## Variable Frequency Drive Fundamentals

AC Motor Speed - The speed of an AC induction motor depends upon two factors:

1) The number of motor poles

2) The frequency of the applied power.

AC Motor Speed Formula:

 $RPM = \frac{120 \text{ x Frequency}}{\text{Number of Poles}}$ 

Example: For example, the speed of a 4-Pole Motor operating at 60 Hz would be:

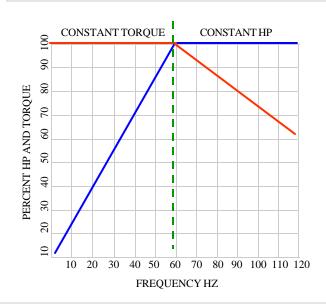
120 x 60 / 4 = 7200 / 4 = 1800 RPM

**Inverter Drives -** An inverter is an electronic power unit for generating AC power. By using an inverter-type AC drive, the speed of a conventional AC motor\* can be varied through a wide speed range from zero through the base (60 Hz) speed and above (often to 90 or 120 hertz).

**Voltage and Frequency Relationship** - When the frequency applied to an induction motor is reduced, the applied voltage must also be reduced to limit the current drawn by the motor at reduced frequencies. (The inductive reactance of an AC magnetic circuit is directly proportional to the frequency according to the formula  $XL = 2 \pi f L$ . Where:  $\pi = 3.14$ , f = frequency in hertz, and L= inductive reactance in Henrys.)

Variable speed AC drives will maintain a constant volts/hertz relationship from 0 - 60 Hertz. For a 460 motor this ratio is 7.6 volts/Hz. To calculate this ratio divide the motor voltage by 60 Hz. At low frequencies the voltage will be low, as the frequency increases the voltage will increase. (Note: this ratio may be varied somewhat to alter the motor performance characteristics such a providing a low-end boost to improve starting torque.)

Depending on the type of AC Drive, the microprocessor control adjusts the output voltage waveform, by one of several methods, to simultaneously change the voltage *and* frequency to maintain the constant volts/hertz ratio throughout the 0 - 60 Hz range. On most AC variable speed drives the voltage is held constant above the 60 hertz frequency. The diagram below illustrates this voltage/frequency relationship.



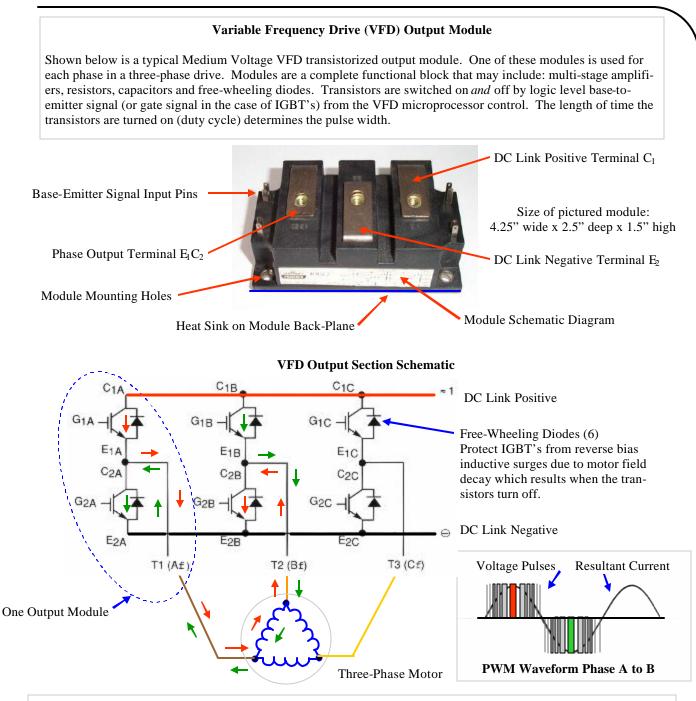
## **VFD Speed Torque Characteristics**

Blue = Horsepower Red = Torque Green = Motor Nameplate Frequency (60 Hz)

In Constant Torque Area - VFD supplies rated motor nameplate voltage and motor develops full horsepower at 60 hertz base frequency.

In Constant Horsepower Area - VFD delivers motor nameplate rated voltage from 60 Hertz to 120 hertz (or drive maximum). Motor horsepower is constant in this range but motor torque is reduced as frequency increases. Note: Motor HP = Torque x RPM

\*Inverter Duty Motors - Initially standard AC motors were employed on inverter drives. Most motor manufacturers now offer Inverter Duty Motors which provide improved performance and reliability when used in Variable Frequency Applications. These special motors have insulation designed to withstand the steep-wave-front voltage impressed by the VFD waveform, and are redesigned to run smoother and cooler on inverter power supplies.



## **Inverter Principle**

Inverter circuitry generates an Alternating Current (AC) by sequentially switching a Direct Current (DC) in alternate directions through the load. The illustration above shows the generation of a single positive pulse (red) and a single negative pulse (green) which occurs 180 electrical degrees later. To analyze the circuit assume a conventional current flow (positive to negative direction). The black arrows on the emitter of each transistor indicate the direction of conventional current through the transistors. This is a three-phase drive, so at certain times during the cycle transistors will be turned on to cause current flow through the A - C and B - C motor windings (see next page) but for clarity this is not shown in the above illustration. For this analysis also assume that the free-wheeling diodes are non-conducting.

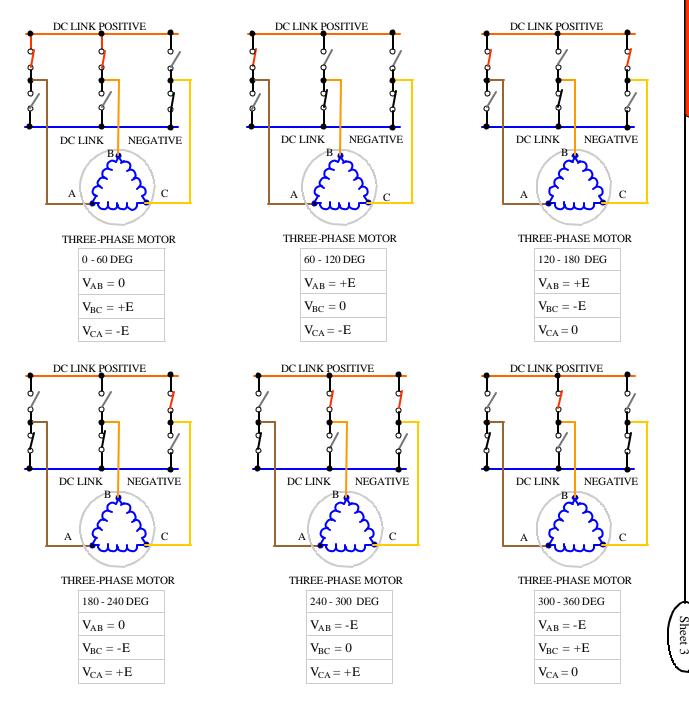
Transistors 1A and 2B are turned on and off by the microprocessor control and current flows from the DC bus positive, through the motor windings as shown by the red arrows producing the positive (red ) voltage pulse, and back to the DC bus negative. To generate the next half-cycle transistors 1B and 2A will be turned on and off and the current flow will reverse through the motor winding as shown by the green arrows which result in the negative (green) pulse.

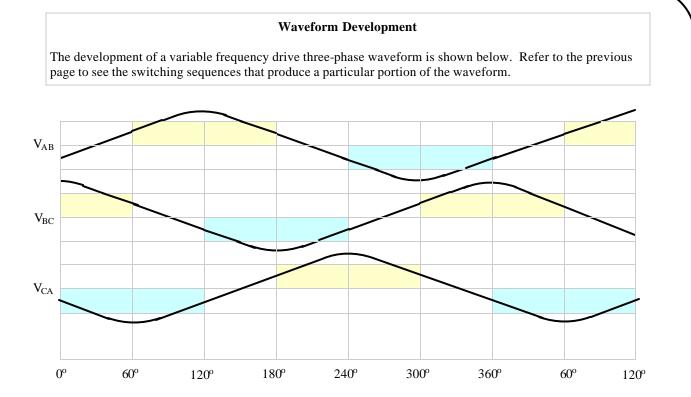
Variable Frequency

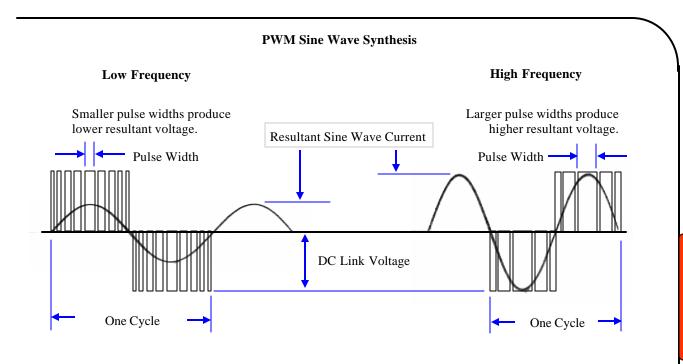
The following illustrations show the switching sequence of the output transistors, SCR's, or GTO's used in a VFD to produce a three-phase AC waveform. Since each these devices are functioning as solid-state switches, the circuit operation can be easily visualized by representing these devices as open or closed mechanical switches.

Switches closed to the positive bus are shown in red, switches closed to the negative bus are shown in black, and open switches are shown in gray. When a particular winding is connected to the *same* bus potential (either positive or negative) the voltage across that winding will be zero. If a winding is connected so that the positive voltage is connected to the *first* letter of the winding label (for example the <u>A</u> in <u>AB</u>) the voltage produced across that winding is positive. If a winding is connected so that the positive voltage is connected to the *second* letter of the winding label (for example <u>B</u> in <u>AB</u>) the current flow reverses and the voltage produced across that winding will be of a negative polarity.

Below each diagram is a table listing of the number of electrical degrees through which the switches operate and the resultant phase voltage produced. Note: On a six-step drive the output devices will be closed throughout the listed operating range; on a PWM drive, pulses will be produced through this range. See next page for generated waveform.







## **PWM Drive Characteristics**

- VFD drive DC link voltage is constant .
- Pulse *amplitude* is constant over entire frequency range and equal to the DC link voltage.
- Lower resultant voltage is created by more and narrower pulses.
- Higher resultant voltage is created by fewer and wider pulses.
- Alternating current (AC) output is created by reversing the polarity of the voltage pulses.
- Even though the voltage consists of a series of square-wave pulses, the motor *current* will very closely approximate a sine wave. The inductance of the motor acts to *filter* the pulses into a smooth AC current waveform.
- Voltage and frequency ratio remains constant from 0 60 Hertz. For a 460 motor this ratio is 7.6 volts/Hz. To calculate this ratio divide the motor voltage by 60 Hz. At low frequencies the voltage will be low, as the frequency increases the voltage will increase. (Note: this ratio may be varied somewhat to alter the motor performance characteristics such as providing a low-end boost to improve starting torque.)
- For frequencies above 60 Hz the voltage remains constant. Some AC drives switch from a PWM waveform to a six-step waveform for 60 Hz and above.