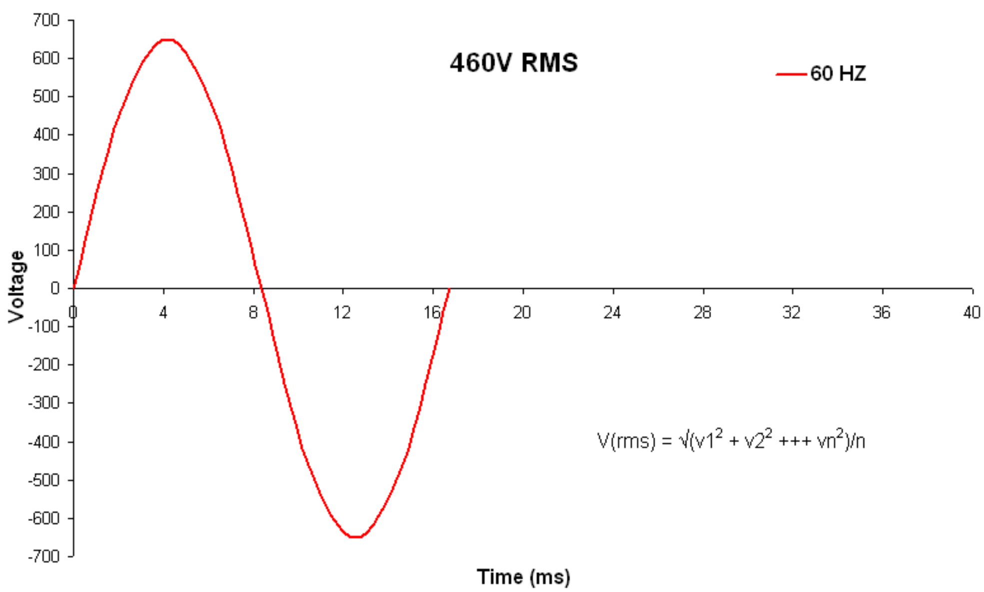
Fluctuating Flux - Balancing AC Voltage & Frequency

Joe Evans, Ph.D http://www.pumped101.com

Have you ever wondered why a motor manufacturer would state that many of their 60hz motors will operate on 50hz power as long as you reduce the nameplate voltage by 1/6? Well, it turns out that, unlike DC, AC voltage is a "time varying" quantity and if you alter the duration of the AC cycle, you better alter the voltage too. This is also the reason why a VFD must continuously modify its output voltage relative to its output frequency. Lets see if we can put this time varying quantity into perspective.

A good starting point is to review the wave form produced by AC. Figure 1 shows one cycle of a 460V, 60hz single phase sine wave. The x-axis is time and the y-axis is voltage intensity. It begins its cycle at 0V, rises to some positive maximum, and returns to 0V. It then falls to some negative maximum and again, returns to 0V. All of this occurs in just 1/60 of a second or about 16.6 milliseconds.

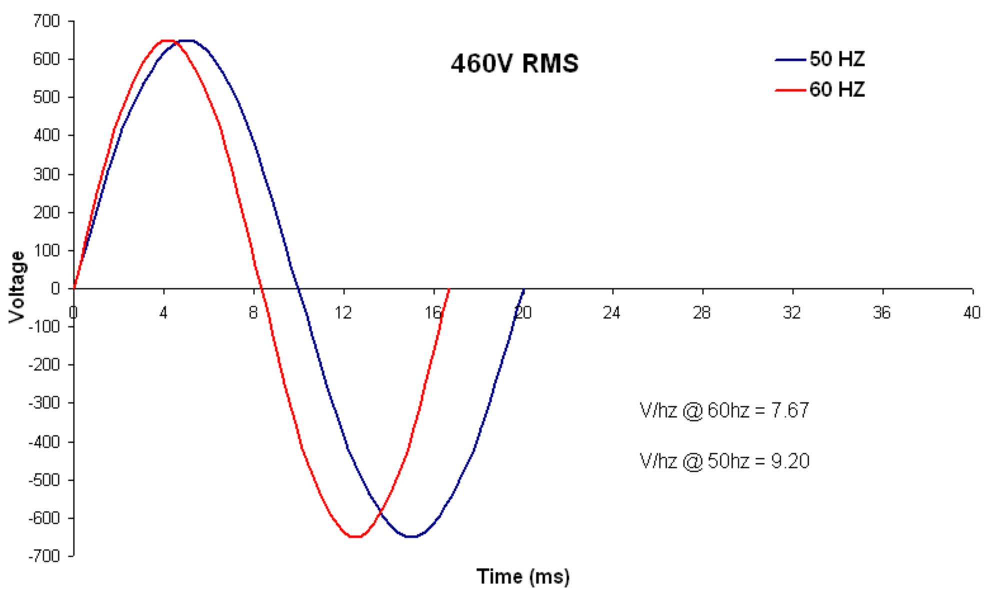


The first thing we notice about this wave is that its voltage intensity varies at every single point in time. In fact, it has a value of zero at three points and is even negative during the last half of the cycle! Another observation is that the maximum voltage intensity of the upper and lower peaks is quite a bit more (about 650V) than the 460V we claim the curve represents. These two observations are a big part of the reason Thomas Edison almost won the war over power generation and distribution in the US.

Although AC has several significant advantages over DC, it happens to be far more complex.

So, why do we measure 460V on a wave that varies from +650V to -650V? Could it be that 460V is the average of all those points? Unfortunately it is not that simple because the average intensity would be zero since half of the wave is positive and the other half is negative. Even if we took the average of the “absolute values” it would fall well below 460V. It turns out that it is a result of a function known as the “root mean square” (RMS) and it is the RMS voltage that you measure when you use a typical voltmeter. To calculate RMS voltage, the intensity at every point on the curve is multiplied times itself (now the negative values become positive) and all of the results are added together. The total is then divided by the number of measurements to obtain the mean (or average) of the squares. Finally, the square root of this mean gives us the RMS voltage. It turns out that the RMS voltage will always be 0.707 times the peak voltage and peak voltage is always 1.414 that of the RMS voltage.

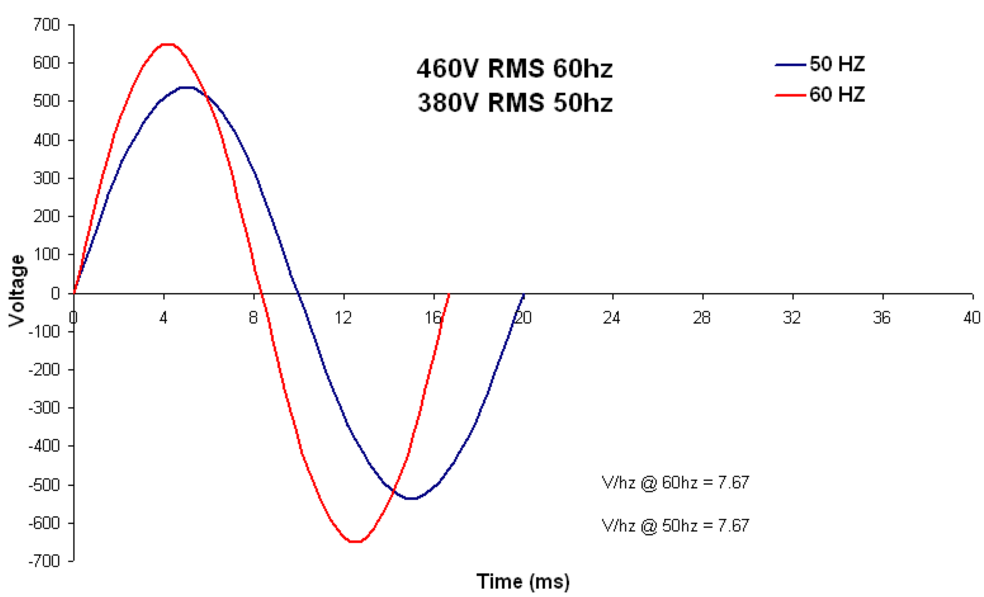
Figure 2 compares that same 60hz wave form with one that has a frequency of 50hz. Both have a peak voltage of 650V and an RMS voltage of 460V. The major difference between the two is that the 50hz wave requires more time to complete one full cycle than does the one at 60hz (20ms vs 16.6ms for the 60hz wave).



If you look closely at the two waves you will also notice that the area under the 50hz curve appears to be quite a bit larger than that of the 60hz curve (focus on the positive portions of the two curves as both have the same starting point). Since total voltage per cycle is proportional to these areas, the 50hz curve produces more voltage per cycle than does the 60hz curve. We can get a simple quantitative comparison by dividing the RMS voltage by the frequency and obtain a quantity known as volts per hertz (V/hz). At 60hz, V/hz is 7.67 and at 50hz it is 9.20. So, why is this ratio important and how does it affect the operation of an electric motor?

An AC induction motor is designed to operate with a rotating magnetic field of constant strength. The magnetic field produced by the stator and the lines of flux that it generates is directly proportional to voltage and inversely proportional to frequency (flux ≈ V/hz). If we are to keep flux (and the torque produced) constant we must maintain a constant V/hz ratio. For example, a 460V / 60hz, two pole motor operates at a synchronous speed of one rotation per AC cycle. At 50hz that same motor will still operate at one rotation per cycle but, since the cycle takes longer, the stator will see a greater voltage "quantity" (volt - seconds) during that cycle. This additional voltage will generate a higher flux which can cause magnetic saturation in the stator and result in undesirable torque characteristics and potential overheating of the motor.

So how do we cure this problem? It is pretty simple, just reduce the voltage of the lower frequency wave so that its V/hz ratio is the same as it is for 60hz. Figure 3 shows the result when the 50hz voltage is reduced. At a reduced RMS voltage of 380V (5/6 of 460V), the area beneath the 50hz curve now appears equal to that of the 60hz curve. This is confirmed by the equal values (7.67) of the two V/hz ratios.



When frequency and the resulting motor speed is changed, the applied voltage is always changed in the same proportion. This allows magnetic flux and the torque it produces to remain constant regardless of speed. In the case of a 60hz motor running on 50hz power, voltage is reduced by 1/6. In the case of VFD control, that voltage is varied in proportion with every single change in frequency whether it be up or down.

There are, however, VFD applications (centrifugal pumps for example) where constant torque is not a requirement. In such cases voltage can be reduced below the normal constant V/hz level at lower speeds. We will address this control technique and its effect on power and efficiency in a later column.

Joe Evans is the western regional manager for Hydromatic Engineered Waste Water Systems, a division of Pentair Water, 740 East 9th Street Ashland, OH 44805. He can be reached at joe.evans@pentairwater.com, or via his website at www.pumped101.com. If there are topics that you would like to see discussed in future columns, drop him an email.