FLIR CM275 multimeter showing infrared camera monitoring breaker temperatures in an electrical panel.

Looking for some hot stuff, baby!

BY MICHAEL MATTHEWS

Using measurement tools to find problems before they become a "disco inferno."

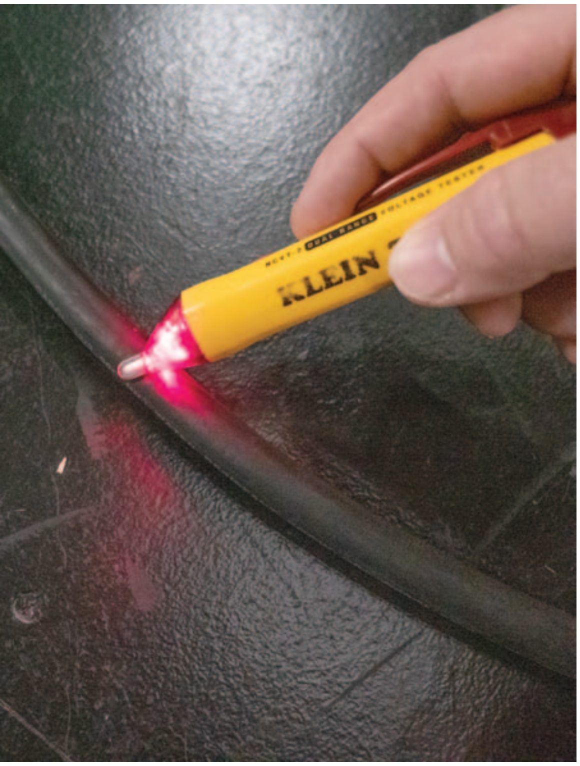
TOO OFTEN ELECTRICAL SAFETY is left to the electricians. Electrical hazards present a danger to everyone, and so the responsibility is on everyone plugging in anything, from an iron or a power tool to a rig full of speakers and lights and hoists, to be part of the risk management process. Electrical safety essentially comes down to two main hazards: shock and fire. Both of these hazards are equally present, but recognizing them can be quite different. In this article I will discuss a handful of measurement tools and techniques for finding problems—tools that every technician should have in their toolbox.

Recognizing shock hazards

Shock hazards are generally found through a visual inspection: open panels, exposed copper in a wire or connector, lack of proper grounding or broken ground pins on plugs. Some shock hazards are not visible; and for those there is a cheap easy tool out there, the voltage detector pen. They come in various forms, starting with the most basic that just lights up when there is voltage over a certain level. For personal safety, the threshold should be no higher than 50 V. There are options available that will indicate different levels of voltage. These are small, easy to carry on your person, and can be a great way to identify live conductors before they bite you.

In the shock hazard category also comes ground safety. By maintaining the integrity of the low-impedance ground fault path, you help prevent both shocks and fires in the event of equipment failure. A tool for this job is the receptacle tester. This affordable, easy-to-deploy device can let you know if a circuit is wired properly and safe to use. It will identify a handful


A multimeter can check the ground continuity between the connector and the equipment's housing.



A voltage sensor can help detect live conductors.

of hazardous circuit issues such as open ground or reversed connections. Another tool and technique in this category is a good multimeter with a continuity test function. Use the continuity tester to check your equipment ground integrity by touching one lead to the ground pin on the connector and the other to any part of the equipment frame that is metal. If it beeps (or whatever your meter does) to indicate a circuit path, then your ground is good. If it does not, the equipment needs to be pulled out of service for the troubleshooting and repair process.

Recognizing fire hazards

Fire hazards can be difficult to spot before they become big problems. Circuit overloading or equipment failure can cause a thermal runaway condition. Here's a common example: A connector is faulty and not making a good connection. This bad connection introduces heat and resistance, and drops the voltage delivered to the load. The load's current demand on the circuit increases. The circuit continues to heat, which causes more resistance, beginning a runaway cycle that will feed itself until the overcurrent protection trips. The danger here is if the insulation melts before the overcurrent protection trips, exposing conductors, or generating enough heat to start a fire. A faulty connector isn't the only thing that can start this vicious cycle: Undersized cable or improper equipment can create runaways as well. Proper inspection of equipment, cables, and connectors can help identify possible connection point issues, but once you're plugged in it's hard to see when a connector is on the road to failure until it's often too late.

Where infrared imaging really shines is in spotting potential problems.

Back to the good old multimeter. Any technician using gear that is fed by single-conductor feeder cable should have a multimeter that includes a clamp for measuring current. Using the clamp on a single-conductor feeder cable will let you monitor your current pull on each leg of power, so you keep within the manufacturer's specifications. These measurements also can guide you in balancing your power distribution, so each leg is as equally loaded as possible, which is best practice. It reduces current on the neutral and heat buildup in the transformer, helping efficiency. Additionally, the voltage measuring function of a multimeter can be used to check for voltage drop. By checking voltage at each end to the circuit you can find resistance in the circuit. On branch circuits, the circuit from the last overcurrent device to the equipment, the *NEC* allows

Clamp meter current reading corresponding to the FLIR infrared image in Figure 1.

for a maximum of 3% voltage drop. If any more than that, you need to confirm if your cable is properly sized and check for any bad connections causing excessive resistance.

The latest and greatest device for your tool kit to help monitor your equipment is the Infrared imaging camera. It's easy to use and provides data that can help you quickly isolate bad connections or overloaded cable, or indicate if you are approaching the operating temperature limits of your equipment. Using infrared imaging to check that you are within equipment specifications is straight forward. Your camera will show you a temperature reading for a hot spot, which you can then reference against the manufacturer's specification. Much of the industrial grade equipment used for entertainment electrics is rated for 90° C (194° F). Many of the consumer grade extension cords are rated for 60° C (140° F), so it's important to always check the specs.

Where infrared imaging really shines is in spotting potential problems. In this case you want to look for things that aren't like the other. With feeder, if you measure your hot legs and find them equally loaded, but the camera shows you one is at a much higher temperature than the others, you know there is a problem along the cable and it needs to be addressed. Infrared imaging can be especially helpful in isolating bad connection points. Bad connections account for a large amount of the fire hazards I come across. Cable takes a beating in production, especially on the road, it is common for the screws and bolts in connectors to vibrate loose. On an infrared image a bad connection point will just about jump out at you. The tell-tale sign of a bad connection is a hot spot along the cable where the heat dissipates as you get further away from the connection.

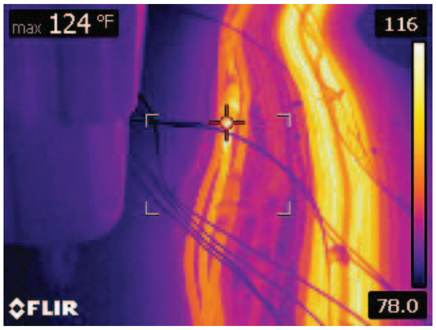


Figure 1 – A hot spot at a connection point indicates a bad connection.

Figure 1 shows a bad connection along a long feeder run. Notice the feeder group to the right all looks relatively hot, but it is all equally warm. That feeder was from a heavily loaded service; the heat is consistent among the conductors and well within manufactures specifications. The feeder group on the left is decidedly cooler, except at the connection point where it has a hot spot. As you get further from the hot spot, the cable cools down. This indicates a bad connection. The common practice for monitoring feeder prior to infrared was either the very basic, walk the line and put your hand on the cable to feel if it is warm, or using contact-based temperature sensors to test the cable. This can be labor intensive as it requires physically touching multiple points on the cable to determine temperature. The infrared technology is far more efficient and easier to deploy. You can get detailed data on long cable runs quickly and easily with the ease of a point and shoot camera.

Another note: It is common to group feeder conductors together and common practice is dressing the cables right next to each other for a neat and clean feeder river. Better practice, if you have the space, is to leave a little separation between each cable so that they have air around them to dissipate heat. Per the *National Electrical Code*, Article 520.54(c) bundled (conductors that are tied, wrapped, taped, or otherwise bound together periodically) feeder is not allowed in theatres and audience areas of motion picture and television studios, and it is not recommended anywhere else. Bundles create heat and resistance points, exacerbating thermal runaway conditions that might start with other failures in the circuit.

Infrared is better used in conjunction with other measurements, particularly current measurements. **Figure 2** shows a hot connection point at a rack. Again, this shows the tell-tale sign of a bad connection

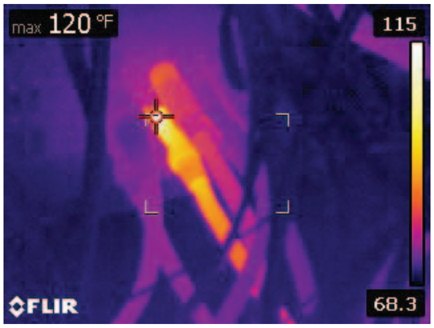


Figure 2 – A hot connection is a bad connection.

point: a hot spot that dissipates with distance. A hot cable is not necessarily cause for concern if the heat is consistent with the load on the conductor. In this case, the load was approximately 80 A on a 4/0 cable rated for 400 A, with a hot spot measuring 120° F. The other phases were measuring 80 A, but were at a temperature of around 80° F. This again indicates a bad connection.

> You can get detailed data on long cable runs quickly and easily with the ease of a point and shoot [infrared] camera.

Heat is not always an indication of failure. Electrical current generates heat, as long as that heat is within the operating specifications of the equipment and consistent with expectations. Sustained loads, or loads that are on for three hours or more will build up heat. When you have a sustained load, it should not be more than 80% of what your overcurrent device is rated for. This is because over time the load will generate heat, so you need some buffer to allow for this heat buildup to keep your circuit from exceeding the heat capabilities of the equipment and cable. **Figure 3** shows three phases equally loaded at a company switch. This 400 A service had its phases loaded at approximately 280 A per leg with a sustained load. Over the course of eight hours it would heat up to approximately 130° F. This is normal for a circuit loaded like this. The infrared imaging shows that the evenly loaded phases are operating at temperatures consistent with expectations for the load.

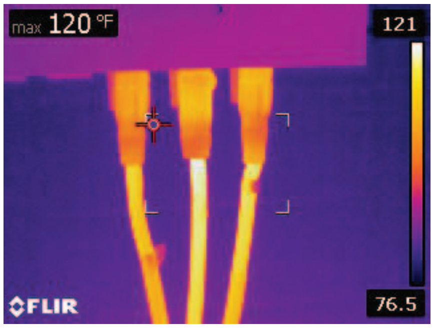


Figure 3 – Conductors uniformly warm, but not too hot, are good.

Monitoring your loads

Using these tools is fairly straight forward. Once you develop a protocol it does not require much time and energy, and can help you isolate and solve problems before they get out of control. I keep a log of electrical usage on the services I manage. This gives a reference point to determine possible issues. The question then remains: What do you do when there is an issue?

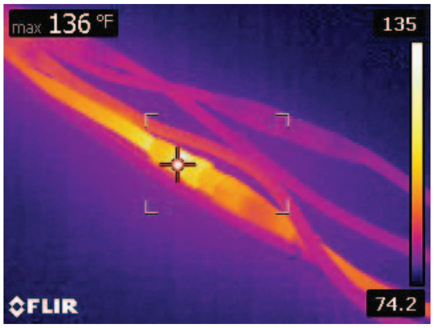


Figure 4 – Bad connections also can occur in neutral conductors.

Figure 4 shows a bad connection on a neutral conductor from a dimmer rack. Dimmer racks produce complex waveforms that create current-producing harmonics. This results in excessive heat and adds yet another contributing factor to failure. The challenges when identifying an issue are: what to do about it, and when to do it? Sometimes we notice these issues in the middle of a show or event. The decision can be difficult as to whether it is necessary to shut down the service immediately, or if the equipment can make it to a point where it will not disrupt the production to shut down the service and replace. The infrared imaging is again a perfect tool to monitor the heat, to make sure you are not approaching the limits of the equipment and to see if the heat stabilizes at some point. In this case, this neutral was in need of replacement, but it stabilized below 140º F and did not continue to rise. The production needed another hour or so of use, so we monitored the equipment and continued. Once we wrapped for the day we shut the service down, let the cable cool, and replaced it prior to our next use. Had the conductor continued to rise in heat, the decision to shut down would have been necessary.

Don't leave electricity to the electricians.

FLIR, (stands for Forward Looking Infrared) is leading the game right now in infrared imaging tools. There are a range of tools out there, from the most budget-friendly cameras that plug into your iOS or Android device, running around $300, to the much more expensive cameras running into the thousands of dollars. The FLIR CM275 combines a multimeter with a built in infrared camera and costs about $700. While there is an expense to this technology, the benefit provided in maintaining electrically safe conditions, in an efficient and easy to deploy solution, is worth every penny.

These tools and methods are things that every technician that plugs something in can and should employ. Don't leave electricity to the electricians. ■

FLIR makes a range of point-and-shoot style cameras that see infrared.

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