50 / 60 Hz Operations

As international trade proliferates, there is increasing use of equipment on both 50 and 60 Hz. Sixty Hz is primarily used in the Western Hemisphere as well as Philippines, Korea, Taiwan, Hong Kong, Guam, Okinawa, Liberia, and in some areas of Japan and Saudi Arabia. Europe and the remainder of Asia and Africa typically operate at 50 Hz. Aviation equipment is rated at 400 Hz. The primary benefit of higher frequency is smaller physical size. As the frequency changes, the performance also changes.

With few exceptions, the single-phase voltage of 60 Hz countries systems is a nominal 120 Volts, while the 50 Hz systems are nominally 220 to 240 Volts. The international single-phase voltages are one phase of a three-phase grounded wye system. That simply means that the 3-phase voltage is 1.732 times the single phase.

$$V(3\varphi) = 1.732\ V(1\varphi)$$

System voltage is the nominal rating at the secondary of the transformer. Typically 5% voltage drop is assumed in the wiring. Therefore, motor voltages are 5% less than the system. The ratings are often rounded to the nearest whole number. For example, on a 60 Hz system, the transformer voltage is 480 V and the motor voltage is rounded to 460 V.

The corresponding voltages for 60 and 50 Hz are given in the table.

60 Hz 3-ph V	50 Hz 3-ph V	50 Hz 1-ph V
498	415	240
480	400	230
456	380	220

Performance

When using a machine from one system to another, the performance will change. To understand the relationships, it is necessary to review the magnetic, electrical, and mechanical conversion characteristics of machines.

Electrical voltage (V) equals the machine constant (K) multiplied by the magnetic flux (φ) and the angular speed (ω).

$$V = K\ \varphi\ \omega$$

Mechanical torque (T) equals the machine constant multiplied by the magnetic flux and the current (I).

$$T = K\ \varphi\ I$$

Mechanical power (P) is the product of torque and angular speed.

$$P = T\ \omega$$

Angular speed in radians/sec is the circular or cyclic frequency. It is related to 2π times electrical frequency (f) in Hertz. The electrical frequency is the number of magnetic poles times the RPM (revolutions/minute) divided by a constant 120.

$$\omega = 2\pi\ f$$

$$f = RPM * poles / 120$$

Electrical power is the product of voltage, current, phase factor, and power factor (pf). The phase factor is 1.732 for 3-phase and 1 for 1-phase. The power factor depends on the inductance. It is typically 0.8 for machines.

$$P = 1.732\ V\ I\ pf$$

The key common ingredient to performance is the magnetic flux. First consider the effect of frequency on voltage. Keep the flux constant. Then the voltage to frequency ratio is constant. Hence, voltage is proportional to the frequency.

$$V = K \varphi \omega$$
$$K \varphi = V1 / f1 = V2 / f2$$
$$480 / 60 = 400 / 50$$

Next consider the effect of frequency change on the current. If the power load is fixed, then the voltage and current product at one frequency equals the product at another. Hence, current is inversely proportional to the new frequency.

$$P = 1.732\ V1\ I1\ pf = 1.732\ V2\ I2\ pf$$
$$V1\ I1 = V2\ I2$$
$$480 * 10 = 400 * 12$$

Speed is obviously proportional to the frequency, since the number of poles and 120 are fixed.

$$f = RPM * poles / 120$$
$$poles / 120 = f1 / RPM1 = f2 / RPM2$$
$$60 / 1800 = 50 / 1500$$

There is a significant benefit to running at higher speed. The power is proportional to the speed. If the voltage is adjusted for the frequency and the current is allowed to rise to the rated current, then the available power increases proportional to the frequency.

$$P = T\ 2\pi\ f$$
$$2\pi\ T = P1 / f1 = P2 / f2$$
$$1.2 / 60 = 1 / 50$$

Considerations

1. Running a 50 Hz machine on 60 Hz will cause the flux to increase above its rating. Over saturation, will then cause overheating and burnout.

2. Running a 60 Hz machine on 50 Hz will often work, but perhaps not as effectively.

3. If the load is fixed, and the machine is rated 50 Hz, and the 60 Hz voltage is proportional to the frequency, then the current will decrease. The machine is then operating with a service factor increase proportional to the frequency ratio (60 /50 = 1.2).

4. Alternately, if the current is allowed to rise to rating, then the available power from the machine is increased by the frequency ratio (60 /50 = 1.2).