Stationary Battery String Testing Using Infrared Thermography

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Abstract

In stationary power battery strings, a single bad cell can cause failure. Cells have multiple modes of failure, each of which causes electrical instability within the cell. Many of these modes of failure will also have a thermal indication that accompanies them. These thermal indications can be detected with thermography and provide early warning signs of impending cell or circuit failures.

This article will explore the various modes of cell charging and power circuit failures, and how those modes of failure could present thermally. This testing methodology is applicable in any type of battery application, and for various battery types. Whether an application is using Valve Regulated Lead Acid (VRLA) cells, flooded lead acid cells, or any of the various other types, thermal indications of impending failure can be detected utilizing thermal imaging technology. This article will also discuss the conditions needed for successful battery inspections using thermography, as well as showing several case studies with supporting example images.

Introduction

To understand how thermography as a predictive maintenance tool applies to testing stationary battery applications, it is important to understand the overall application of thermography to electrical apparatus testing. Thermal inspections of electrical apparatus are one of the longest standing applications of infrared imaging. Shortly after the earliest commercial thermal imagers became available in the late 1960s, business entities that could afford the capital expenditure for a thermal imager were utilizing this remarkable technology to inspect generation, transmission, and distribution apparatus. Over the past years, there have been considerable breakthroughs in the market for thermal imagers. The cost of thermal imagers has dropped significantly, and image quality has improved. The availability of affordable imaging platforms has allowed the applications of infrared thermography to grow to inspection of industrial and commercial power systems.

Relationship of Current and Heat

Heat is inherent to electrical systems, as a result of what's known as the *Joule Effect*[1]*.* The Joule Effect occurs due to the relationship between current, resistance, and heat, which is demonstrated by combining Ohm's Law and Watt's Law.

Ohm's Law and Watt's Law combined:

Power = I x E and E = I x R

Power = I x (I x R)

or

$$P = I^2R$$

Watt's Law states that power that is converted to heat is the product of current and voltage. Ohm's Law states that voltage is the product of current and resistance. Therefore, when these laws are combined, we find that heat is the product of **current** *times* **current** *times* **resistance**, or as it is often denoted, $\mathbf{I^2R}$. In a normal circuit, with no abnormalities, heat will be present because of resistance to current passing through the conductors and circuit parts. Abnormal heating is generally caused by an increase in electrical resistance, usually at the junction of a conductor and circuit part.

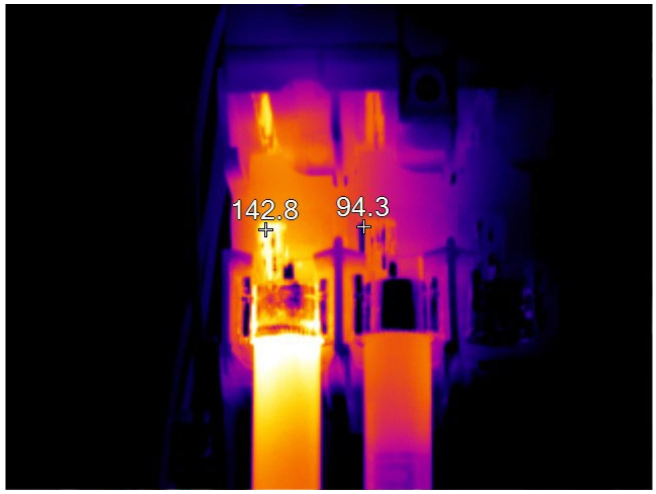

Figure 1. Thermal anomaly detected during inspection of commercial data center.

In an electrical circuit, abnormal heating is differentiated from the inherent heating by its pattern. When heat energy that is present due to normal circuit conditions is discovered with infrared thermography, the pattern is very even throughout the circuit. By comparison, heating that is caused by an abnormal increase in electrical resistance presents a much different pattern. As seen in Figure 1, the area of highest heating is at the point of the highest or abnormal resistance, with a pattern of cooling along the circuit part as it moves away from the high resistance. Electrical conductors are also good thermal conductors, and as such, they provide a path for the dissipation of the heat generated from the current passing through the point of increased resistance.

The relationship between current and heat is not linear. The relationship between current and apparent temperature is not either, but it is less than exponential. The reason for this phenomenon exists because of how we detect the change in heat output of the connection. The heat is produced at the point of the increased resistance. That physical point very often is *not* visible to the thermal imager as infrared imaging only detects and displays surface energy. Some of that heat energy is lost to conduction through the circuit part, and then the surface itself is subjected to convective cooling. The thermal imager only sees the energy emitted from the surface, which is not the entire amount that is being generated by the current passing through the point of increased resistance.

Because of this relationship between electrical current and heat generation, the greatest advantage in detection of increased resistance is realized when current through the circuit is at its highest. In the case of intercell connections, load testing provides the best conditions for the discovery of anomalous thermal conditions. For optimum results, the National Fire Protection Association document, *NFPA 70B Standard for Electrical System Maintenance*[1] recommends current levels to be at least 40% of full or rated load. At load levels below 40%, there may not be sufficient generation of heat at the point of abnormal resistance for detection on the inspection surface. As such, infrared thermography inspections of battery strings on float charge are not the best candidates for inspection of intercell connections. For a 100Ah battery the increase in current from float to full discharge can go from as low as 100 milliamps to as high as 100 amps. That's an increase of 99,900%. No; that is NOT a typo. With that kind if increase in current, imagine the increase in heat generation

Detectable Thermal Anomalies in Batteries

The relationship between temperature and battery life is well known, and is addressed in a number of standards. Optimum ambient air temperature around a VRLA battery is 22°C +/- 5°C (72°F +/- 9°F)[3]. This is applicable to batteries inside of enclosures as well. They will operate in temperatures outside of these parameters, but there can be a drastic reduction in the life of the cell, as well as issues with warranty replacement, since most manufacturers base their specifications on industry recommendations. Reduction in battery life as a result of excessive operating temperatures is approximately 5% for every 1°C, or 1.8°F above design. Thermal imaging can be utilized to monitor the thermal condition, including ambient conditions, of battery systems under any mode of operation, to help ensure that conditions conducive to maximum battery life are maintained.

Additionally, a condition that can be detected thermally in VRLA batteries on float charge is thermal runaway. Thermal runaway is caused when the amount of heat internal to the battery increases to a level that is unable to be dissipated on the exterior surface. There are a number of causes for thermal runaway to occur, one of which is an increase in electrical resistance internal to the cell. When this occurs, the result is an increase in the amount of power converted to heat. The I^2R relationship applies to this increase in internal resistance. Once internal cell resistance increases, greater levels of heat energy are generated inside of the cell.

Guidelines suggested by the IEEE Battery Working Group suggest that cell temperature should be considered abnormal when they are greater than a 1-2 degree Celsius separation from ambient for the string[4]. One of the reasons that infrared thermography inspections of VRLA cells on float might not be considered is due to the presumption that modern thermal imagers are incapable of resolving such small differences in surface temperatures. This simply is not true.

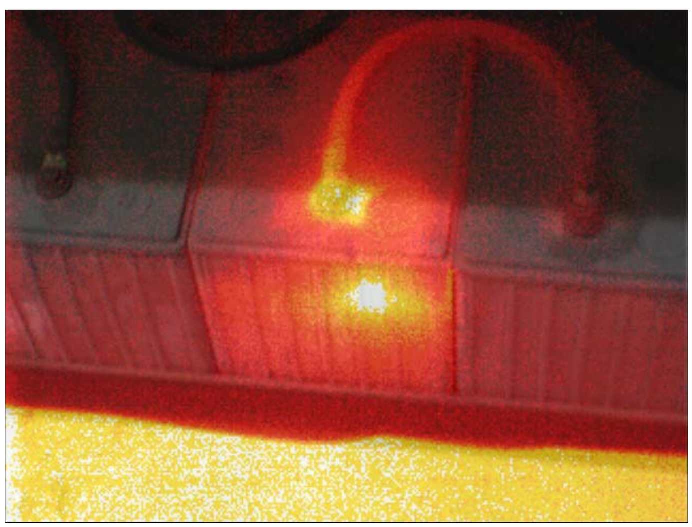

Figure 2. A blended thermal image of a VRLA jar on a float charge in a stationary power application

In addition to the capability to resolve differences in surface heat energies down to fractions of a degree Celsius, thermal imagers also provide a visual representation of the thermal condition that is discovered. Figure 2 depicts a blended thermal image of a VRLA jar on float charge in an industrial stationary power application. A "blended thermal image" simply means an image that has an overlay of the corresponding digital photograph of the object interest. Several modern thermal imaging processing software packages have this capability. The blending function has been utilized in this image to provide perspective to the thermal pattern. This discovery was made during a semi-annual electrical infrared thermography inspection in this facility where the VRLA strings had not been previously inspected.

There had been no other indications of impending failure of this string. The thermal inspection of the string was accomplished in less than a minute, by panning the camera along the length of the string, with contrast settings at their most sensitive to make very minute differences in heat energies on the surface more readily apparent. The addition of thermal imaging to existing periodic maintenance actions adds virtually no time to the normal testing action. The process of further optimizing the thermal image, saving the images to the internal camera memory, and taking notes on the system conditions took less than five minutes in this particular case but the positive impact was immeasurable.

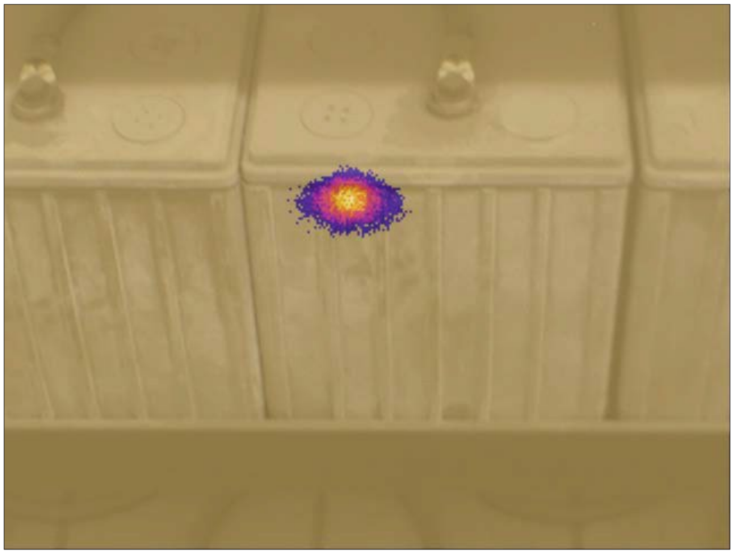

Figure 3. A blended thermal image of a VRLA jar on a float charge in a stationary power application

Figure 3 is an additional example from an inspection of a commercial data center. This image is also blended, again to provide perspective of the installation. This facility had provisions in place for quarterly PMs of the uninterruptible power supply (UPS) and associated stationary battery applications. At the PM interval just prior to this thermal discovery, no indications were present in terms of an increase in float current or AC ripple measured on the string. However, a thermal anomaly was again detected in mere seconds of inspection time.

Conclusion

Discoveries such as these demonstrate the potential of applying infrared thermography inspections to existing VRLA maintenance and testing actions. Often the application of thermocouples for the purpose of predicting thermal runway is cost prohibitive and requires additional time to compile and analyze findings. Thermal imaging is fast and noncontact. Price points for imagers with resolution and features required for this type of application are quite affordable, especially in light of the potential cost avoidance related to early discovery of increased cell resistance. With NFPA 70B now elevated to the status of a standard, more and more IR inspections will be performed for other electrical apparatus in facilities where stationary power systems are installed. Adding battery strings to inspection lists should be an easy decision.

Thermal imaging as part of a comprehensive battery maintenance and testing strategy can add value from the first inspection and should be considered as integral a part of battery programs as are other testing methodologies. Application of thermal imaging can provide immediate verification of operating temperatures, as well as measurements of intercell connections and external jar temperatures. Thermal imaging can be utilized alone, or to correlate other temperature measurement and monitoring techniques.

References

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