ABSENCE OF VOLTAGE TESTERS: A GUIDE TO LISTING REQUIREMENTS

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Abstract –This paper provides a description of Absence of Voltage Testers (AVTs), their use, listing requirements (as defined in UL 1436), and application considerations. A discussion of how AVTs can be used to support NPFA 70E work practices, as well as advantages and limitations are also addressed.

Index Terms — Absence of Voltage Tester (AVT), voltage testing, electrical safety, listing requirements, UL 1436, NFPA 70E.

I. INTRODUCTION

Absence of Voltage Testers (AVTs) are permanently mounted testers intended to be used to determine if a circuit part is de-energized before opening doors or covers to access electrical equipment. They combine the best features of handheld voltage testers and installed voltage indicators and leverage safety by design principles to address their limitations. AVTs are a new product listing category that was added to UL 1436, the Standard for Outlet Circuit Testers and Similar Indicating Devices, in September 2016.

A. The need for AVTs

Performing work without turning off power and verifying that a de-energized condition exists is one of the leading causes of workplace injury. A study on common practices with voltage test instruments found that over a five-year period 18.3% of facilities surveyed had experienced a personal injury when using handheld voltage test instruments, with 36.7% reporting near misses of personal injury [1]. This same survey reported that 11.7% of facilities experienced interruptions to plant operations due to voltage testing incidents.

When electricians and technical personnel at a large chemical company were asked, “How do you test for the absence of voltage?” more than 90% did not know how to perform a thorough test [2]. When it comes to safety, the initial reaction to this type of data is to propose more training. Yet training alone is not sufficient. In a study of electrical burn patients, researchers found that none of the patients followed all appropriate safety measures [3].

More than 24,000 electrical injuries were reported in the US workplace from 2003-2012 [4]. Roughly 35% of these were attributed to contact with wiring, transformers, or other electrical components [4] – the category that represents electrical injuries likely to occur in the Pulp, Paper & Forest Products Industry. A study of the US OSHA injury database found that about 60% of incidents with key words “electric arc” and “burn” occurred at low voltages (<1000V), with the majority of these on three phase systems [5]. Finding a better way to verify the absence of voltage on low voltage systems could lead to as much as a 20% reduction of electrical injuries in the workplace—that would equate to 10 fewer injuries per week.

II. UL 1436 AND ABSENCE OF VOLTAGE TESTERS

Installed devices designed specifically to test for the absence of voltage have unique requirements that are not addressed by existing standards for other product categories. Recognizing this, work was undertaken by UL to define these requirements and identify the best place to publish them.

Three standards were considered: UL 61010-1, UL 1436, and IEC 61243-3. UL 61010-1 addresses requirements for measurement devices with testing circuits (such as handheld voltage testers). UL 1436 addresses circuit testing products (such as GFCIs and AFCIs) that are permanently mounted and test a circuit at point of use. IEC 61243-3 addresses two-pole voltage detectors for live work.

IEC 61243-3 was ruled out because the scope states it is limited to handheld testers that are not intended for continuous operation. UL 61010-1 was in many ways appropriate and is even referenced in NFPA 70E for voltage verification. However, it is an internationally harmonized document; revisions and amendments have long cycle times. Ultimately, UL 1436 was selected because its scope includes other installed testers and it could be revised in a timeframe that coincided with the NFPA 70E revision cycle. The new AVT requirements in UL 1436 reference many of the construction requirements in the UL 61010 series.

UL 1436 [6] describes an absence of voltage tester (AVT) as, “*a permanently-mounted test device that is used to verify that a circuit is de-energized prior to opening an electrical enclosure that contains energized electrical conductors and circuit parts. An AVT is provided with a test circuit with active indications to verify the absence of phase-to-phase voltage and phase-to-ground voltage. AVTs are provided with a test circuit and visual indicators to confirm that the tester is functioning properly before and after the process of determining that voltage is absent.*”

A comprehensive set of requirements for AVTs are described in UL 1436 that must be met in order for a product to be listed as an AVT. The following is a summary of select features of AVTs. Refer to UL 1436 for complete requirement details.

A. Construction requirements

AVTs must comply with construction requirements described in UL 61010, The Standard for Electrical Equipment for Measurement, Control, and Laboratory Use, Part 1: General Requirement [7], and Part 2-030 Particular Requirements for Testing and Measuring Circuits [8]. Handheld voltage test instruments are designed and often listed to these same construction requirements.

The AVT circuit requirements in UL 1436 (Appendix B) do not permit direct conduction between the AVT and the electrical system to which it is installed. This isolation condition is a requirement for AVTs during both normal operation and single-fault conditions.

B. User initiated test

UL 1436 requires that the user initiate the test for absence of voltage with an AVT. This is intended to help ensure that performing the step is a conscious effort by a qualified electrical worker and that the test occurs at the point of use.

C. Active indicator for absence of voltage

An active indicator is required to visually convey when the absence of voltage has been confirmed. Use of an active indicator is an important fail-safe feature of AVTs. This is because the lack of illumination does not guarantee that a de-energized condition exists[1].

Additionally, the absence of voltage indicator will illuminate only if all phase-to-phase and phase-to-ground voltages are below a pre-determined threshold. De-energized industrial systems are rarely measured at 0V. Often, there is a small residual voltage due to RF interference or noise on the ground plane. To ensure that the AVT maintains personnel safety and operates reliably, an absence of voltage threshold must be selected. The threshold must be low enough to avoid any injuries to personnel and high enough to avoid nuisance indications when small amounts of voltage are detected in the environment where the AVT is installed. For AVTs, a de-energized condition is defined as when the voltage is measured below 3.0 Vac (rms) or V dc.

This absence of voltage indicator is required to be green. No other indicators on the AVT may use the color green in order to ensure standardization among multiple manufacturers and eliminate confusion when AVTs are used.

D. Installation of the AVT

If the tester is not in contact with a circuit part when the voltage measurement is taken, no voltage will be detected. Thus, to ensure reliability, it is critical that the tester be in contact with the circuit that it is monitoring. To address this, UL 1436 listing requirements include several provisions regarding installation of the AVT. These requirements are designed to detect open connections between the tester and the circuit and the reversal of tester leads. The absence of voltage indicator cannot illuminate if the tester is not in direct contact with the circuit part being tested. Additionally, the AVT must detect if phase and ground connections are reversed. Under this scenario, the AVT absence of voltage indicator will not illuminate.

E. Test circuit to verify functionality

With an installed device, the operator must have a high degree of confidence in the performance. Several requirements have been written in UL 1436 to address the reliability of the AVT. One requirement includes a supervisory test circuit to verity that the tester is functioning properly. The supervisory test circuit is activated before and after the absence of voltage measurements are taken. Like the process used to validate the functionality of a handheld tester, verifying that the tester is functioning as expected before and after the test ensures that the tester was not damaged during the test leading to a false indication.

F. SIL rating for safety functions

To further establish reliability of the device, all safety functions of the AVT are required to be designed using functional safety principles. Functional safety is a methodology described in IEC 61508 [9]. It is used to ensure that electrical, electronic, or programmable electronic systems (E/E/PE) are designed in such a way to prevent dangerous failures or to control them if they arise. Functional safety certification requires quantitative and qualitative analysis by an ANSI accredited certification body that includes rigorous testing of the product and audits of the manufacturer's processes.

Functional safety is measured by Safety Integrity Levels or SILs. The SIL demonstrates the safety and reliability of the parts of the product that impact the safety functions, particularly with regards to hardware and firmware. SIL levels in IEC 61508 are designated as SIL 1, 2, 3, or 4 with 4 having the most stringent requirements. A higher SIL ensures a higher level of safety, and a lower level of probability that a system will fail-dangerous.

UL 1436 requires SIL 3 for safety functions of absence of voltage testers. SIL 3 is the highest SIL level that can be expected for an AVT (SIL 4 typically applies only if there is a risk of multiple casualties). Stating a specific SIL level as a requirement ensures standardization across the industry and does not leave hazard analysis and risk assessment to the manufacturers.

SIL 3 means that the average frequency of a dangerous failure of the safety function is $\geq 10^{-8}$ to $< 10^{-7}$ (high demand or continuous mode of operation). This is equivalent to one hazardous failure in 10,000,000 hours or 1,000+ years of continual operation. Note that the safety functions in the AVT typically operate only when the absence of voltage test is in progress (for a few seconds after the user prompt initiates the test), so this is an extremely high level of reliability.

III. APPLICATION CONSIDERATIONS

The AVT listing requirements in UL 1436 were written to ensure the product can be installed and operate under a variety of application scenarios. Furthermore, there are

[1] Lack of illumination of an indicator may be because the system is de-energized, but it could also be due to a device failure, an installation failure (if the device becomes disconnected from the wiring, it will not detect voltage), or an indicator (e.g., LED) failure.

extensive provisions to ensure field wiring related to the AVT can be completed in a safe manner.

A. Use of overcurrent protection

Installation of an AVT with overcurrent protection is neither required nor recommended. When testing for the absence of a signal, it is important to ensure that the tester is in direct contact with the circuit test point. Installing overcurrent protection between the AVT and test point could lead to false readings. For example, if a fuse is installed between the circuit test point and the Absence of Voltage Tester, it is possible that voltage could be on the line and not be detected by the Absence of Voltage Tester if the fuse is open.

AVTs that comply with UL 1436 are not permitted to provide a direct path for conduction through the device. Certification requires impulse tests, static tests, and impact tests to evaluate the AVT's ability to avoid critical internal failures under normal and single-fault conditions. Thus, UL 1436 states that overcurrent protection does not need to be specified for AVTs.

The sensor leads of the AVT can be treated as a feeder circuit per NEC article 240.21 (B) (1) (b) exception. This rule allows a tap of no more than 10 feet on a feeder circuit without the need for overcurrent protection.

B. Effect on short circuit current rating

The AVT is required to operate as a galvanically isolated secondary circuit that is isolated from the circuit conductors by use of a transformer, optical isolator, or limiting impedance, or other similar means. This is intended to reduce the risks of both electric shock and thermal hazard. These galvanic isolation circuits allow very limited current flow, if any, through the AVT.

Based on their designs and results of testing to UL 1436, AVTs are marked as suitable for use on circuits delivering a specified current (not to exceed 300,000 rms symmetrical A) at a maximum voltage.

C. Installation

AVTs are supplied with field wiring leads (pigtails) or factory-installed wiring terminals for connecting the AVT to each phase of the circuit being tested as well as ground. Field wiring must be at least 14 AWG (2.1 mm^2) copper and between 12 in and 10 ft (0.3 – 3 m) in length. If leads are provided, they should not be extended with a splice. Additionally, leads should not leave the equipment enclosure.

The manufacturer of the AVT must provide documentation that includes schematics for connection and routings. When installing an AVT, care should be taken to ensure that conductors used to connect the AVT to the circuit are not longer than necessary and are routed to avoid sharp edges, pinch points and mechanical damage.

IV. COMPARISON OF AVTS AND HANDHELD TESTERS

The process used by AVTs to determine if voltage is absent is based on the steps described in NFPA 70E [11] to verify the absence of voltage, with the addition of a step to verify that the tester is in contact with the circuit parts being tested.

There was nothing in previous versions of NFPA 70E that prohibited the use of an installed tester for voltage verification[2]. However, in the upcoming 2018 edition of NPFA 70E, a distinction between handheld voltage test instruments and permanently-mounted AVTs is expected. The following is an excerpt from the NFPA 70E-2018 draft published in January 2017, formatted with legislative text [13].

> 120.5 Elements of Process for Establishing and Verifying an Electrically Safe Work Condition
>
> …
>
> (7) Use an adequately rated portable test instrument to test each phase conductor or circuit part to verify it is de-energized. Test each phase conductor or circuit part both phase-to-phase and phase-to-ground. Before and after each test, determine that the test instrument is operating satisfactorily through verification on any known voltage source.
>
> Exception No. 1: An adequately rated permanently mounted test device shall be permitted to be used to verify the absence of voltage of the conductors or circuit parts at the work location, provided it meets the all following requirements:
>
> a) It is permanently mounted and installed in accordance with the manufacturer's instructions and tests the conductors and circuit parts at the point of work
> b) It is listed and labeled for the purpose of verifying the absence of voltage
> c) It tests each phase conductor or circuit part both phase-to-phase and phase-to-ground
> d) The test device is verified as operating satisfactorily on any known voltage source before and after verifying the absence of voltage

In NFPA documents an exception is used to describe an allowance or required alternate procedure to a general rule when limited, specified conditions apply [14]. This text allows AVTs rated for the application for which they are installed and that meet the conditions described in the exception to be used in lieu of a handheld tester to verity the absence of voltage, provided the conditions described in parts a) through d) are satisfied.

AVTs, like any installed electrical device, must be installed per their intended use and in accordance with ratings, environment, and manufacturer instructions. The provision in part a) regarding "at point of work" is an important distinction in that the absence of voltage indication must be displayed on the equipment being tested. This helps ensure that there are

[2] A distinction must be made between AVTs and voltage indicators, a type of installed device that provides active indications when hazardous voltage is present. Although AVTs may optionally incorporate a voltage indicator function, they are a unique product category and should not be confused with voltage indicators. OSHA has previously determined that LED-style voltage indicators are not sufficient to verify the absence of voltage [12]. This proposed language in NFPA 70E applies only to AVTs and does not apply to voltage indicators.

no errors due to mislabeled or look alike equipment if only a remote indication was provided.

The requirement in part b) to be listed and labeled for the purpose of verifying the absence of voltage would be met by a product that conforms with the AVT requirements in UL 1436. At the time the language in 70E was voted on, the revisions to UL 1436 adding AVT requirements had not yet been published so it could not be directly referenced.

Part c) requires that the AVT directly test for voltage in between each phase and ground. (In the case of a three-phase systems that is six tests: A-B, B-C, A-C, A-ground, B-ground, C-ground.) This is addressed by 12.1.6 in UL 1436.

The "test-the-tester" functionality described in part d) is also included in UL 1436. This is addressed by 12.1.4 (the known source) and 12.1.5 (verification before and after the measurement).

It should be noted that verifying the absence of voltage is only one step in the Process for Establishing and Verifying an Electrically Safe Work Condition and thus using AVTs do not replace the lockout/tagout process. They are simply an optional tool that can be used to supplement the lockout/tagout process and existing electrical safety procedures.

V. ADVANTAGES & LIMITATIONS

An overview of advantages and limitations of AVTs are briefly discussed in this section (Fig. 1). For a thorough analysis of benefits, limitations and best applications for AVTs, refer to [15].

Summary of AVT Features
Advantages
• No direct exposure to electrical hazards when testing • Automated test sequence reduces procedure time, complexity, and human error • Active absence of voltage indicator • Safety functions meet SIL 3 • Self-contained with known voltage source
Limitations
• Must be installed per instructions by qualified electrical personnel • Will only test for voltage at the point in circuit it is installed • Provides information about status of voltage, but does not prevent user from taking further action if energized

Fig. 1 Advantages and Limitations of AVTs

A. Advantages

The greatest advantage of using absence of voltage testers is improved worker safety. AVTs determine the status of voltage inside the equipment before doors and covers are removed, greatly reducing the risk of exposure to electrical hazards.

Additionally, AVTs can enhance productivity by reducing testing procedure time and complexity. The test sequence can be automated ensuring each of the pre-/post-verification test as well as individual phase-to-phase and phase-to-ground measurements occur in the correct order every time. Automation reduces the likelihood of human error or distraction. The SIL 3 rating of the safety functions ensures the reliability of the green absence of voltage indicator in the event of hardware or firmware failures.

The AVT is a completely contained solution – in other words, there is no need for additional tools or testers to operate and the known source is contained within the tester (for example a battery that can supply voltage when power from the circuit is de-energized). This is particularly useful in remote or difficult to access locations. This feature also helps ensure that the pre- and post- test to verify functionality of the AVT are automatically completed as part of every test.

B. Limitations

As with any new technology, it is important to understand the limitations of an AVT to ensure it is used in a safe and effective manner.

The AVT must be installed properly. Even with the ability to detect open or reversed phase and ground leads, if the AVT is installed in an application that exceeds its specified environment or design limits, performance cannot be guaranteed. The use of active indications and SIL rating of the safety functions help ensure the AVT will fail safely.

Similarly, it is important to remember that the AVT will only test for voltage at the point in the circuit at which it is installed. If there is more than one power source within the enclosure or stored energy at another point within the enclosure, the AVT will not detect additional sources during the test. In these applications, more than one AVT may be required or the handheld tester method could be used.

Finally, the device still requires user interaction and human error can occur when interpreting results. Remember that the absence of voltage test must be initiated by user prompt. It is possible that the user could not initiate the test and assume that lack of any indicators illuminated could be a de-energized condition (having the green indicator clearly labeled as representing "de-energized equipment" can help mitigate this risk). Similarly, even if the test is initiated on the AVT and the result is that the panel is not de-energized (no green indication), there is nothing to prevent the user from accessing the panel. This could be mitigated through training and well-designed interfaces as well as interactions with other systems.

VI. CONCLUSIONS

Verifying the absence of voltage is a critical step that is part of nearly every job involving electrical work, with the exception of troubleshooting. Using handheld voltage test instruments can be time consuming and expose workers to electrical hazards. AVTs that are listed to UL 1436 can improve worker safety and the efficiency of the voltage testing process.

There are a variety of construction features detailed in UL 1436 that help ensure listed AVTs are reliable and fail-safe. In addition to product safety, installation considerations such as overcurrent protection, short circuit current rating, and field wiring are also addressed in the new requirements.

It is important to understand the advantages as well as the limitations when selecting safety products. AVTs have many benefits and will soon be recognized as a means to comply with the voltage verification process described in NFPA 70E. As with any electrical device, there are always limitations. Understanding how AVTs are intended to perform, as well as their limitations, is important to ensure they are used safely and effectively.

VII. ACKNOWLEDGEMENTS

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IX. VITA

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