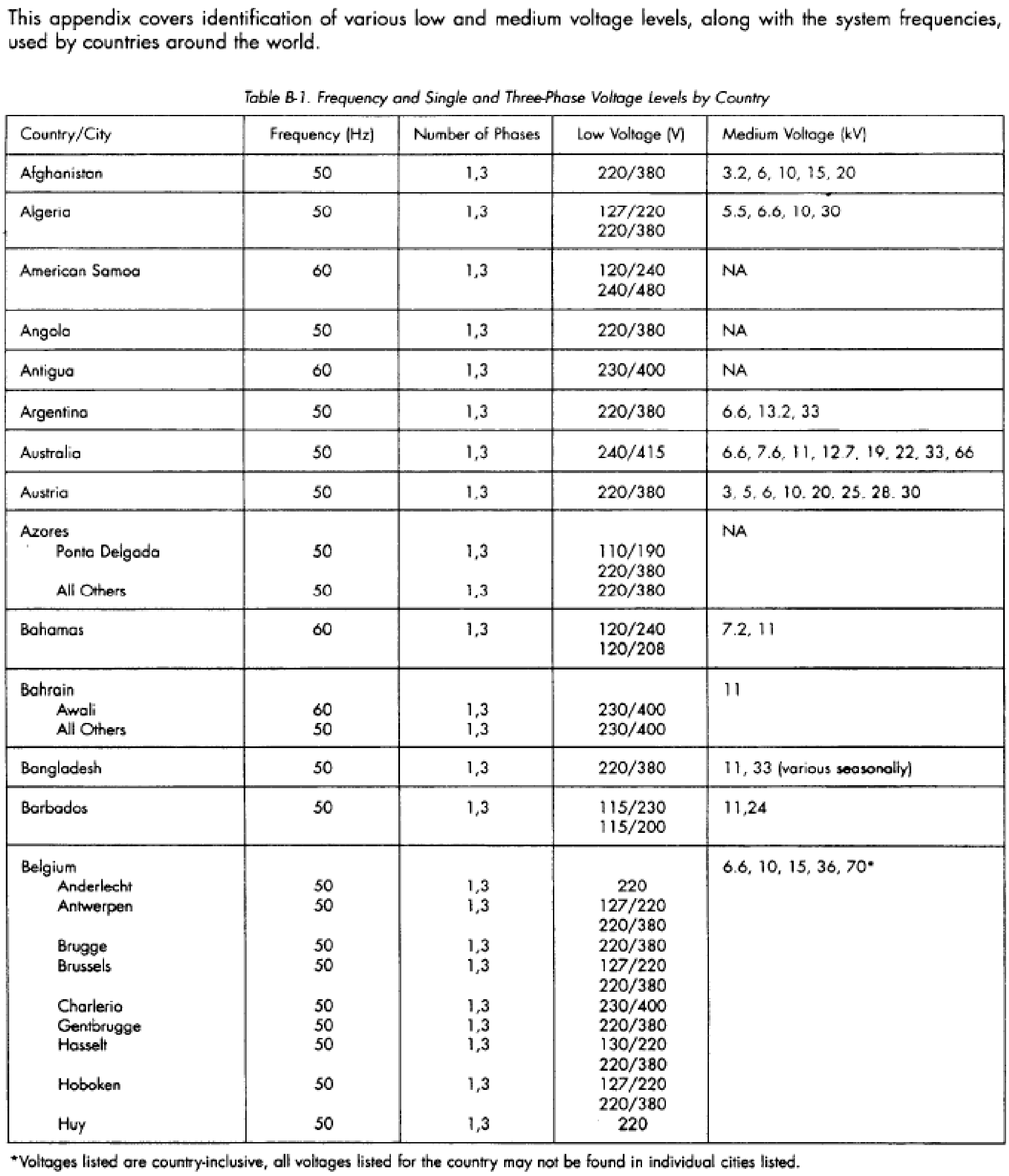
APPENDIX B
Frequency and Single- and Three-Phase Voltage levels by Country



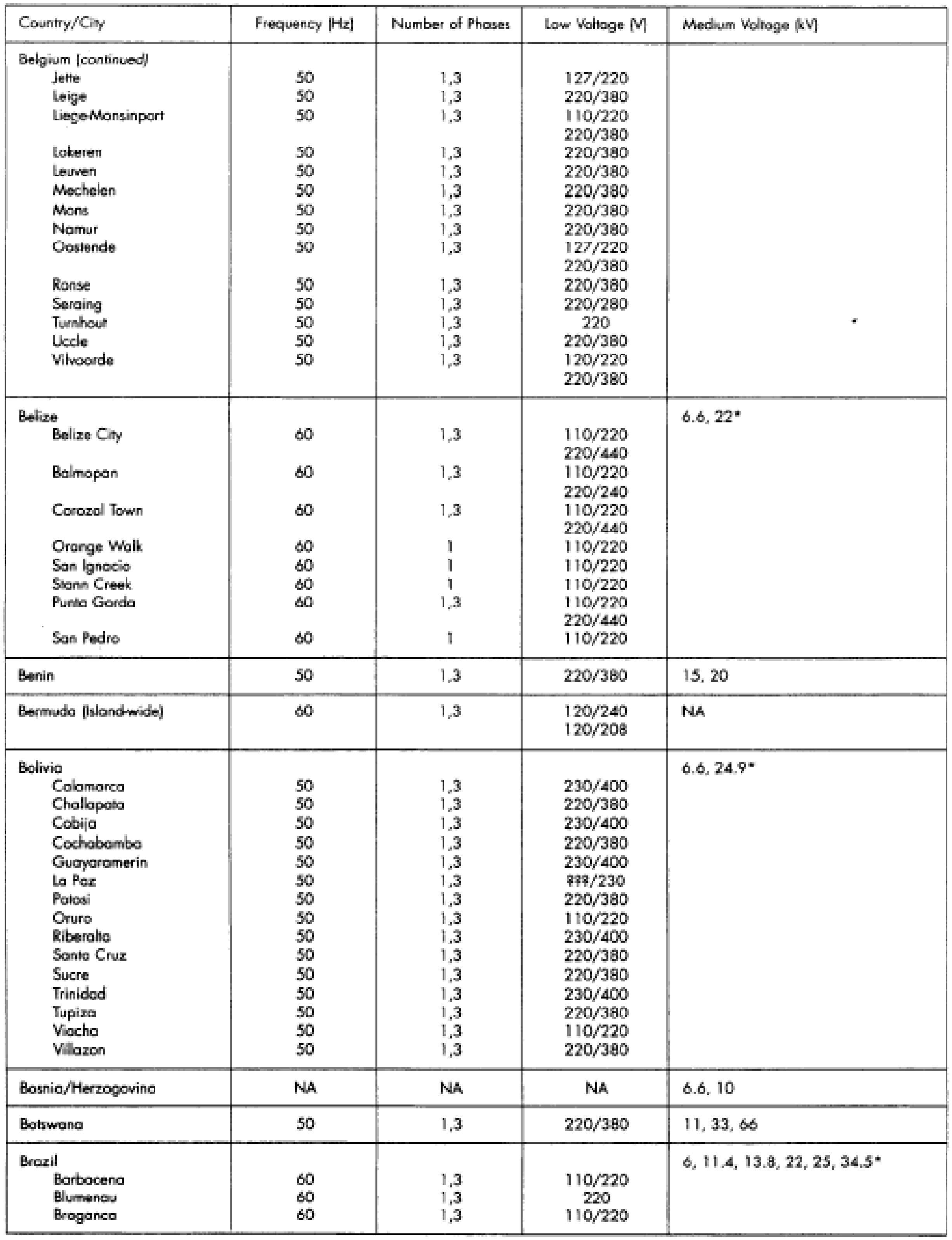
This appendix covers identification of various low and medium voltage levels, along with the system frequencies, used by countries around the world.

Table B-1. Frequency and Single and Three-Phase Voltage Levels by Country

Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
Afghanistan	50	1,3	220/380	3.2, 6, 10, 15, 20
Algeria	50	1,3	127/220 220/380	5.5, 6.6, 10, 30
American Samoa	60	1,3	120/240 240/480	NA
Angola	50	1,3	220/380	NA
Antigua	60	1,3	230/400	NA
Argentina	50	1,3	220/380	6.6, 13.2, 33
Australia	50	1,3	240/415	6.6, 7.6, 11, 12.7, 19, 22, 33, 66
Austria	50	1,3	220/380	3, 5, 6, 10, 20, 25, 28, 30
Azores				NA
Ponta Delgada	50	1,3	110/190 220/380	
All Others	50	1,3	220/380	
Bahamas	60	1,3	120/240 120/208	7.2, 11
Bahrain				11
Awali	60	1,3	230/400	
All Others	50	1,3	230/400	
Bangladesh	50	1,3	220/380	11, 33 (various seasonally)
Barbados	50	1,3	115/230 115/200	11,24
Belgium				6.6, 10, 15, 36, 70*
Anderlecht	50	1,3	220	
Antwerpen	50	1,3	127/220 220/380	
Brugge	50	1,3	220/380	
Brussels	50	1,3	127/220 220/380	
Charlerio	50	1,3	230/400	
Gentbrugge	50	1,3	220/380	
Hasselt	50	1,3	130/220 220/380	
Hoboken	50	1,3	127/220 220/380	
Huy	50	1,3	220	

*Voltages listed are country-inclusive, all voltages listed for the country may not be found in individual cities listed.

Table B-1. Frequency and Single and Three-Phase Voltage Levels by Country–Continued



Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
Belgium *(continued)*				
Jette	50	1,3	127/220	
Leige	50	1,3	220/380	
Liege-Monsinport	50	1,3	110/220 220/380	
Lokeren	50	1,3	220/380	
Leuven	50	1,3	220/380	
Mechelen	50	1,3	220/380	
Mons	50	1,3	220/380	
Namur	50	1,3	220/380	
Oostende	50	1,3	127/220 220/380	
Ronse	50	1,3	220/380	
Seraing	50	1,3	220/280	
Turnhout	50	1,3	220	
Uccle	50	1,3	220/380	
Vilvoorde	50	1,3	120/220 220/380	
Belize				6.6, 22*
Belize City	60	1,3	110/220 220/440	
Balmopan	60	1,3	110/220 220/240	
Corozal Town	60	1,3	110/220 220/440	
Orange Walk	60	1	110/220	
San Ignacio	60	1	110/220	
Stann Creek	60	1	110/220	
Punta Gorda	60	1,3	110/220 220/440	
San Pedro	60	1	110/220	
Benin	50	1,3	220/380	15, 20
Bermuda (Island-wide)	60	1,3	120/240 120/208	NA
Bolivia				6.6, 24.9*
Calamarca	50	1,3	230/400	
Challapata	50	1,3	220/380	
Cobija	50	1,3	230/400	
Cochabamba	50	1,3	220/380	
Guayaramerin	50	1,3	230/400	
La Paz	50	1,3	???/230	
Potosi	50	1,3	220/380	
Oruro	50	1,3	110/220	
Riberalta	50	1,3	230/400	
Santa Cruz	50	1,3	220/380	
Sucre	50	1,3	220/380	
Trinidad	50	1,3	230/400	
Tupiza	50	1,3	220/380	
Viacha	50	1,3	110/220	
Villazon	50	1,3	220/380	
Bosnia/Herzogovina	NA	NA	NA	6.6, 10
Botswana	50	1,3	220/380	11, 33, 66
Brazil				6, 11.4, 13.8, 22, 25, 34.5*
Barbacena	60	1,3	110/220	
Blumenau	60	1,3	220	
Braganca	60	1,3	110/220	

Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
Brazil *(continued)*				
Brasilia	60	1,3	220/380	
Caxias do Sul	60	1,3	220/380	
Cel Fabriciano	60	1,3	110/220	
Corumba	60	1,3	110/220	
Florianopolis	60	1,3	220/380	
Fortaleza	60	1,3	230/400	
Goiania	60	1,3	220/380	
Goias	60	1,3	220/380	
Itajai	60	1,3	220	
Joao Pessoa	60	1,3	220	
Joinville	60	1,3	220/380	
Jundiai	60	1,3	110	
Livramento	60	1,3	220/380	
Londrina	60	1,3	127/220 110/220	
Macapa	60	1,3	110/220	
Maceio	60	1,3	220/380	
Manaus	60	1,3	120/240	
Mossoro	60	1,3	220/380	
Natal	60	1,3	220/380	
Novo Friburgo	60	1,3	220	
Olinda	60	1,3	127/220 220/380	
Paranagua	60	1,3	110/220	
Parnaiba	60	1,3	110/220	
Pelotas	60	1,3	220/380	
Petropolis	60	1,3	127/220 115/220	
Ponta Grossa	60	1,3	220	
Porto Velho	60	1,3	110/220	
Santo Andre	60	1,3	115/230	
Sao Bernaroo do Campo	60	1,3	115/230	
Sao Caetano do	60	1,3	110/220	
Sul	60	1,3	110/220	
Sao Luis	60	1,3	115/230	
Sao Paulo	60	1,3	110/220	
Teresina	60	1,3	125/216	
Volta Rendonda	60	1,3	127/220	
All Others				
Brunei	NA	NA	NA	11, 68
Bulgaria	50	1,3	220/380	NA
Burma/Myanmar	50	1,3	230/400	3.3, 6.6, 11, 33
Burundi	50	1,3	220/380	6.6, 15
Cambodia				4.4, 6.3, 15*
Phnom-Penh	50	1,3	220/380	
Sihanoukville	50	1,3	220/380	
All Others	50	1,3	120/208	
Cameroon				10, 15, 30, 33, 55*
Buea	50	1,3	230/400	
Eseka	50	1,3	127/220	
Maroua	50	1,3	127/220	
Mbalmayo	50	1,3	127/220 220/380	
Nkongsamba	50	1,3	127/220 220/380	
Sangmelima	50	1,3	127/220 220/380	

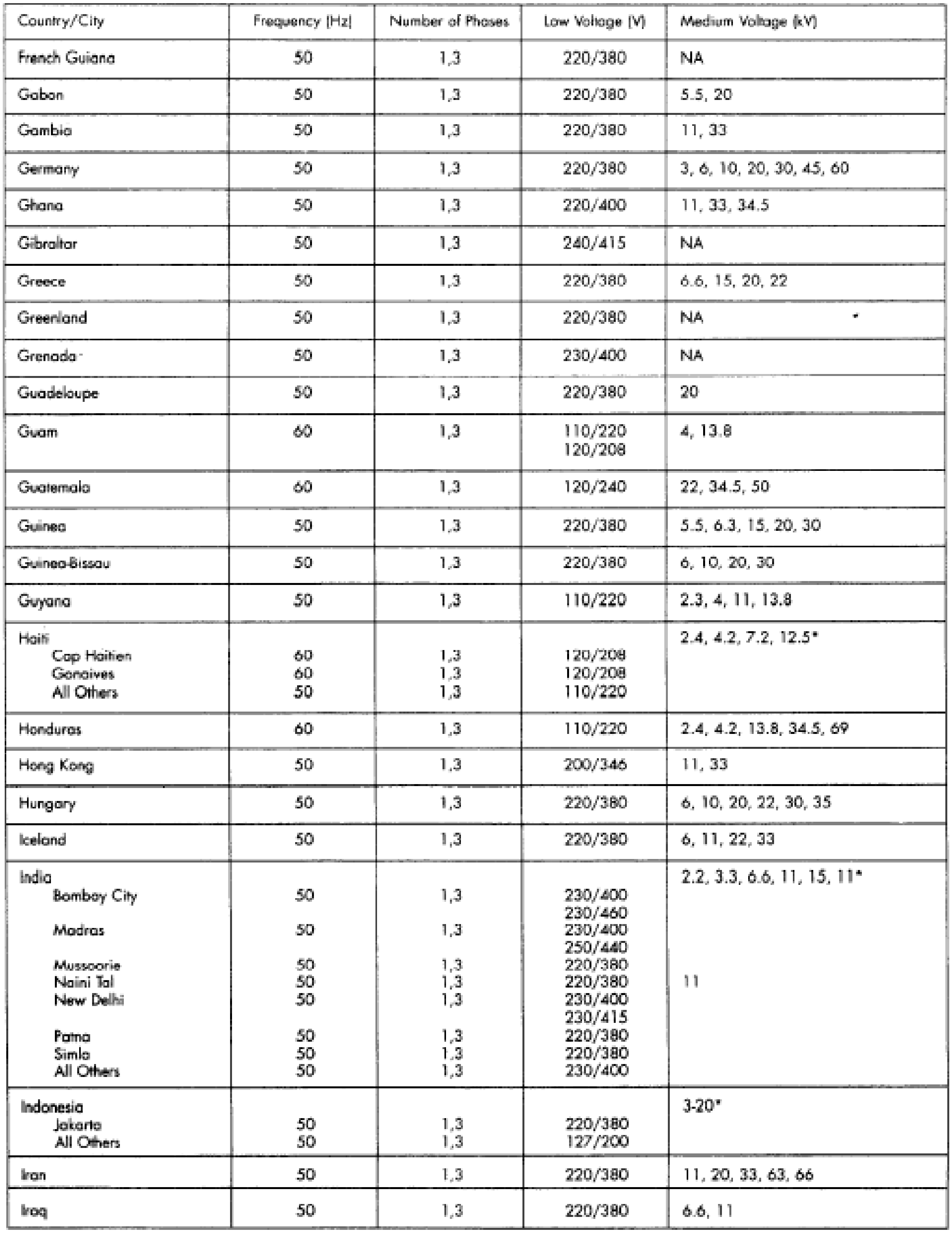
Table B-1. Frequency and Single and Three-Phase Voltage Levels by Country–Continued

Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
Cameroon *(continued)*				
Victoria	50	1,3	230/400	
Yaounde	50	1,3	127/220	
			220/380	
All Others	50	1,3	220/380	
Canada	60	1,3	120/240	2.4, 4.16, 7.2, 8, 12.47, 13.8, 14.4, 20, 25, 34.5, 44, 49
Canary Islands	50	1,3	127/220 220/380	NA
Cape Verde (Praia)	50	1,3	220/380	6, 6.3, 13, 15, 20
Cayman Islands	60	1,3	120/240	NA
Central African Republic	50	1,3	220/380	NA
Chad	50	1,3	220/380	15
Channel Islands				11
Alderney	50	1,3	240/415	
Guernsey	50	1,3	230/400	
Jersey	50	1,3	240/415	
Chile	50	1,3	220/380	12, 13.2, 13.8, 15, 23
China	50	1,3	220/380	10, 20, 35
Colombia				4.16, 7.6, 13.2, 13.8, 33, 34.5, 44*
Bogota	60	1,3	150/240	
Duitama	60	1,3	120/208	
Honda	60	1,3	120/208	
Sogamosa	60	1,3	120/240	
All Others	60	1,3	110/220	
Congo	50	1,3	220/380	5.5, 6.6, 10, 20
Costa Rica	50	1,3	120/240	4.2, 13.2, 24.9, 34.5
Croatia	50	1,3	220/380	10,35
Cyprus	50	1,3	240/415	11
Czech Republic	50	1,3	220/380	6, 10 (urban) 22, 35 (rural)
Denmark	50	1,3	220/380	6, 10, 20, 30
Djibouti	50	1,3	220/380	NA
Dominican Republic	60	1,3	110/220	2.5, 4.16, 12.5
Ecuador				13.8, 34.5, 46, 69*
Cuenca	60	1,3	120/208	
Esmeraldas	60	1,3	120/208	
			120/240	
Guaranda	60	1,3	120/208	
			120/240	
Ibarra	60	1,3	127/220	
Latacunga	60	1,3	120/208	
Loja	60	1,3	127/220	
Machala	60	1,3	127/220	

Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
Ecuador *(continued)*				
Morona	60	1,3	120/208	
Portoviejo	60	1,3	127/220	
Puyo	60	1,3	127/220	
Quito	60	1,3	120/208 127/220	
Riobamba	60	1,3	110/220	
Tulcan	60	1,3	121/210 127/220	
Zamora	60	1,3	121/210 127/220	
All Others			120/208 127/220	
Egypt	50	1,3	220/380	3, 6.6, 11, 20, 33, 66
El Salvador	60	1,3	115/230	4.16, 4.4, 13.2, 23, 34.5
England (see United Kingdom)				
Equatorial Guinea	50	1	220	NA
Ethiopia	50	1,3	220/380	15
Faroe Islands	50	1,3	220/380	NA
Fiji	50	1,3	240/415	11
Finland	50	1,3	220/380	10, 20, 30, 45
France				3.3, 5.5, 10, 15, 20, 30*
l'Alpe d'Huez	50	1,3	127/220 220/380	
Alencon	50	1,3	127/220 220/380	
Amiens	50	1,3	115/220 220/380	
Angers	50	1,3	127/220 220/380	
Angouleme	50	1,3	127/220 220/380	
Annecy	50	1,3	127/220 220/380	
Arcachon	50	1,3	127/220 220/380	
Argenteuil	50	1,3	127/220 220/380	
Asnieres	50	1,3	115/200 220/380	
LaBaule	50	1,3	127/220 220/380	
Besancon	50	1,3	127/220 220/380	
Beziers	50	1,3	127/220 220/380	
Biarritz	50	1,3	127/220 220/380	
Boulogne-sur-Mer	50	1,3	127/220 220/380	
la Bourboule	50	1,3	127/220 220/380	
Bourges	50	1,3	127/220 220/380	
Bourg-En-Bresse	50	1,3	127/220 220/380	

Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
France *(continued)*				
Marseille	50	1,3	115/200 220/380	
Megev	50	1,3	127/220	
Metz	50	1,3	110/190 220/380	
Lemont-Dore	50	1,3	127/220 220/380	
Motlucon	50	1,3	127/220 220/380	
Morzine	50	1,3	127/220 220/380	
Mulhouse	50	1,3	230 220/380	
Nancy	50	1,3	127/220 220/380	
Nantes	50	1,3	110/190	
Neuilly	50	1,3	115/230 127/220 220/380	
Nice	50	1,3	127/220	
Nimes	50	1,3	220 220/380	
Orleans	50	1,3	127/220	
Paris	50	1,3	115/230	
Perpignan	50	1,3	127/220 220/380	
Roanne	50	1,3	127/220 220/380	
LaRochelle	50	1,3	115/200 127/220 220/380	
Roubaix	50	1,3	220/380	
Royan	50	1,3	127/220 220/380	
Saint-Etienne	50	1,3	115/230 127/220 220/380	
Saint-Gervais-Les-Bains	50	1,3	127/220 220/380	
Saint-Jean-de-Lux	50	1,3	380	
Saint Lo	50	1,3	127/220 220/380	
Saint Quentin	50	1,3	127/220 220/380	
Sallanches	50	1,3	127/220	
Strasbourg	50	1,3	125/220 220/380	
Tabes	50	1,3	115/200 220/380	
Toulon	50	1,3	127/220 220/380	
Tourcoing	50	1,3	110/220 220/380	
Tours	50	1,3	127/220	
Val d' Isere	50	1,3	127/220 220/380	
Valenciennes	50	1,3	127/220 220/380	
Valloire	50	1,3	127/220	
Verdun	50	1,3	127/220 220/380	
Versailles	50	1,3	127/220 220/380	
Vichy	50	1,3	127/220 220/380	
Vincennes	50	1,3	127/220 220/380	
All Others	50	1,3	220/380	

Table B-1. Frequency and Single and Three-Phase Voltage Levels by Country–Continued



Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
French Guiana	50	1,3	220/380	NA
Gabon	50	1,3	220/380	5.5, 20
Gambia	50	1,3	220/380	11, 33
Germany	50	1,3	220/380	3, 6, 10, 20, 30, 45, 60
Ghana	50	1,3	220/400	11, 33, 34.5
Gibraltar	50	1,3	240/415	NA
Greece	50	1,3	220/380	6.6, 15, 20, 22
Greenland	50	1,3	220/380	NA
Grenada	50	1,3	230/400	NA
Guadeloupe	50	1,3	220/380	20
Guam	60	1,3	110/220 120/208	4, 13.8
Guatemala	60	1,3	120/240	22, 34.5, 50
Guinea	50	1,3	220/380	5.5, 6.3, 15, 20, 30
Guinea-Bissau	50	1,3	220/380	6, 10, 20, 30
Guyana	50	1,3	110/220	2.3, 4, 11, 13.8
Haiti				2.4, 4.2, 7.2, 12.5*
Cap Haitien	60	1,3	120/208	
Gonaives	60	1,3	120/208	
All Others	50	1,3	110/220	
Honduras	60	1,3	110/220	2.4, 4.2, 13.8, 34.5, 69
Hong Kong	50	1,3	200/346	11, 33
Hungary	50	1,3	220/380	6, 10, 20, 22, 30, 35
Iceland	50	1,3	220/380	6, 11, 22, 33
India				2.2, 3.3, 6.6, 11, 15, 11*
Bombay City	50	1,3	230/400 230/460	
Madras	50	1,3	230/400 250/440	
Mussoorie	50	1,3	220/380	
Naini Tal	50	1,3	220/380	11
New Delhi	50	1,3	230/400 230/415	
Patna	50	1,3	220/380	
Simla	50	1,3	220/380	
All Others	50	1,3	230/400	
Indonesia				3-20*
Jakarta	50	1,3	220/380	
All Others	50	1,3	127/200	
Iran	50	1,3	220/380	11, 20, 33, 63, 66
Iraq	50	1,3	220/380	6.6, 11

Table B-1. Frequency and Single and Three-Phase Voltage Levels by Country—Continued

Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
France (continued)				
Brest	50	1,3	127/220 220/380	
Briancon	50	1,3	115/200	
Cabourg	50	1,3	127/220 220/380	
Caen	50	1,3	127/220	
Calais	50	1,3	115/220 220/380	
Cauterets	50	1,3	127/220	
Chalons	50	1,3	127/220 220/380	
Chateauroux	50	1,3	120/208 220/380	
Chaumont	50	1,3	120/208 220/380	
Cherbourg	50	1,3	127/220 220/308	
Chinon	50	1,3	127/220 220/308	
Clermont-Ferrand	50	1,3	127/220 220/308	
Collioure	50	1,3	127/220 220/380	
Courbevoie	50	1,3	115/230	
Deauville	50	1,3	127/220 220/380	
Dieppe	50	1,3	127/220 220/380	
Dijon	50	1,3	127/220 220/380	
Dinan	50	1,3	127/220 220/380	
Douai	50	1,3	127/220 220/380	
Dreux	50	1,3	127/220 220/380	
Etain	50	1,3	115/200 220/380	
Evreux	50	1,3	127/220	
Fontainbleau	50	1,3	127/220 220/380	
Frejus	50	1,3	127/220 220/380	
Grenoble	50	1,3	127/220	
LeHavre	50	1,3	110/190 127/220 220/380	
Jounge	50	1,3	127/220 220/380	
Juan-les-Pins	50	1,3	127/220	
Lens	50	1,3	127/220 220/380	
Lille	50	1,3	110/220 220/380	
Luchon	50	1,3	127/220 220/380	
Luxeuil-Bains	50	1,3	127/220 220/380	
Lyon	50	1,3	110/220 127/220 220/380	
LeMans	50	1,3	127/220 220/380	
Marly-le-Roi	50	1,3	127/220 220/380	

Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
Ireland	50	1,3	220/380	5, 10, 20, 38
Isle of Man	50	1,3	240/415	NA
Israel	50	1,3	230/400	6.3, 12.6, 22, 33*
Jerusalem	50	1,3	220/380	
Italy	50	1,3	127/220 220/380	3.6, 10, 15, 20, 30, 45, 66
Ivory Coast	50	1,3	220/380	NA
Jamaica	50	1,3	110/220	6.9, 13.8, 24
Japan				3, 6, 6.6, 11, 20, 22, 60*
Chiba	50	1,3	100/200	
Hakodate	50	1,3	100/200	
Kawasaki	50	1,3	100/200	
Muroran	50	1,3	100/200	
Niigata	50	1,3	100/200	
Otaru	50	1,3	100/200	
Sapporo	50	1,3	100/200	
Sendai	50	1,3	100/200	
Tokyo	50	1,3	100/200	
Yokohama	50	1,3	100/200	
Yokosuka	50	1,3	100/200	
All Others	60	1,3	100/200	
Jordan	50	1,3	220/380	6.6, 11, 33
Kenya	50	1,3	240/415	11, 33, 40, 66
Korea	60	1,3	110/220	22.9
	60	1,3	120/208	
	60	1,3	220/380	
	60	1	120/240	
Kuwait	50	1,3	240/415	NA
Laos	50	1,3	220/380	6.6, 22
Lebanon				11, 15, 33*
Tripoli	50	1,3	110/190 220/380	
Zahleh	50	1,3	220/380	
All Other	50	1,3	110/190	
Lesotho	50	1,3	120/240 120/208	11, 33
Liberia	60	1,3	120/240 120/208	7.2, 12.5
Libya				NA
Barce	50	1,3	230/400	
Benghazi	50	1,3	230/400	
Darnah	50	1,3	230/400	
Al Bayda	50	1,3	230	
Sebha	50	1	230	
Tubruq	50	1,3	230/400	
All Other	50	1,3	127/220	
Luxembourg	50	1,3	120/208 220/380	5, 15, 20, 65

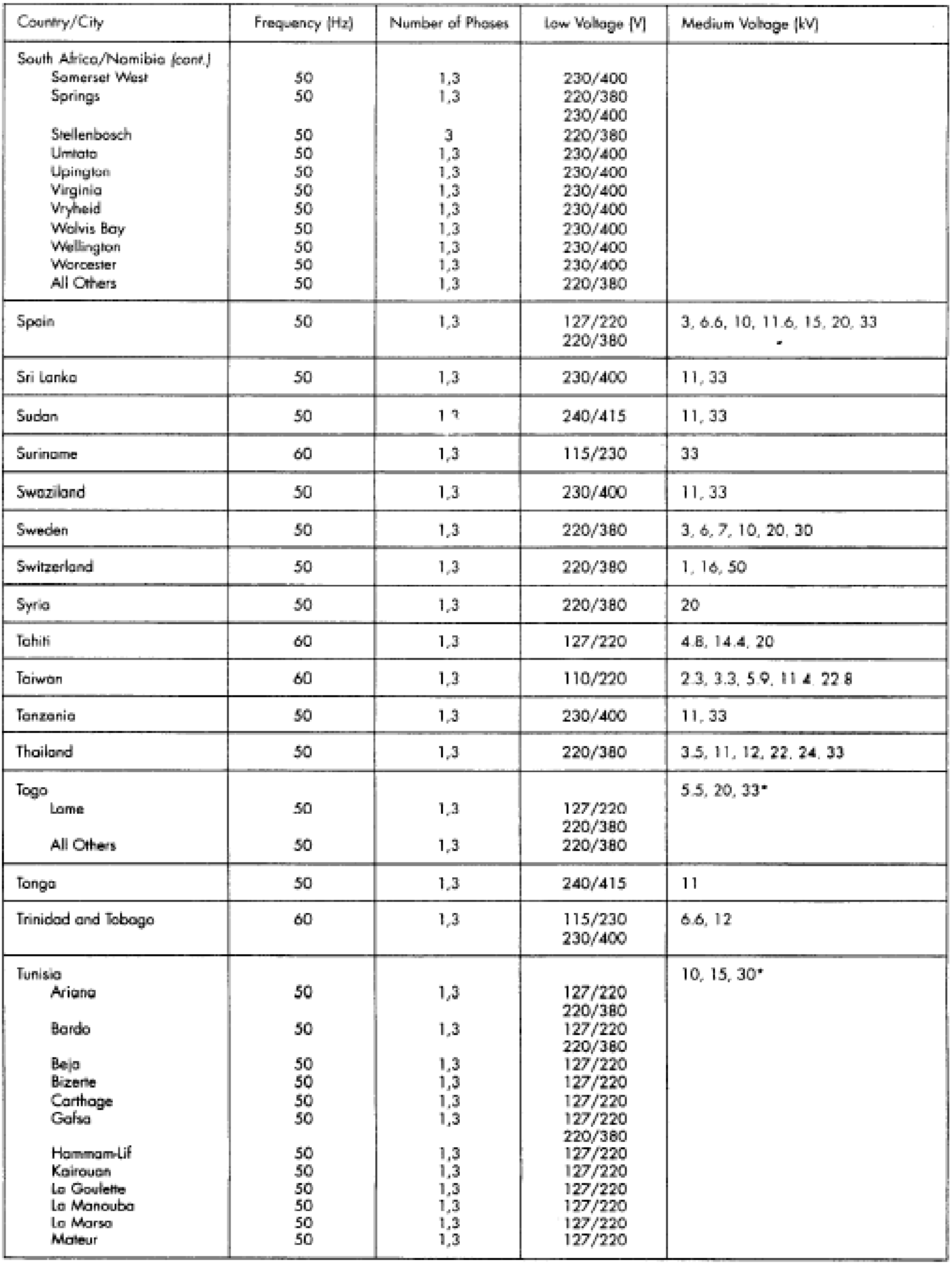
Table B-1. Frequency and Single and Three-Phase Voltage Levels by Country–Continued

Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
Macau	50	1,3	220/380	11
Macedonia	NA	NA	NA	6.6, 10
Madagascar				5, 20, 35*
Ambatolampy	50	1,3	220/380	
Ambatondrazaka	50	1,3	220/380	
Tulear	50	1,3	220/380	
All Others	50	1,3	127/220 220/380	
Majorca Island	50	1,3	127/220 220/380	NA
Malawi	50	1,3	230/400	3.3, 11, 33, 66
Malaysia	50	1,3	240/415	6.6, 11, 22, 33
Maldives	50	1,3	230/400	11
Mali, Republic of	50	1,3	220/380	15, 30
Malta	50	1,3	240/415	6, 11
Martinique	50	1,3	220	NA
Mauritius	50	1,3	230/400	6.5, 22
Mexico	60	1,3	127/220	6.6, 13.2, 13.8, 23, 34.5, 44, 69
Monaco	50	1,3	127/220 220/380	10, 20
Montserrat	60	1,3	230/400	NA
Morocco				5.5, 20, 22*
Agadir	50	1,3	127/220 220/380	
Beni-Mellal	50	1,3	127/220 220/380	
El-Hoceima	50	1,3	220/380	
Khemisset	50	1,3	220/380	
Khenifra	50	1,3	220/380	
Oued-Zem	50	1,3	127/220 220/380	
Sidi Kacem	50	1,3	127/220 220/380	
Sidi Slimane	50	1,3	127/220 220/380	
Souk-El-Arba Gharb	50	1,3	127/220 220/380	
All Others	50	1,3	127/220	
Mozambique	50	1,3	220/380	6.6, 11, 22, 33
Myanmar/Burma	50	1,3	230/400	3.3, 6.6, 11, 33
Nepal	50	1,3	220/440	11, 33
Netherlands				5.3, 6, 10, 12.5, 20, 25*
Amsterdam	50	1,3	220/380 220	
Delft	50	1,3	220/380 220	
All Others	50	1,3	220/380	

Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
Netherlands Antilles				NA
Aruba:				
Lago Colony	60	1	115/230	
Oranjestad	60	1,3	127/220	
San Nicolas	60	1,3	127/220	
Bonaire:				
Kralendijk	50	1,3	127/220	
Curacoca:				
Emmastad	50	1,3	223/380	
Willemstad	50	1,3	127/220	
St. Martin:				
Philipsburg	60	1,3	120/208	
New Caledonia	50	1,3	220/380	NA
New Zealand	50	1,3	230/400	11
Nicaragua	60	1,3	120/240	13.8, 24.9
Niger	50	1,3	220/380	5.5, 15, 20
Nigeria	50	1,3	230/415	11, 33
Norway	50	1,3	230	NA
Okinawa				NA
Military Facilities	60	1	120/240	
All Cities	60	1	100/200	
Oman	50	1,3	240/415	11, 33
Pakistan				11, 33
Hyderabad	50	1,3	220/380	
Karachi	50	1,3	220/380	
All Others	50	1,3	230/400	
Panama				11, 12, 34.5*
Colon	60	1,3	115/230	
Panama City	60	1,3	115/230 126/208	
Puerto Armuelles	60	1,3	120/240	
All Others	60	1,3	110/220	
Papua New Guinea	50	1,3	240/415	11, 22
Paraguay	50	1,3	220/380	23
Peru				5, 10, 20, 30*
Arequipa	50	1,3	220	
Talara	60	1,3	110/220	
All Others	60	1,3	220	
Philippines				2.4, 4.8, 6.24, 7.62, 13.2, 13.8, 34.5*
Manila	60	1,3	115/230 110/220	
All Others	60	1,3	110/220	
Poland	50	1,3	220/380	6, 15, 20, 30, 40, 60
Portugal	50	1,3	220/380	6, 10, 15, 30, 40, 60
Puerto Rico	60	1,3	120/240	4.16, 13.2
Qatar	50	1,3	240/415	11

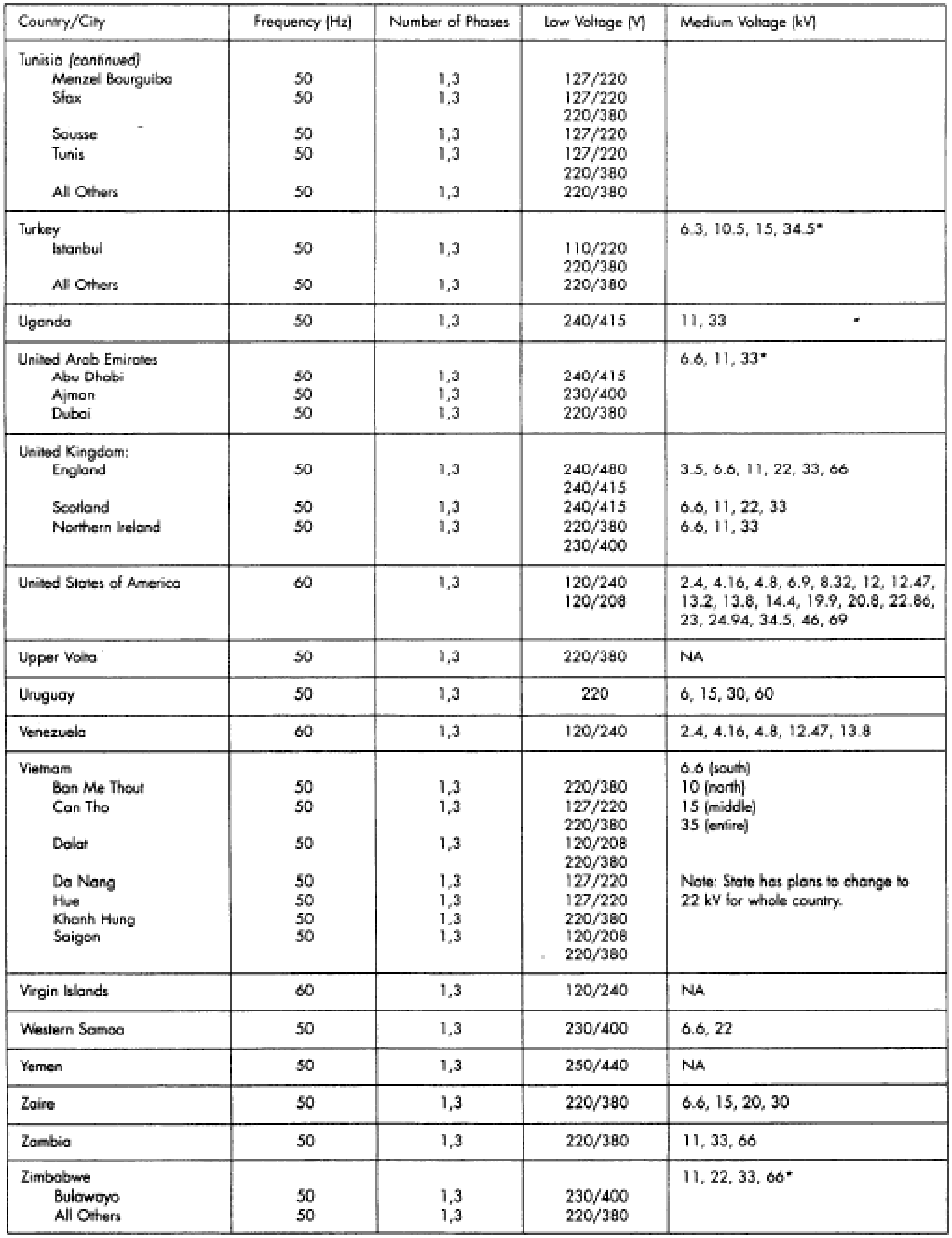
Table B-1. Frequency and Single and Three-Phase Voltage Levels by Country—Continued

Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
Romania	50	1,3	220/380	6, 10, 20
Russia	50	1,3	220/380	NA
Rwanda	50	1,3	220/380	6.6, 15, 30
St. Kitts and Nevis	60	1,3	230/400	NA
St. Lucia	50	1,3	240/416	11
San Marino	NA	NA	NA	15
St. Vincent	50	1,3	230/400	6.3, 11, 33
Saudi Arabia				13.8, 33, 34.5, 69*
Al Khobar	60	1,3	127/220	
Buraydah	50	1,3	220/380	
Dammam	60	1,3	127/220	
Hufuf	50	1,3	230/400	
Jiddah	60	1,3	127/220	
Mecca	50	1,3	230/400	
Medina	60	1,3	127/220	
Riyadh	60	1,3	127/220	
Taif	50	1;3	230/400	
Senegal	50	1,3	127/20	5.5, 16.6, 30
Serbia	50	1,3	220/380	10, 20, 35
Seychelles	50	1,3	240	11
Sierra Leone	50	1,3	230/400	11
Singapore	50	1,3	230/400	6.6, 22
Slova Republic	NA	NA	NA	6, 10, 22, 35
Slovenia	NA	NA	NA	6.6, 10
Somalia				3, 15*
Berbera	50	1,3	230	
Brava	50	1,3	220/440	
Chisimaio	50	1,3	220	
Hargeysa	50	1,3	220	
Marka	50	1,3	120/220	
Mogadishu	50	1,3	220/380	
South Africa/Namibia				6.6, 11, 22, 33*
Beaufort West	50	1,3	230/400	
Benoni	50	1,3	230/400	
Boksburg	50	1,3	230/400	
Cradock	50	1,3	230/400	
Germiston	50	1,3	230/400	
Grahaamstad	50	1,3	250/430	
Keetmanshoop	50	1,3	230/400	
King Williams	50	1,3	220/380 250/433	
Klerksdorp	50	1,3	230/400	
Kroonstad	50	1,3	230/400	
Paarl	50	1,3	230/400	
Port Elizabeth	50	1,3	250/433	
Pretoria	50	1,3	240/415	
Roodepoort	50	1,3	230/400	



Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
South Africa/Namibia *(cont.)*				
Somerset West	50	1,3	230/400	
Springs	50	1,3	220/380 230/400	
Stellenbosch	50	3	220/380	
Umtata	50	1,3	230/400	
Upington	50	1,3	230/400	
Virginia	50	1,3	230/400	
Vryheid	50	1,3	230/400	
Walvis Bay	50	1,3	230/400	
Wellington	50	1,3	230/400	
Worcester	50	1,3	230/400	
All Others	50	1,3	220/380	
Spain	50	1,3	127/220 220/380	3, 6.6, 10, 11.6, 15, 20, 33
Sri Lanka	50	1,3	230/400	11, 33
Sudan	50	1,3	240/415	11, 33
Suriname	60	1,3	115/230	33
Swaziland	50	1,3	230/400	11, 33
Sweden	50	1,3	220/380	3, 6, 7, 10, 20, 30
Switzerland	50	1,3	220/380	1, 16, 50
Syria	50	1,3	220/380	20
Tahiti	60	1,3	127/220	4.8, 14.4, 20
Taiwan	60	1,3	110/220	2.3, 3.3, 5.9, 11.4, 22.8
Tanzania	50	1,3	230/400	11, 33
Thailand	50	1,3	220/380	3.5, 11, 12, 22, 24, 33
Togo				5.5, 20, 33*
Lome	50	1,3	127/220 220/380	
All Others	50	1,3	220/380	
Tonga	50	1,3	240/415	11
Trinidad and Tobago	60	1,3	115/230 230/400	6.6, 12
Tunisia				10, 15, 30*
Ariana	50	1,3	127/220 220/380	
Bardo	50	1,3	127/220 220/380	
Beja	50	1,3	127/220	
Bizerte	50	1,3	127/220	
Carthage	50	1,3	127/220	
Gafsa	50	1,3	127/220 220/380	
Hammam-Lif	50	1,3	127/220	
Kairouan	50	1,3	127/220	
La Goulette	50	1,3	127/220	
La Manouba	50	1,3	127/220	
La Marsa	50	1,3	127/220	
Mateur	50	1,3	127/220	

Table B-1. Frequency and Single and Three-Phase Voltage Levels by Country–Continued



Country/City	Frequency (Hz)	Number of Phases	Low Voltage (V)	Medium Voltage (kV)
Tunisia *(continued)*				
Menzel Bourguiba	50	1,3	127/220	
Sfax	50	1,3	127/220	
			220/380	
Sousse	50	1,3	127/220	
Tunis	50	1,3	127/220	
			220/380	
All Others	50	1,3	220/380	
Turkey				6.3, 10.5, 15, 34.5*
Istanbul	50	1,3	110/220	
			220/380	
All Others	50	1,3	220/380	
Uganda	50	1,3	240/415	11, 33
United Arab Emirates				6.6, 11, 33*
Abu Dhabi	50	1,3	240/415	
Ajman	50	1,3	230/400	
Dubai	50	1,3	220/380	
United Kingdom:				
England	50	1,3	240/480	3.5, 6.6, 11, 22, 33, 66
			240/415	
Scotland	50	1,3	240/415	6.6, 11, 22, 33
Northern Ireland	50	1,3	220/380	6.6, 11, 33
			230/400	
United States of America	60	1,3	120/240 120/208	2.4, 4.16, 4.8, 6.9, 8.32, 12, 12.47, 13.2, 13.8, 14.4, 19.9, 20.8, 22.86, 23, 24.94, 34.5, 46, 69
Upper Volta	50	1,3	220/380	NA
Uruguay	50	1,3	220	6, 15, 30, 60
Venezuela	60	1,3	120/240	2.4, 4.16, 4.8, 12.47, 13.8
Vietnam				6.6 (south)
Ban Me Thout	50	1,3	220/380	10 (north)
Can Tho	50	1,3	127/220	15 (middle)
			220/380	35 (entire)
Dalat	50	1,3	120/208	
			220/380	
Da Nang	50	1,3	127/220	Note: State has plans to change to 22 kV for whole country.
Hue	50	1,3	127/220	
Khanh Hung	50	1,3	220/380	
Saigon	50	1,3	120/208	
			220/380	
Virgin Islands	60	1,3	120/240	NA
Western Samoa	50	1,3	230/400	6.6, 22
Yemen	50	1,3	250/440	NA
Zaire	50	1,3	220/380	6.6, 15, 20, 30
Zambia	50	1,3	220/380	11, 33, 66
Zimbabwe				11, 22, 33, 66*
Bulawayo	50	1,3	230/400	
All Others	50	1,3	220/380	

APPENDIX C
Derating Factors

C-1. Heating, ventilation, and air conditioning (HVAC).

a. *50 Hz.* The output of directly coupled, motor driven equipment must be derated to account for the reduction in shaft speed to 5/6 the 60 Hz value. Otherwise, the mechanical coupling used between the motor and driven equipment should be purchased to give the required rotating speed. HVAC controls that are frequency dependent must be purchased in 50 Hz configurations.

b. *Voltage.* Derating for voltage is not an option.

C-2. Electrical distribution and protection for transformers.

a. *50 Hz.* In general, derating for frequency is not recommended. See chapter 3 for details.

b. *Voltage.* Derating for voltage is not recommended. Vendors can provide almost any needed input voltage rating. Consult vendor regarding derating possibility if derating is absolutely necessary.

C-3. Electrical distribution and protection for power factor capacitors.

a. *50 Hz.* Derate kilovolt-amperes reactive (KVAR) rating by multiplying 60 Hz KVAR rating by 5/6 to yield 50 Hz VAR rating.

b. *Voltage.* Derating for voltage is not recommended. Vendors can provide almost any needed voltage rating. Consult vendor regarding derating possibility if derating is absolutely necessary.

C-4. Electrical distribution and protection for protection equipment.

a. *50 Hz.* Different trip curves may be needed. Consult vendor for these curves.

b. *Voltage.* Derating for voltage should not be needed. Verify with vendor since special protection equipment may need derating.

C-5. Other electrical distribution and protection.

Derating either cannot or should not be performed. Contact vendors to purchase appropriately rated equipment.

C-6. Safety and security equipment.

a. *50 Hz.* Depends on type of power supply. Derating is either not necessary or not possible. Contract vendor to purchase appropriately configured power supply.

b. *Voltage.* Derating far voltage is not recommended. Contact vendor to purchase appropriately configured power supply, or use transformer to convert supply voltage level to power supply input level.

C-7. Communication equipment.

a. *50 Hz.* Depends on type of power supply. Derating is either not necessary or not possible. Contact vendor to purchase appropriately configured power supply.

b. *Voltage.* Derating for voltage is not recommended. Contact vendor to purchase appropriately configured power supply, or use transformer to convert supply voltage level to power supply input level.

C-8. Incandescent lighting.

a. *50 Hz.* No derating necessary. incandescents are frequency insensitive.
b. Voltage. Not possible. Bulb life will suffer drastically. Contact vendor to purchase high voltage bulbs, or use transformer to convert supply voltage to lamp voltage.

C-9. Fluorescent and high intensity discharge (HID) lighting.

50 Hz. Derating is not recommended. Fixtures configured for 50 Hz should be purchased.

C-10. Motors.

a. *50 Hz.* In general, derating a 60 Hz motor is not recommended. See chapter 3 for exceptions
b. *Voltage.* Derating for voltage is not recommended. Contact vendor to purchase appropriately configured equipment, or use transformer to convert supply voltage to motor's rated voltage level.

C-11. Motor starters.

a. *50 Hz.* Derate by multiplying 60 Hz horsepower rating by 4/5 to yield the 50 Hz horsepower rating.
b. *Voltage.* Derating for voltage is not possible. Contact vendor to purchase appropriately configured equipment, or use transformer to convert supply voltage to motor starter's rated voltage level.

C-12. Clocks.

a. *50 Hz.* Derating is possible but meaningless since 60 Hz clock will not keep correct time in 50 Hz environment
b. *Voltage.* Derating for voltage is not recommended. Contact vendor to purchase appropriately configured clocks, or use transformer to convert supply voltage to clock's rated voltage level.

C-13. Computer power supplies.

a. *50 Hz.* Derating is not possible due to equipment construction. Contact vendor to purchase 50 Hz rated equipment.
b. *Voltage.* Derating for voltage is not possible. Contact vendor to purchase appropriately configured equipment, or use transformer to convert supply voltage to equipment's rated voltage level.