

How to measure output voltage from a VFD to a motor

Application Note

Learn the step-by-step measurement sequence for assessing variable-frequency drive output factors when troubleshooting electrical signals.

When troubleshooting the electrical signals within a motor/drive system, think of it terms of input vs. output. A variable-frequency drive (VFD) transforms the input mains of constant voltage and frequency into a voltage and frequency range that can be varied to control motor torque. Troubleshooting at the input starts with testing power supply and quality.

Troubleshooting at the output starts with measuring that transformed voltage and frequency. This article steps through the measurement sequence for assessing VFD output factors:

- DC Bus
- Output voltage/current/frequency
- Unbalance
- Volts/hertz ratio
- Output reflections

Figure 1 illustrates the components of a VFD input ac-to-dc converter and output pulse width modulated signal, with the dc link in-between. In a VFD, the pulse width modulation (PWM)

inverter regulates both voltage **and** frequency to the motor. The voltage and frequency of the motor is varied by modulating the width of the output pulses, which is accomplished by controlling the semiconductor switch.

The input diodes provide constant dc buffer for the switching inverter section, equivalent to 1.414 times the peak of the input voltage. The capacitor acts as a filter to reduce ripple in the dc section.

The control devices in the inverter section are usually insulated gate bipolar transistors (IGBT), and nowadays have enough power to handle loads up to 500 hp.

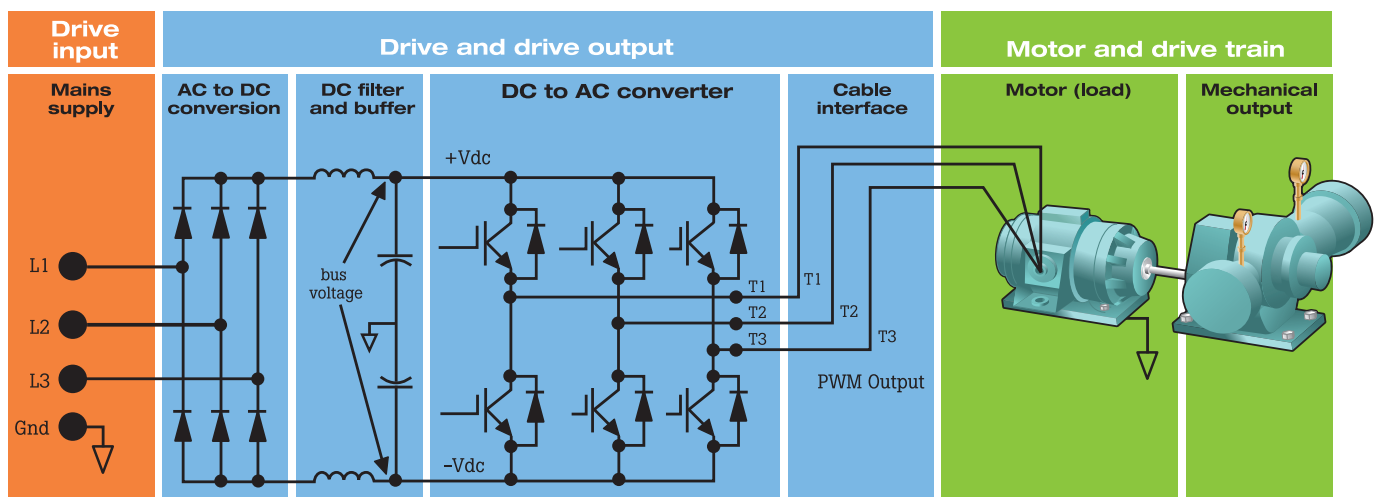


Figure 1. Envisioning a motor/drive system as three segments—input, output and load—helps clarify what specific measurements and troubleshooting steps to take in each segment.

Step 1: Measure dc bus voltage

An oscilloscope can be used to measure the absolute value of the rectified dc voltage; when ac coupled, it also can be used to zoom into the signal to view the extent of ripple (see **Figure 2**).

- Measure the dc bus voltage across the + and – terminals using oscilloscope or DMM.
- Use ac or dc input coupling to measure the absolute or ripple voltages.
- Make sure the scope and probe are rated appropriately to measure the voltage level.

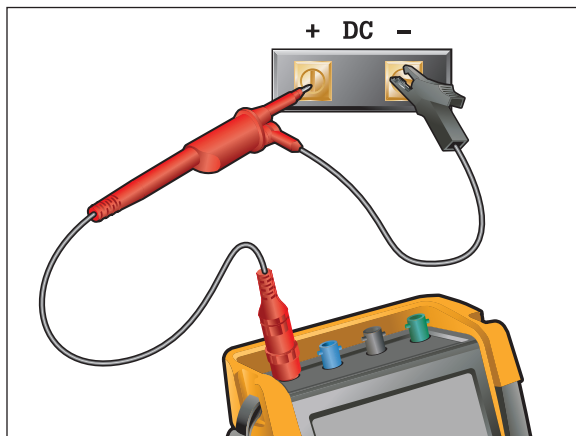


Figure 2. Connecting an oscilloscope to measure negative dc and positive dc buffer voltage.

Interpreting dc bus measurements

The dc bus voltage is relative to the peak voltage of the mains input.

- dc bus voltage is $\sim 1.414 \times$ the rms line voltage. For example, for a 480 V ac drive, the dc bus should be ~ 678 V dc.
- A dc voltage value that is too low can cause the drive to trip. At the cause, the mains input voltage is probably too low, or the input sine wave might be distorted by flat topping.
- If the ripple's peaks have a different repetitive level, one of the rectifier diodes is possibly malfunctioning (this is load dependent). Ripple voltages above 40 V can be caused by malfunctioning capacitors or a drive rating that is too small for the connected motor and load (see **Figure 3**).

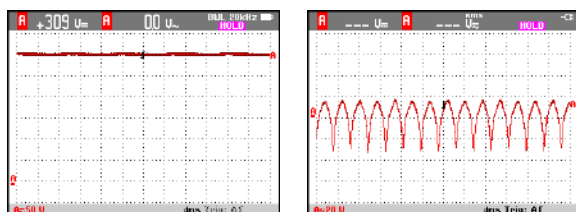


Figure 3. These show an example of dc coupled versus ac coupled waveform traces from an oscilloscope used to inspect overall dc and ripple voltages.

Step 2: Measuring voltage and unbalance

- Use an oscilloscope with a V PWM function connected between the three motor terminals (see **Figure 4**).
- Compare the scope readings to drive's display values.
- Voltage drop between drive and motor terminals should not exceed 3%.
- Unbalance greater than 2% is problematic.
- Use a multichannel oscilloscope to check for motor voltage unbalance across the three output phases.
- Measure the voltage on each terminal, and record each measured voltage for use in the next step.
- Measure voltage unbalance at full load.

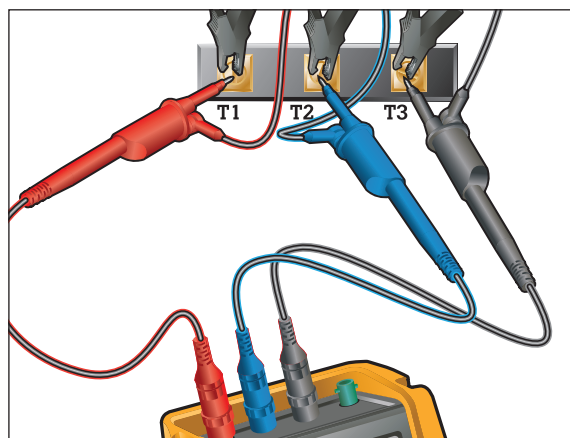


Figure 4. Use an oscilloscope with appropriately safety rated electrically isolated inputs to perform differential measurement on the three-phase output.

Step 3: Measuring current unbalance

Use an oscilloscope with a current clamp on all three drive output terminals separately to measure the current draw on each terminal (see **Figure 5**).

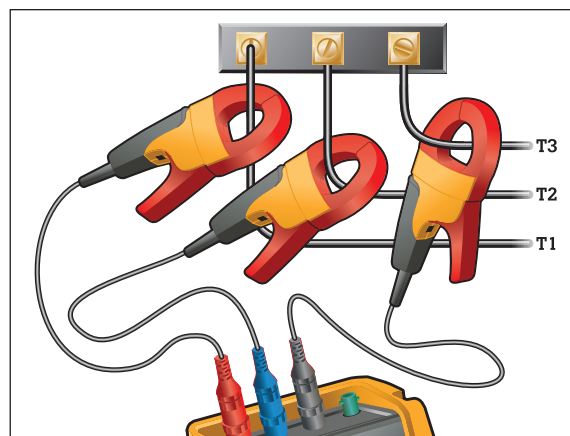


Figure 5. Measure the current through each phase using appropriately rated current clamps.

Because the current measurement will be made in a high-energy, electrically noisy environment, be sure to use the proper current clamp. If your test setup doesn't automatically evaluate unbalance, see the sidebar on manually calculating unbalance.

The level of unbalance should not exceed 10%.

- For every 1% of voltage unbalance, motor current unbalance will be 3% to 4%.
- If voltage unbalance is low, then excessive current unbalance could indicate shorted motor windings or phases shorted to ground.
- Generally, current unbalance for three-phase motors should not exceed 10%.
- Voltage unbalance will result in current unbalance.
- If the voltage unbalance is within acceptable limits, then any excessive current unbalance detected could indicate shorted motor windings or one of the phases shorted to ground.

Step 4: Volts/Hertz Ratio

The ratio of voltage to frequency, measured in hertz, determines the amount of torque produced by an ac induction motor. By keeping this ratio constant, the magnetic field inside the motor is kept at a constant level. This results in a constant torque.

Above the nominal frequency of 60 Hz, the voltage will not increase anymore, and the torque will decrease (see **Figure 6**).

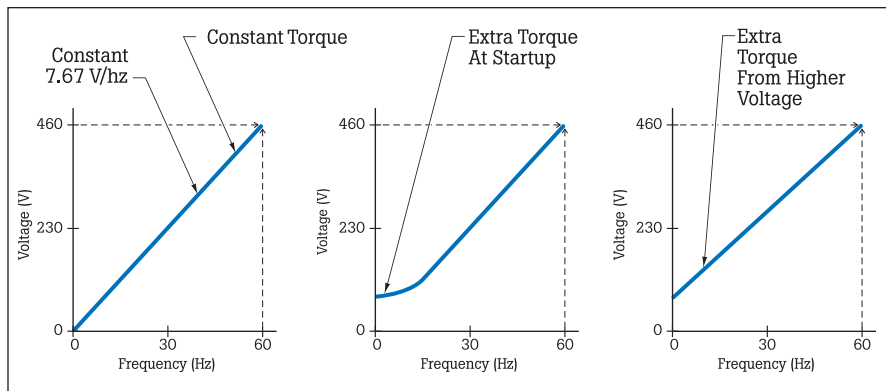


Figure 6. Voltage and frequency in constant-torque variable horsepower applications can be measured easily to verify proper drive programming and motor operation.

To measure volt/hertz ratio, use a digital multimeter with a V PWM option, where V PWM reflects the amplitude of the fundamental frequency, or an oscilloscope. The oscilloscope should simultaneously display the frequency of the PWM output and a voltage comparable to the motor nameplate rating (see **Figure 7**).

Use a current clamp to measure the frequency. It should be ~7.6 for 460 V motor, ~3.8 for a 230 V motor.

Step 5: Output reflections

Reflections occur as a result of an impedance mismatch or change in the current transmission path (see **Figure 8**). In a motor drive circuit, the peak of the reflection could be as high as the dc bus voltage level.

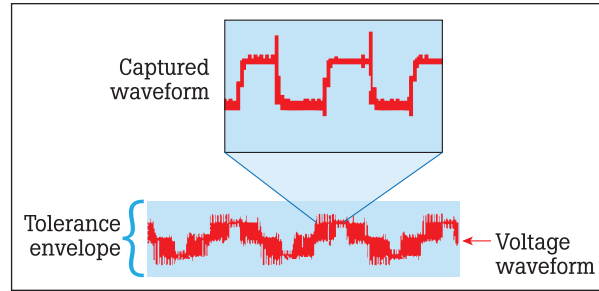


Figure 8. Note the voltage spikes on the trailing edge of this pulse width modulated (PWM) signal, as captured by an oscilloscope.

To use an analogy, consider what happens to a garden sprinkler when the flow of water is momentarily changed by someone stepping on the rubber hose. The pressure at the sprinkler head changes peaking as the built-up pressure is released. Using an overly long cable (>100 ft.) also can result in reflections along the length, measurable as transients.

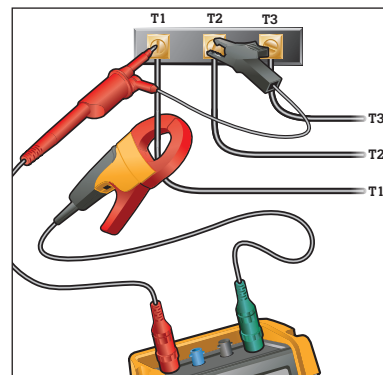


Figure 7. Setup for connecting the oscilloscope input to measure output voltage and a current clamp to measure output frequency.

The reflection itself manifests as spikes on an oscilloscope display in a wide range of waveforms, amplitudes and durations. As a rule of thumb, reflections or transients >50% of nominal voltage are problematic.

One possible solution includes shortening the conductors between the motor and inverter. Another solution is to increase the grade of cabling, thus reducing the impedance or switching to Inverter Rated Motors with a higher insulation value of 1,600 V or greater that can withstand the transients.

Most reflections are caused by fast switching dc voltage by the IGBTs (dV/dt). The IGBT is an element of the drive that functions like a very fast On/Off switch. The IGBT outputs dc voltage as a PWM signal on an inductive load. This causes very high inductive voltages over a very short (switching) time, also referred to as dV/dt.

The IGBT has a built-in free-wheel diode to compensate for this. However, transients are visible when the oscilloscope “glitch detect” setting is switched on.

Measuring and interpreting output reflections

Most digital multimeters don't have the sample rate and frequency bandwidth to detect short, fast output transients. For this reason, use an oscilloscope connected to the motor terminals as illustrated in **Figure 3**. The B input trace in **Figure 9** demonstrates how excessive reflections appear in waveform view. Knowing what a particular distortion looks like helps reduce the time necessary to identify root cause.

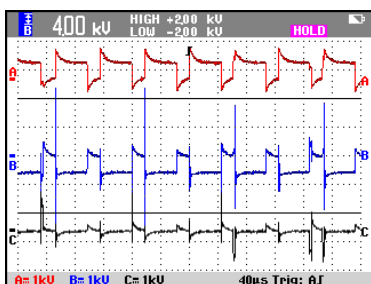


Figure 9. This shows an oscilloscope screen capture of a PWM drive signal with excessive reflections (B input trace).

Conclusion

Determining the root cause of motor drive system failures requires systematically performing tests and measurements at key points in the system. Specifically regarding power supply, differentiate between power input and output and apply both different measurement techniques and evaluation criteria at each. With a little knowledge, those measurements can guide troubleshooting to the true root cause, bringing the system up as quickly as possible.

Manually calculate unbalance

If you manually measured voltage or current, the next step in determining if there is a voltage unbalance is to calculate the percentage unbalance.

- Determine the voltage or current average.
- Calculate the largest voltage or current deviation.
- Divide the maximum deviation by the average voltage or current and multiply by 100.

This results in a percentage of voltage or current unbalance for the supply voltage to the drive input. Here's an example:



$$\% \text{ unbalance} = (\text{Max deviation from average V or I} / \text{average V or I}) \times 100$$

Example:

$$30 + 35 + 30 = 95$$

$$95/3 = 31.7 \text{ average current}$$

$$35 - 31.7 = 3.3 \text{ maximum deviation}$$

$$3.3/31.7 = .104$$

$$.104 \times 100 = 10.4\% \text{ current unbalance}$$

In this example, the current unbalance is 10.4%. Depending on the rating and impedance of the circuit, this either could be acceptable or a big problem. If the load current is close to the rated current for the circuit, high levels of unbalance can cause nuisance breaker tripping.

Consideration: A manual unbalance calculation is a point-in-time determination of voltage or current unbalance. A power quality analyzer will show voltage or current unbalance in real time, including any variations in unbalance.

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