Illuminating Wet Cells: An optical Infrared Electrolyte Level Detector

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Abstract
This paper presents a new novel optical infrared electrolyte level detector with insight into the technology it is based on. It reviews different liquid level monitoring approaches and explains why electrolyte level detection has requirements that make conventional and previous solutions unsuitable. The paper explains why this technology is well suited for utility substation applications. Best practices and a glimpse into future versions of the electrolyte level monitoring technology will also be presented.

Introduction
According to the NERC PRC- 005 standard the maximum maintenance interval for inspection of electrolyte level of flooded VLA batteries is every four calendar months. This can be accomplished either by manual site maintenance visits or the use of a battery monitoring system equipped with electrolyte level detectors. Many utility substations are at remote locations where frequent visits per year would be inconvenient and costly, and so a remote monitoring system can be very cost effective. NERC also requires that accurate records be maintained, which if data is gathered by numerous individuals rather than a monitoring system, it is prone to significant human error. The data also needs to be integrated, analyzed and stored in a secure location for future reference.

There are many fluid level detection technologies utilized in a variety of industries.

Technologies include:

- Optical – with measurement device submerged in the liquid
- Optical directed from the top of the container towards the fluid surface
- Fluid pressure
- Float switches
- Ultra sound technology inside the container to measure distance of fluid level from top of the container
- Conductive rods placed at appropriate heights inside the container to detect conductive fluids surfaces

A challenge with these technologies is that they are invasive. All of them are fitted inside the container and while this is appropriate for use with many liquids and containers, these technologies expose the apparatus to sulphuric acid and with VLA cells there is limited room to mount detectors inside the container. Monitoring electrolyte levels in VLA cells requires a non-invasive technology such as ultra-sonic radar, electrical capacitance or an optical technique which can operate on the outside of the container and detect the fluid level inside. There are several electrolyte level detectors on the market using these techniques.

Numerous experiments were conducted on these non-invasive technologies before developing this novel infrared optical electrolyte level detector. The resulting design is an extremely reliable, low cost solution that works over a wide temperature range. The selected technology uses infrared LEDs with a wavelength of 940nm –well outside the visible range of 400 – 700nm. Utilizing IR light reduces sensitivity to labels and markings on the container, as many substances are transparent to IR light. A secondary benefit is that there is limited sensitivity to ambient light at this wavelength.

Operating Principle

The picture below shows what happens when you shine light into the container below the electrolyte surface. As you can see, light is reflected from objects in the container and particles in the electrolyte causing the electrolyte to illuminate. However, very little light penetrates the liquid surface as it is reflected back into the liquid due to the high angle of incidence at the surface causing total internal reflection so the air space above the electrolyte is much darker than the liquid.

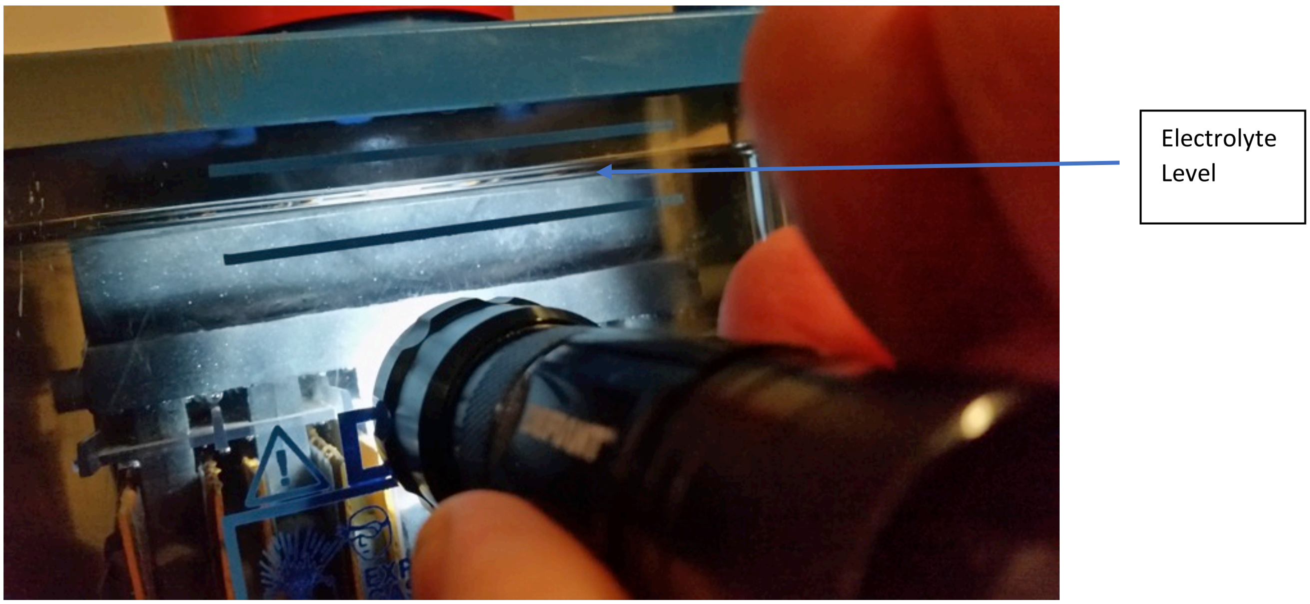

Figure 1. Light Below the Liquid Level

When the light is shone into the air above of the electrolyte some light is reflected within the cavity, but again, very little light penetrates the electrolyte surface, keeping the electrolyte dark.

Figure 2. Light Above the Liquid Level

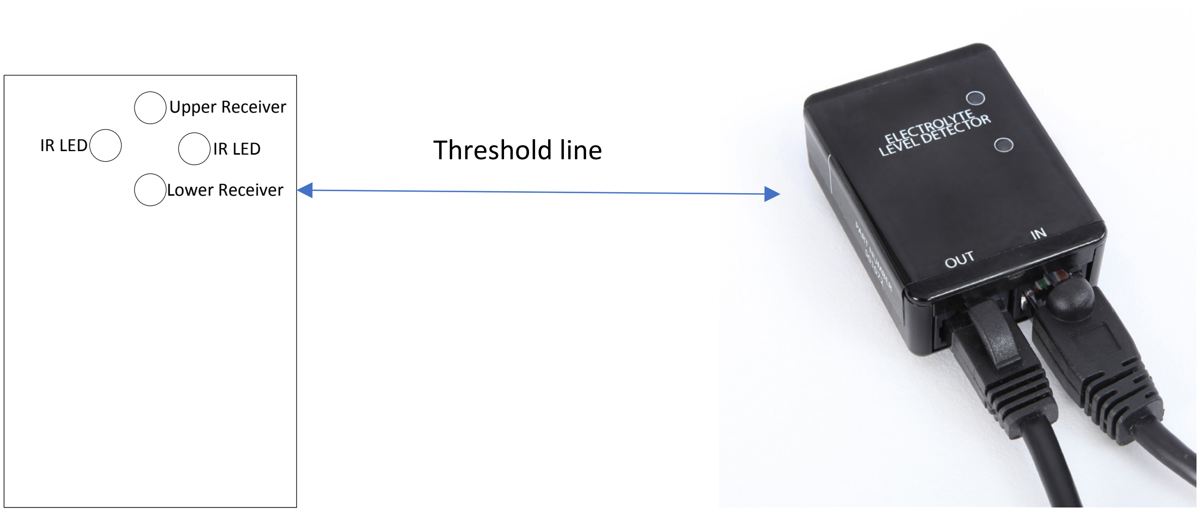

Figure 3. Optical Placement Diagram for the Infrared Level Detector

One manifestation of the technology is to use two IR receiver devices: one above and one below the IR transmitters. As you can see from the diagram in Figure 3 we have positioned two IR receivers vertically with IR LED light sources positioned halfway between. The threshold line at which the detector gives a low-level alarm is centered on the lower receiver.

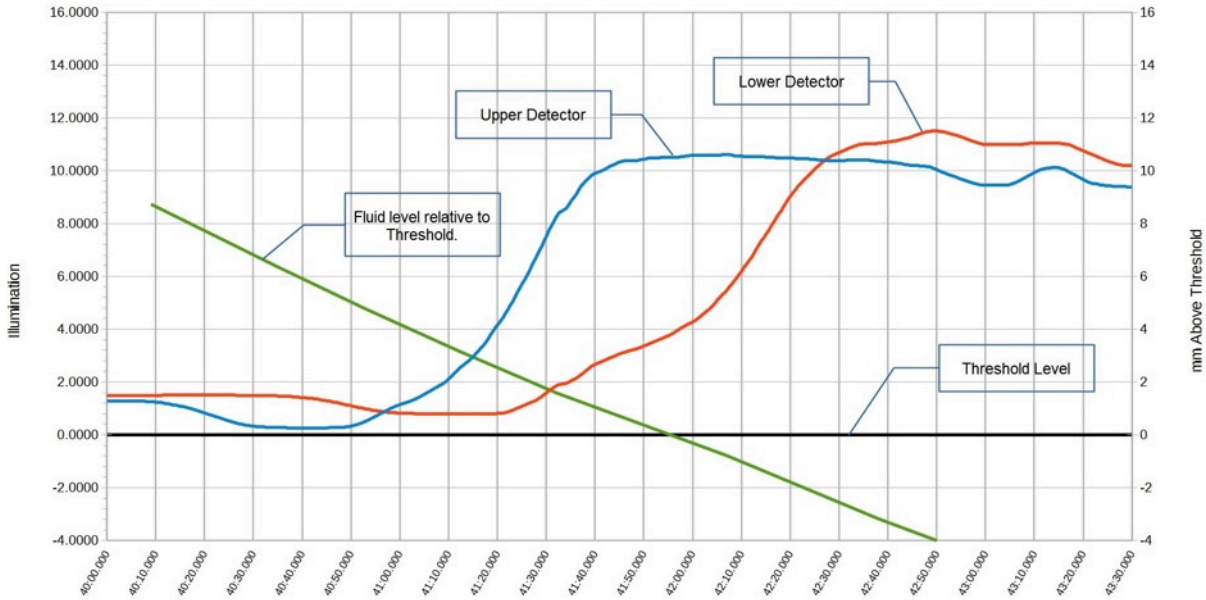

Figure 4. Graph of IR Receiver Output Samples for the Two Detectors as the Electrolyte Level Falls

This graph illustrates the change in detected light by the upper and lower detectors as the fluid level changes. The X axis shows time as the electrolyte level falls as it is drained from the container with the two Y axis's showing relative illumination and surface level above the threshold in millimeters.

How the Detector Works

The electrolyte level detector is fitted to the container such that the threshold line is set where you want the unit to alarm when the level drops. This is user selectable but most users fit them just below the low-level line while others set it just above or on the low-level line. This is totally at the discretion of the installer. It is noted that some maintenance crews do not want to roll a truck to fill containers where the level is still above the line. The electrolyte detectors are connected to a central controller that continuously scans the devices and records the results.

When the electrolyte level detectors are installed, a site calibration is performed. This site calibration ensures that the detector will work on any container. For proper calibration both receivers should be below the surface of the electrolyte. Common practice is to top off the containers prior to installation. This allows the device to calibrate for the container translucence, the reflective properties of the electrolyte, placement of plates and the effects from markings on the container including the low-level line itself, so there is no interference with the measurement.

As you can see from Figure 4, this represents hundreds of samples of sensor output measurements captured during the changing of the fluid levels in the container. After site calibration with the cell filled to the high-level mark, both detectors are below the fluid level and receiving light reflected from the electrolyte. As the fluid level drops to uncover the upper receivers its signal output drops as it is exposed to air and not the reflected light from the electrolyte. At the same time, the light source is still beneath the electrolyte and the lower detector is still emitting the full output signal. As the fluid level drops further the LED light source begins to shine into the air space above the electrolyte and so the signal out for the upper receiver starts to increase.

Note there is a much higher signal output when the light sources and detectors are exposed to air than when both are exposed to the electrolyte as the electrolyte absorbs more of the light than the air and will disperse and scatter the light thus reducing its intensity.

As the level drops across the lower detector it starts receiving light from the air and its output signal rises until it eventually matches the upper detector. The unit triggers an alarm when the ratio of the upper to the lower receiver reaches a pre-set value indicating the electrolyte is precisely at the predetermined location relative to lower receiver.

As you can see from Figure 4 the ratio of output of the two detectors changes rapidly with electrolyte level change making it a very precise and reliable measurement device. The electrolyte level detector is accurate and repeatable to 1mm as illustrated later.

To protect against oscillating alarms the detection algorithm includes 2 mm of hysteresis. After the unit generates an alarm the level must go up by at least 2 mm for the alarm to end. This prevents the alarm from oscillating on and off as the level changes slightly for example due to a change in the state of charge.
An important consideration in the design is to measure the light emitted from the level detector and to ignore background illumination. By pulsing the light source LEDs, the detector calibrates out any background illumination by subtracting it from the measured signal.

Infrared light penetrates and works well with both transparent and translucent containers.

The use of two detectors provides a more accurate and reliable trigger point detection as the upper receiver serves as a reference, which is then compared to the lower threshold detector. For accurate level detection, the device generates an alarm when the upper detector is in air and the lower detector is partially in air and partially under the electrolyte or if both detectors are seeing the high reflectance in air for instance if the level is below both detectors.

It is also important that the detector generates an alarm if it is removed from the container or accidentally knocked off the container and thus unable to detect the electrolyte level.

The level detectors are daisy chained together and can support strings up to 250 detectors. It was important to make the detector narrow enough to address all the utility market applications. Therefore, the detector is sized for the narrowest cells in the market. The detector can be attached to multi-cell containers with 4.5 cm width cells. The detectors are attached to the containers using a high strength acrylic adhesive tape that will not damage the container. The detector can be easily installed and removed.

Most electrolyte level detector systems will give an indication locally with an indicator on each cell in alarm. However, most devices do not provide a remote indication of the cell in alarm. Without specific indication of the source of the alarm, it is difficult to determine exactly which cell is in alarm if the status changes between the initial alarm and the next site visit. For instance, if a container is cracked and there is a slow leak, the infrared electrolyte level detector records exactly which cell was low and this record can be used to highlight if a cell is repeatedly going lower than those around it. Each detector in the system indicates which cells are in alarm and that information is stored both locally and available remotely in a SCADA or historian. See figure 5.

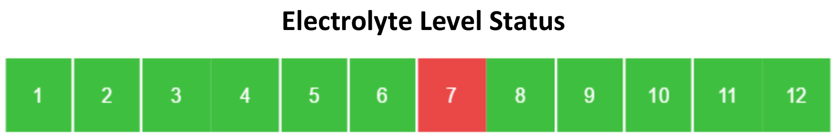

Figure 5. The User Interface Shows Which Cell has a Low-level Alarm

The current product alarms when the level drops to the threshold line, a future development could compare the signal for the upper and lower detector to give an indication of how far the level was above the threshold.

Accuracy and Repeatability Testing

To verify the accuracy and repeatability of the measurement device an experiment was conducted. A level detector was mounted to a container, and then using a high precision syringe, fluid was added and removed. The fluid level change was calculated based on the volume of fluid relative to the surface area of the container. This approach provided both precision and repeatability.

As you can see from the graph below in Figure 6, the detector's repeatability was well within 0.1 mm in this sample and demonstrated comparable results for each sample taken. With this level of repeatability, the only variable that could impact accuracy is the positioning of the label that sets the threshold line and the placement of the device on the container. Therefore, the device was given a specification of +/- 1mm since the other variables should be factored.

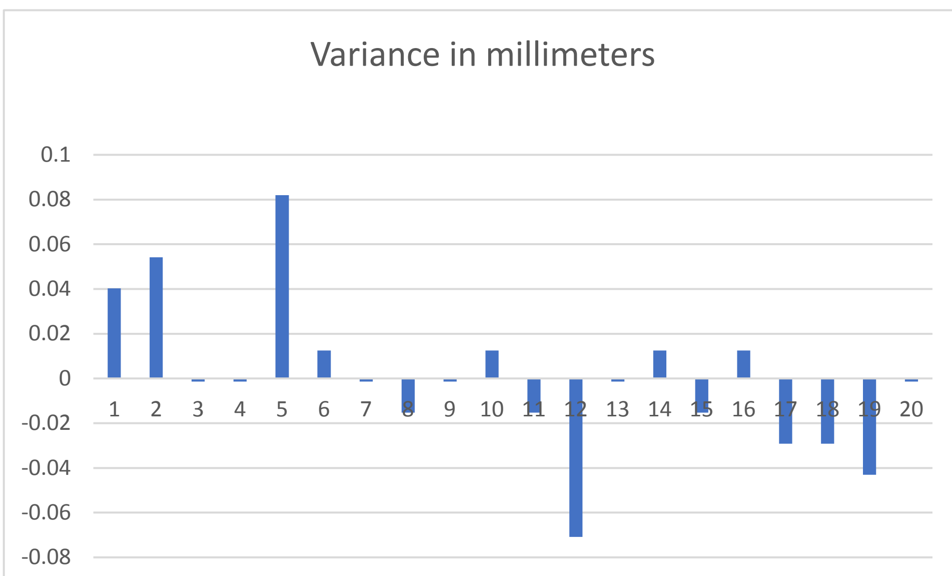

Figure 6. Threshold Level Repeatability

Advantages of the Optical Infrared Technology for Monitoring Electrolyte Level

While many elements of this technology have been applied to other problems, this specific implementation had not been applied to battery electrolyte level monitoring. The genesis of the design stems from early work by the author where he was involved in the design of dual beam spectrophotometers for use in the measurement of color.

The use of a dual beam approach allows for a more reliable measurement. In the case of our electrolyte level detector we are comparing the output of a reference beam to the threshold beam, which removes the potential for drift. The electronics design is very simple thus providing reliable performance over a wide temperature range – 0° C to 60° C. It was considered that most remote batteries are stored in a controlled environment but this is not always the case and therefore, it was determined that to meet the full addressable market, the design should be robust across a temperature range far beyond typical battery operating environments. It was also determined that the device needed to be easy to install and remove, since users would move the device from one set of containers to the next, or would reuse the device if a container was replaced.

The device needed to be extremely small so that it could fit any VLA containers. Often multi-cell containers have a cell width of less than 4.5 cm. Using the infrared light allowed the technology to work on tinted or colored containers and penetrate many labels and markings on the container. Building a device that works in every application means that customers and installers will experience fewer problems using the technology.

It was also important to provide control for the technology remotely. A device that will not allow for remote calibration and that doesn't provide clear identification of the cell in alarm means that the service technician doesn't understand the exact issue or the magnitude of the issue until arriving at site. With this device, alarms and status are available via Modbus or DNP3. In the unlikely event a unit is unexpectedly removed from a container, the device goes into alarm.

While it is common for technicians to visit every site on a routine basis and electronic monitoring is not an absolute necessity, however, having continuous electronic monitoring allows the service team to perform condition-based maintenance. Visiting sites that are at risk as soon as the risk occurs and having the electronic record means data preservation and reporting are made simple.