FLUKE®

Harmonics
Understanding, measuring, and interpreting results

Application Note

From minor control trips to compressor and transformer failures, harmonics can impact every type of HVAC equipment.

A technician recently documented the fault codes received when a chiller circuit tripped. A close look at the chiller revealed that the indicated faults did not match up to what was going on with the unit. Diagnostics indicated the chiller had undergone a "phase reversal" and, sometime later, a "compressor motor overload." Also, a "condenser pump variable speed drive fault" warning had been received.

It is highly unlikely that a phase reversal had occurred—this is generally an installation issue. Investigation revealed that both the compressor and the condenser pump drive appeared to be operating normally. While the problem causing these nuisance trips could be a component in the control panel itself, another candidate, often overlooked, was harmonics.

Harmonic currents and the electrical distribution system

Harmonic currents flow in a circuit at multiples of the fundamental 60 hertz (Hz) frequency. For example, current flowing in a circuit at 180 Hz is the third harmonic (60 Hz multiplied by 3). Such currents are not directly indicated on multimeters and are usually not found until unusual control and equipment problems begin to surface. Comparing the current readings from an average-responding meter to that of a good quality true-rms meter on the same circuit will help indicate harmonic issues. The average-responding meter will indicate only the 60 Hz current and the true-rms meter will indicate a combination of 60 Hz and harmonic currents.

The production and reflection of these harmonic currents back into the electrical distribution system can cause problems. Here are some examples of harmonic issues:

- Improper operation of control circuits
- Faulty shutdowns of electronically controlled chillers and air handler units (AHUs)
- Overheating of solenoid coils, requiring replacement
- Overheating of 480 volt transformers supplying 208Y/120 volt HVAC systems
- Overheating of fan and chilled water pump motors

With some basic understanding, today's professional technicians and engineers can isolate harmonic problems to their source and mitigate their effects by either replacing the offending item or installing harmonic filters.

Modern electronic circuits must convert the supplied 60 Hz alternating current (ac) into direct current (dc) since the electronics operate using dc voltage and current. The waveform of the current drawn by these electronic loads reveals that the current waveform does not correspond to the voltage waveform applied. Thus, such electronic loads are referred to as “nonlinear” loads. These nonlinear loads produce the harmonic currents reflected back into the system. Harmonic currents appear across a wide spectrum, but generally diminish as the frequencies get higher and higher. See **Figure 1**.

While different harmonic frequencies produce their own unique effect in a circuit, when combined they distort the original 60 Hz sine wave. Distorted power at the input to electronic equipment can cause the erroneous trips and alarms sometimes occurring in control circuits. Some harmonic currents produce excessive heat. Other harmonics actually produce a reverse torque in motors—reducing efficiency and overheating motors.

Troubleshooting

Troubleshooting in any circuit means properly identifying the root cause of the problem and isolating the source. If routine troubleshooting checks in an electrical circuit with nonlinear loads do not reveal the problem, consider looking for harmonics.

To make an initial test for the presence of harmonics, measure with a clamp meter that is capable of indicating total harmonic distortion (THD). THD provides one figure to indicate the total of the harmonics present. THD for voltage should not exceed 5 % and can be easily read on a clamp meter. THD for current will run considerably higher. Excessive THD for voltage means any of the previously mentioned problems can be occurring and corrective action should be taken. To get more detailed information, use a power quality analyzer to further investigate the magnitude and effects of the individual harmonics.

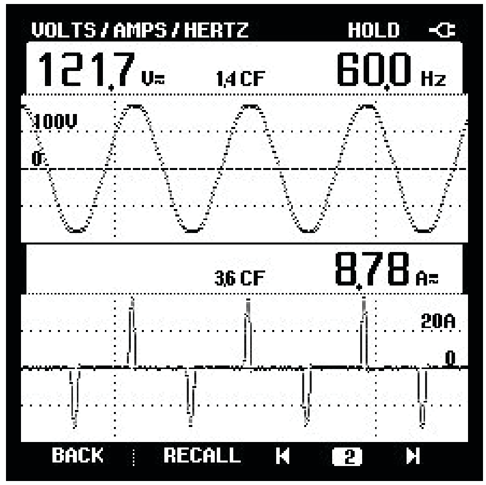

Figure 1. Nonlinear load. Observing one single-phase set of voltage and current sine waves drawn by a variable frequency drive (VFD) readily shows that the current waveform (lower) does not conform at all to the voltage waveform applied. Such nonlinear loads produce harmonic currents that flow into the distribution system.

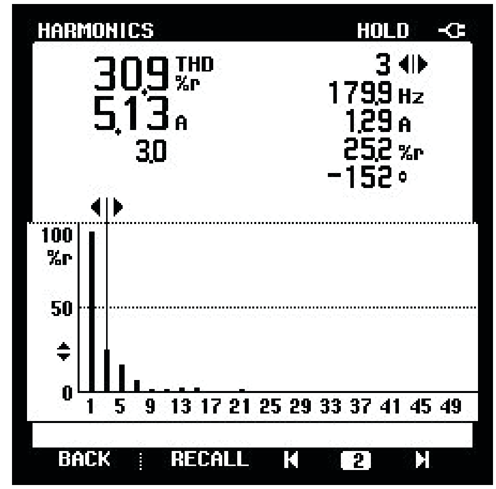

Figure 2. Harmonics. In this power quality analyzer screenshot, the harmonic frequencies appear on the harmonic axis. The percent to which the specific harmonic frequency is a component of the fundamental 60 Hz frequency appears on the vertical axis. The cursor has been placed over the third harmonic frequency, and this third harmonic current appears to represent approximately 25 % of the 60 Hz frequency.

The power quality analyzer measures the level of each harmonic frequency as well as many other issues related to power quality. Power quality analyzers are available for both single-phase and three-phase circuits. They are generally placed on the circuit for a period of time to record disturbances in the line power. Data can later be downloaded to a PC for analysis.

In addition to measuring harmonics, power quality analyzers record other disturbances that can cause malfunction of control circuits. For example, “swells” are increases in voltage above the rated values and can damage equipment. “Dips” are decreases in the applied voltage and will causes spurious shutdowns and false alarms in variable frequency drive (VFD) and programmable logic controller (PLC) circuits.

THD and harmonic levels should be measured at the point of common coupling (PCC). When troubleshooting, the PCC is the point at which the nonlinear loads suspected of causing the problem connect to the remainder of the distribution system.

For example, a quick check at the motor control center (MCC) cubicle supplying a VFD will indicate whether the VFD is creating a potential harmonic problem. Look for THD for voltage approaching 5 % and check for the presence and the levels of different harmonic frequencies. See **Figure 2**. Harmonic output from the VFD will vary as the VFD output varies. It may be necessary to set up the power quality analyzer to record values for a period of time, because ventilation system requirements vary.

What to do when you find excessive harmonics

If you find excessive harmonics, look at each case individually and then make decisions. You can purchase harmonic filters and place them as close as possible to the equipment producing the harmonic currents. It is best to consult the manufacturer of the equipment, or an outside engineering consultant, to find the best harmonic filter for the problem. There is no “one size fits all” when it comes to such filters. You must consider the size of the load and the particular harmonics being generated.

Another alternative is to isolate the problem equipment using an isolation transformer. Relocating either the nonlinear load causing the problem, or the affected circuit to another distribution panel, may help. For example, if the affected controls are supplied from the same panelboard as the nonlinear load causing the problem, moving the control circuit to another panelboard may help alleviate the problem. Harmonic problems tend to diminish moving farther away from the nonlinear load.

Summary

Today's HVAC electrical equipment is a combination of three-phase VFDs supplying fan motors, compressors, water pumps, and cooling tower fans. Control circuits contain PLCs and proprietary electronic circuits that maintain temperatures, flow rates, and pressures. See **Figure 3**. While VFDs are examples of nonlinear loads causing many harmonic problems, other sources of harmonics can range from copy machines in office areas to a neighboring plant on the same electric utility supply line.

The effects of harmonics on HVAC equipment may be nuisance trips on controls or major motor or transformer failures. Initial checks using two clamp meters may easily identify potential harmonic issues. However, the power quality analyzer is the key to measuring, isolating, and correcting harmonic problems. Modern HVAC equipment requires engineers and technicians to understand the cause and effect of harmonics, and how to measure and interpret harmonic values if related problems are to be solved.

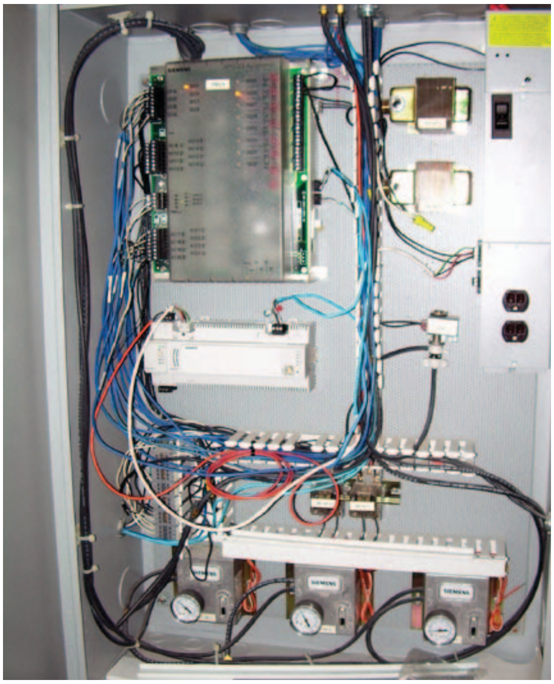

Figure 3. Ventilation controls, such as the electronics and PLC in the left-hand side of this cabinet, can be affected by harmonics—resulting in improper operation of the controlled equipment.

Measuring and interpreting harmonic numbers

Harmonic numbers are assigned in their relationship to the fundamental (or 60 Hz) frequency. To find the frequency of the harmonic current, multiply the harmonic number by the first, or fundamental, frequency of 60 Hz.

Harmonic Number	Frequency of Harmonic Current
1st	60 Hz (fundamental)
2nd	120 Hz
3rd	180 Hz
4th	240 Hz
5th	300 Hz
6th	360 Hz
7th	420 Hz

Harmonic effects

All harmonics tend to distort the original fundamental 60 Hz sine wave. The total harmonic distortion (THD) for the voltage sine wave should not exceed 5 % when measured on a power quality analyzer.

Many VFDs in use today are 6-pulse drives (six diodes in their converter circuits). These drives produce harmonics at the 5th, 11th, 13th, 17th, 19th, etc. If high levels of harmonics exist at these frequencies, consider placing a filter on the input power to the drive.

Basic troubleshooting steps to isolate harmonics

CAUTION: Troubleshooting requires work on live circuits; be sure to follow the requirements of NFPA 70E: Standard for Electrical Safety in the Workplace®.

1. Check possible causes unrelated to harmonics:
   a. Inputs and outputs to electronic controls
   b. Faulty relays, sensors, etc.
2. Determine the possibility of harmonics in the distribution system by taking clamp ammeter readings with an instrument that measures total harmonic distortion.
3. Use a power quality analyzer to identify the harmonic frequencies present and their magnitudes. Record values over time at the feeder supplying the equipment.
4. Verify that total harmonic distortion (THD) for voltage does not exceed 5 %. This is the generally accepted maximum value and would indicate potential problems.
5. Corrective action often includes a specially purchased filter placed on the input power to the load producing the harmonics. This minimizes the reflection of harmonic currents back into the distribution system.

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