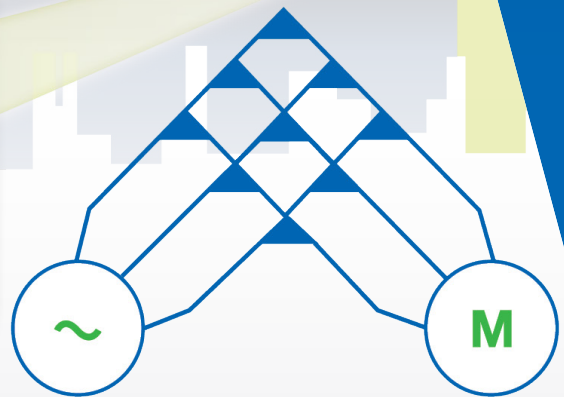


## Inside Matrix Variable Frequency Drive Technology

Providing Cost, Space, and Energy Efficient Solutions for VFD Applications



## What is the Purpose of a VFD?

Variable frequency drives (VFDs), also as variable speed drives (VSDs), and sometimes inverters, have benefited from many advancements since their introduction in the 1970s. During most of that time, however, the basic design of the drive remained the same, with improvements in performance, size, and cost coming mainly from advances in the drives' semiconductor components. From the beginning, VFDs have been used to control the speed of electric motors, which consume approximately 25% of the world's electrical energy in industrial and commercial applications. By definition, VFDs enable a user to operate a motor at any commanded speed, as opposed to running across-the-line at a fixed speed. This variable speed control saves significant energy and also lessens the wear and tear on mechanical couplings, such as gears, belts and pulleys.

## Conventional VFDs

Along with their proven advantages of energy savings and extended equipment life, at times, VFDs can also have an undesired effect on electrical equipment in their proximity. By nature of their conventional design, VFDs are non-linear electrical loads, that is, their input current does not follow the same sinusoidal waveform as the supply voltage. Let's first look at the cause for this non-sinusoidal current. A conventional variable frequency drive rectifies incoming AC voltage to charge capacitors and establish a DC bus voltage level. The drive control then generates two internal waveforms – a carrier and an output. The carrier is a triangle waveform at a frequency much higher than that used to drive the motor, typically in the neighborhood of 8 kHz to 15 kHz. The output frequency is a sine wave at the frequency required for the desired motor speed. Figure 2 shows the two internal waveforms together.

The VFD supplies voltage to the motor at the output frequency by using pulse width modulation (PWM). Since the source for the output voltage is DC from the bus, the VFD uses its Insulated Gate Bipolar Transistors (IGBTs) to create a simulated output voltage sine wave by turning on the DC voltage when the carrier level is less than the output frequency level and turning it off when the carrier is greater. Figure 3 shows the corresponding PWM.

The motor's inductance filters the PWM waveform so that it operates on the pulses as a simulated sine wave. During operation, the VFD varies the timing and width of the pulses to provide the correct frequency to drive the motor at the speed needed for the load. As the motor consumes energy, it draws down the DC bus charge, which is then replenished from the rectified incoming AC voltage. Although the bus voltage level varies with the load, the DC bus draws its replenishment current only at the peaks of the rectified sine wave. These current pulses, while keeping the DC bus charged and the drive operational, lead to some problems with current harmonics.

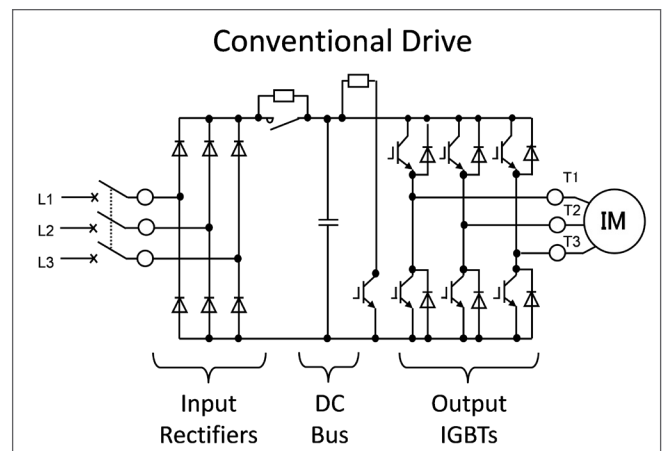


Figure 1: Conventional Drive Topology

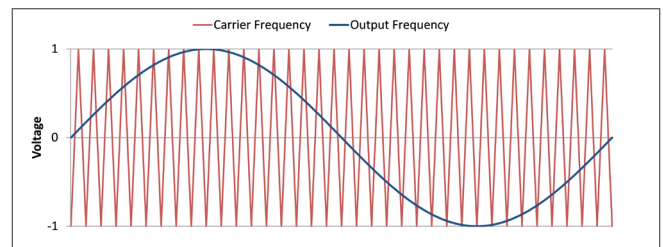


Figure 2: Internal VFD Frequencies

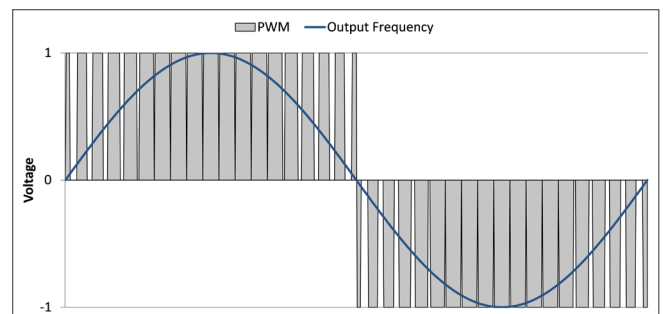


Figure 3: Pulse Width Modulation

## Harmonics

Harmonic currents occur at frequencies in multiples of the fundamental frequency, 60 Hz in the US. Figure 4 below shows the sum of the fundamental (1st) and 5th harmonic currents. For visual simplicity, this shows a single phase representation and only the 5th harmonic. In practice, additional harmonics distort the current waveform further, although to a lesser degree.

The harmonic current (in this case  $5 \times 60 = 300$  Hz) cannot be used for real work and will be converted into wasted heat or mechanical energy. Harmonics can cause cables to overheat, circuit breakers to trip, and cause stress on upstream transformers. Significant current harmonics can have a negative effect on the source's ability to provide clean power, which in turn results in voltage distortion, equipment disruption, and power company fines.

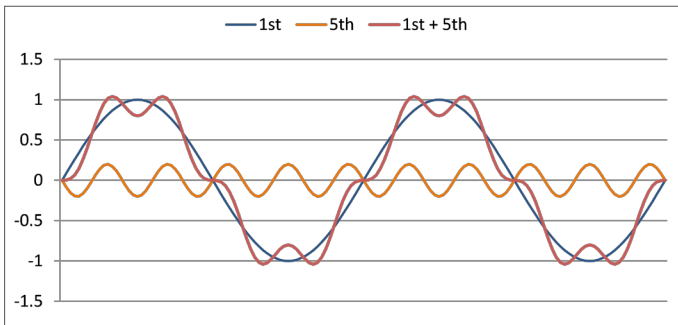
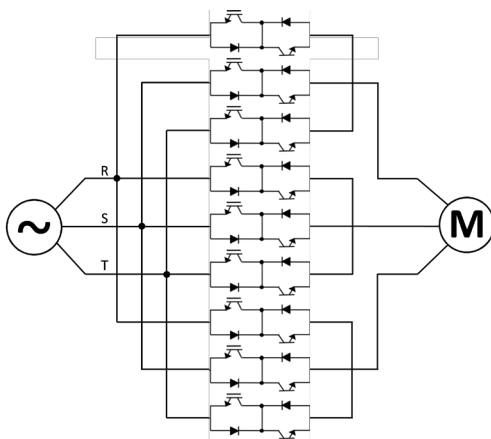


Figure 4: Total Current as Sum of Fundamental and 5th Harmonic

## Matrix VFD Design

A relatively new VFD design, on the other hand, obviates the DC bus by using nine bi-directional IGBTs in a matrix arrangement to generate the variable frequency AC output directly from the AC input. With no DC bus to charge, the associated non-linear input current draw can be eliminated. Figure 5 shows the Matrix topology.

Figure 5: Matrix VFD Topology



Note that in the Matrix design, any input phase can be connected directly to any output phase at any time. The key to the Matrix operation is its ability to turn on and off the bi-directional switches at the correct times to generate the proper output voltage and frequency required to operate the motor.

## Matrix VFD Operation

To better understand, let's look at the three input phase voltages, shown in Figure 6.

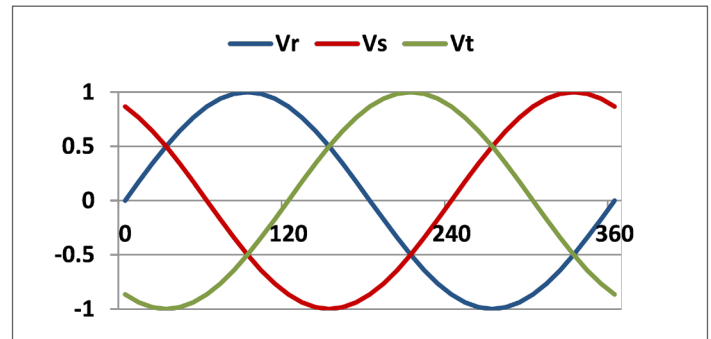


Figure 6: Input Phase Voltages

Now, in operation, the control built into the Matrix VFD continually monitors the voltage difference between each of the phases.

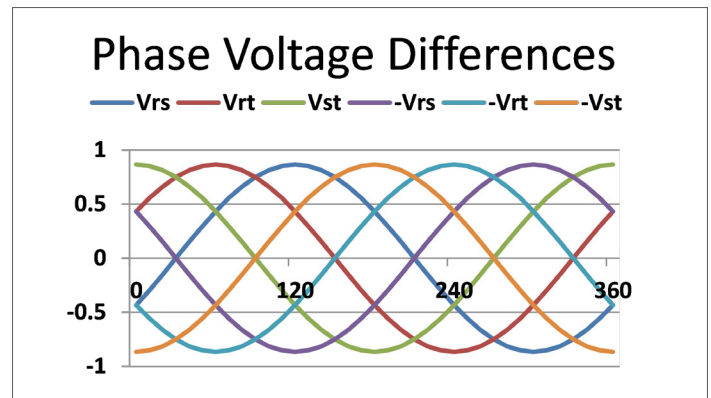


Figure 7: Voltage Phase Differences

These phase voltage differences provide the Matrix with a continuous range of voltages available to send to the motor with its ability to utilize the nine IGBTs to switch any input phase to any output phase at any time. Also using pulse width modulation, it generates the proper voltage at the proper frequency to drive the motor as needed for the load.

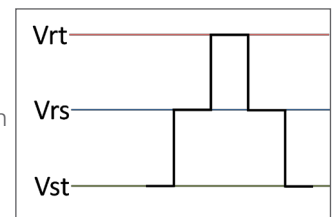


Figure 8: Matrix Stepped Pulse

## Matrix VFD Operation CONTINUED

In addition, the range of voltages available enables the Matrix to build its pulses in steps to reduce the effects from steep voltage rises on motor bearing currents and reflected waves in long motor leads. After all, your HVAC system is all about comfort, and you need to be comfortable with the products that drive it.

## Regeneration

In addition to the ultra-low harmonics and near-unity power factor, the Matrix design also provides energy savings through regeneration. When a motor is being driven by a load, as opposed to driving the load, it acts as a generator, sending voltage back to the VFD. Examples include applications such as pump jacks, where the load oscillates between motoring and regeneration, and downhill conveyors that are in a continuous regenerative state.

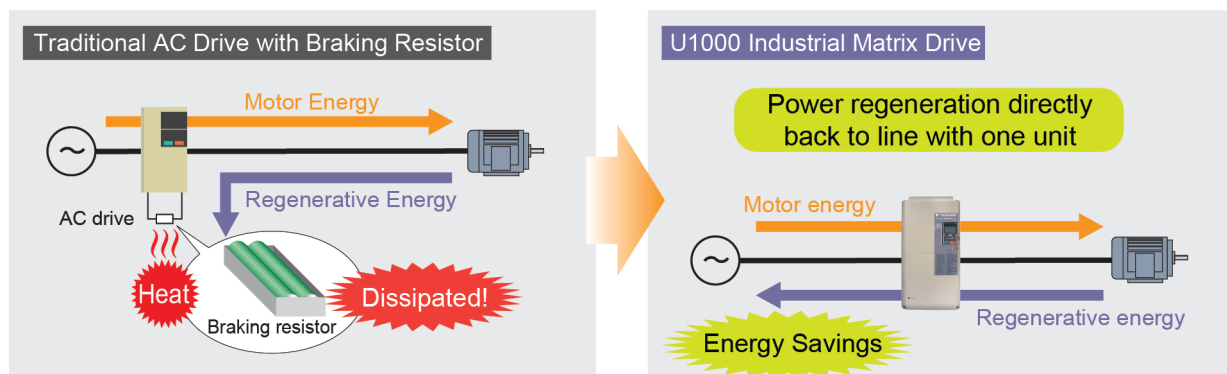


Figure 9: Power Regeneration Comparison

In conventional drives, dynamic braking resistors can be used to divert the regenerative energy away from the VFD and prevent a DC bus overvoltage condition. The Matrix nine bi-directional IGBTs enable the regeneration voltage to be directed back to the supply to be credited against the user's power bill.

## Contactor-less Bypass

Of course, the main benefit of VFDs is to enable a fixed-speed motor to operate at variable speeds. However, some applications require full speed for significant periods of time. In these cases, the Matrix can close the appropriate IGBTs to provide a direct connection between input and output to the motor, thus maximizing efficiency without the requirement of conventional VFDs to use contactors to "bypass" the drive.

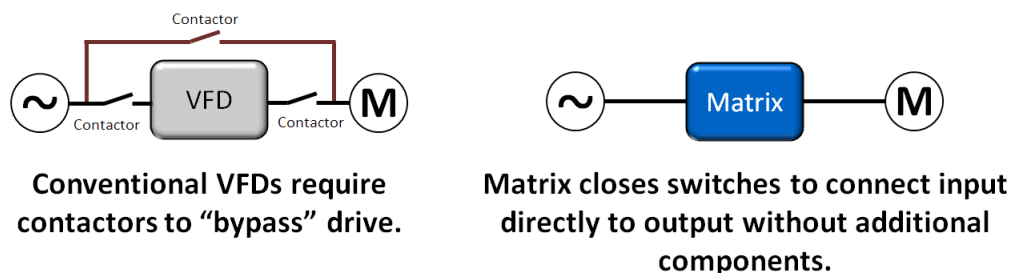


Figure 10: Comparison of Bypass Configuration

This mode also prolongs the life of the VFD by allowing all the IGBTs to "rest" while maintaining a steady state on or off position.

## Monitoring

Some Matrix VFDs can monitor power in several ways to give instant feedback on energy saved. When provided with the \$/kwh billing rate, the display on the drive can show the following information on request:

- Power output
- Power consumption
- Regenerative power
- Power saved
- Power bill

## Comparison to Other Solutions

Of course, there are other means to mitigate the harmonics of VFDs. These include active front ends and multi-pulse transformers, which require significant additional components in combination with the VFD, all of which mean added bulk, cost, and wiring connections. The Matrix accomplishes low harmonics all within the drive – three wires in, three wires out. Though the Matrix VFDs are priced higher than conventional VFDs, their prices are usually comparable or less expensive than other low harmonic solutions.

## Ratings and Certifications

Matrix VFDs are available in a wide range of voltage and horsepower ratings, typically up to 100 HP at 240V and 350 HP or larger at 480V. Look for the same UL, CSA, CE, and RoHS certifications and support for induction, surface permanent magnet, and interior permanent magnet motors.

## Summary

Matrix VFDs provide all the features and functionality users have come to expect from a conventional VFD, plus the added advantages described here. With heightened requirements for sustainability and compliance to IEEE 519-2014, Matrix VFDs provide a cost-efficient, space-efficient, and energy-efficient means for success.

For more information on Yaskawa's HVAC Matrix Drive, please visit:

[www.yaskawa.com/z1000umatrix](http://www.yaskawa.com/z1000umatrix)

For more information on Yaskawa's Industrial Matrix Drive, please visit:

<http://www.yaskawa.com/u1000>