CONNECT AND PROTECT

nVent ERIFLEX Technical Note

A review of UL9540: How nVent ERIFLEX solutions can help you meet and exceed its requirements

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nVent ERIFLEX Technical Note

Key Words
UL9540, UL9540A, IEC 62933-5, energy storage, power connection, power distribution, earthing, bonding, grounding, battery, battery pack, fuel cell

EXECUTIVE SUMMARY

The purpose of this document is to review the contents of UL9540, the standard for safety of energy storage systems. This standard is a system standard that measures and ensures the safety of the various subsystems, components and parts of an energy storage system. nVent ERIFLEX components can be used in a variety of subsystems inside an energy storage systems such as the power conversion system or battery system. It is shown throughout the paper that nVent ERIFLEX solutions help ensure safety and compliance to UL9540. nVent ERIFLEX lug-less solutions allow for the construction of halogen-free, low-smoke, flame retardant sub-assemblies. These solutions also lead to assemblies being lighter, more compact and cost competitive.

INTRODUCTION

nVent provides flexible power connection solutions as well as power distribution and grounding solutions for use in low-voltage sub-systems located inside energy storage units (power conversion sub-system, battery sub-system). nVent ERIFLEX solutions are rated at 1000VDC/1500VAC IEC/UL and can carry currents ranging from 80A all the up to 7400A. Figure 1 below shows at a high-level the various subsystems in which nVent ERIFLEX solutions can be utilized, using a containerized BESS (battery energy storage system) as an example.

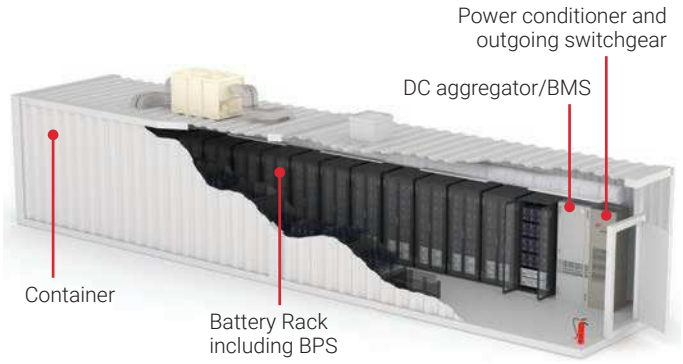

Figure 1 – Schematic of a BESS

ANSI/CAN/UL 9540:2020

UL9540, the standard for safety of energy storage systems and equipment was initially released in November 2016. A second edition was released in February 2020 to cover for the fast technological changes occurring in this rapidly evolving vertical market. Per article 1, scope, the standard contains safety requirements that "cover energy storage systems that are intended to receive and store energy in some form so that the energy storage system can provide electrical energy to loads or to the local/area electric power system (EPS) when needed." This standard covers requirements for various type of energy storage systems such as: electrochemical, chemical, mechanical or thermal. UL9540 is a "system standard" that measures the compatibility and safety of various parts and components integrated into an energy storage system.

nVent ERIFLEX Solutions for use in Energy Storage Systems

nVent ERIFLEX Advanced Conductors: the nVent ERIFLEX Flexibar Advanced is an insulated flexible busbar made of 1 mm thick tin plated copper laminates stacked together. The nVent ERIFLEX IBSB Advanced is a prefabricated insulated flexible braid composed of tin plated wires. Both conductors feature nVent's halogen-free, low smoke, flame retardant insulation. This insulation is rated at 115°C and is considered a reinforced insulation therefore allowing for weight savings and very compact assemblies. Both solutions comply to various IEC, UL or market specific standards (marine, rolling stock). Figure 2 shows both the nVent ERIFLEX Flexibar Advanced and nVent ERIFLEX IBSB Advanced.

Figure 2 – nVent ERIFLEX Flexibar and IBSB Advanced Power Conductors (left to right)

nVent ERIFLEX power and distribution blocks: to facilitate power distribution to and inside the various assemblies of an energy storage system, nVent also provides a range of IEC and UL compliant power and distribution blocks composed of a tinned copper or tinned aluminium current-carrying part inserted into a low-smoke halogen-free flame retardant insulated housing. Connection is made without the use of lugs and allows for the connection of the nVent flexible conductors shown in figure 2. Figure 3 shows the both blocks.

Figure 3 – nVent ERIFLEX Power Block and Distribution Block (left to right)

nVent ERIFLEX earthing and bonding braids: Regarding earthing and bonding, the following two type of braids can be utilized:

- nVent ERIFLEX MBJ
- nVent ERIFLEX CPI

The MBJ is a prefabricated earthing braid made of tin-coated copper strands and manufactured in a similar manner to the IBSB Advanced mentioned earlier (minus the insulation). The CPI is a prefabricated earthing braid made of 316L copper strands. Both solutions are certified to IEC, UL and market specific standards. Figure 4 shows both nVent ERIFLEX grounding strap solutions.

Figure 4 – nVent ERIFLEX CPI and MBJ Earthing Braids (left to right)

DETAILED REVIEW OF UL9540

This section highlights some of the key points of UL9540 and how nVent ERIFLEX solutions can help go above and beyond the standard's requirements.

Highlight #1: 2.1. Components

Per UL9540 clause 2.1 "a component (…) of an energy storage system covered by this standard shall comply with the safety requirements for that component or equipment." Appendix A contains "a list of standards covering components generally used in the energy storage systems". Additionally, article 5 contains a long list of UL, CSA, IEC, ISO, etc. standards referenced throughout UL9540. Looking at Appendix A and article 5, worth noting are the following standards to which the range of nVent ERIFLEX components comply to (if applicable for that components): UL467, UL486A/B, UL508/A/C, UL746A/B/C, UL1059, UL1741, UL 60950-1.

Highlight #2: 10. General Electrical Safety of Systems

Clause 10.14 mentions that "electrical circuits that are an integral part of the ESS including those that are part of a walk-in enclosure including (…), controls, power, (…) comply with the appropriate requirements for the type of equipment and the specific application within the ESS." Outside of component listing to certain UL standards, nVent ERIFLEX products meet the requirements of, and can be used in, UL67 (Panel Board), UL891 (Switchboard) and UL508A (Control Panel) assemblies. As a side comment, export oriented integrators of storage assemblies should take note of the fact that nVent ERIFLEX solutions meet the requirements of IEC 61439-1 (Low-voltage switchgear and controlgear assemblies - Part 1: General rules). Figure 5 shows an example of the compliance marking on the nVent ERIFLEX IBSB Advanced.

Figure 5 – Marking on the insulation of the nVent ERIFLEX IBSB Advanced

Highlight #3: 11. Wiring and Electrical Supply Connections

This article is where the benefits of the nVent ERIFLEX offering resonate the most starting with clause 11.1 which reads "wiring installed on the equipment, including internal wiring or supplied with the equipment for installation on-site, shall be insulated and acceptable for the intended purpose, when considered with respect to temperature, voltage, and the conditions of service".

As mentioned in the introduction, nVent ERIFLEX flexibles are fully insulated, dielectric tested in production and rated at 1000VAC/1500VDC according to UL and IEC standards. Also, mentioned in the introduction is the fact the nVent ERIFLEX Advanced conductors are rated at 115°C. Sizing of the conductors is facilitated using the **nVent ERIFLEX software** shown in figure 6 below. The room temperature of 25°C shown in that figure corresponds to article 6.26 of UL9540 "ROOM AMBIENT – Considered to be a temperature in the range of 25 ±5°C (77 ±9°F)."

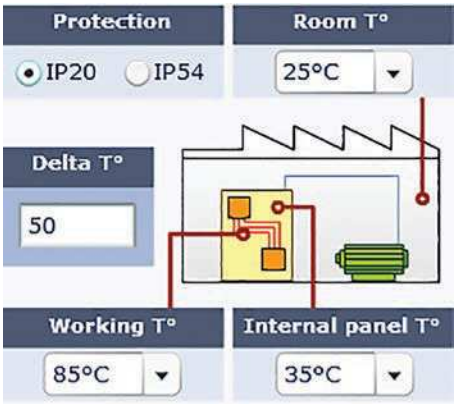

Figure 6 – Snapshot of the nVent ERIFLEX software

Clause 11.7 addresses the fastening and supporting of internal wiring such as electrical power cables ("routed, supported, clamped or secured"). It mentions that "excessive strain on wire and on terminal connections; loosening of terminal connections; and damage of conductor insulation.". As explained earlier in this document, nVent ERIFLEX conductors are lug-less connectors. Figure 7 below shows a close-up of the integral termination of the IBSB which reduces stress on the wire strands as opposed to a traditional crimped lug termination. Furthermore, damage to the conductor insulation is reduced thanks to the quality of the nVent ERIFLEX reinforced insulation which is something that will be discussed in greater details later in this document. Figure 8 shows an example of one type of nVent ERIFLEX support available to facilitate routing of nVent ERIFLEX Advanced conductors.

Figure 7 – Close-up view of the nVent ERIFLEX IBSB Advanced termination as installed

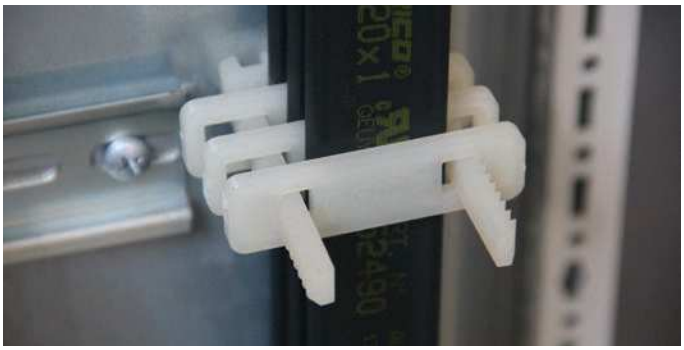

Figure 8 – Example of nVent ERIFLEX support for conductor routing

Clause 11.6 mentions that "field-wiring compartments in which branch circuit connections are to be made shall: permit the connection of the supply wires after the energy storage system is installed; permit the connection to be introduced and connected easily and safely; and be located so that the connections may be readily inspected after the energy storage system is installed." Installation of field wiring is facilitated with the use of power blocks which allows for direct connection of the conductors (supply wire or branch circuit wire) into the terminal blocks. There is no need to add ferules or lugs on the wire end and direct connection to the Flexibar and IBSB Advanced is possible as shown in figure 9. Power blocks are rated for both field and factory wiring (FW code 2) per UL 1059 and inspection is facilitated thanks to the transparent and removable terminal cover. As a side note, it should be added that field wiring should be sized to 125% of the circuit current (see clause 11.2 and 11.4).

Figure 9 – nVent ERIFLEX SB Power Blocks with incoming round supply wire (left) and nVent ERIFLEX flat circuit wire (right)

Highlight #4: 13. Electrical Spacings and Separation of Circuits & 14. Insulation Levels and Protective Grounding

As in any electrical circuit, separation and/or insulation of electrical circuits is key to safety by preventing arc flashes and short-circuits. This is achieved by controlling the clearance and creepage distances between uninsulated lives parts or between live parts and earth. These distances are detailed in table 13.1 of UL9540 and are based on the guideline of UL 60950-1 (Information Technology Equipment – Safety – Part 1: General Requirement) which itself follows IEC 60950-1.

Clause 13.1 states that conductors with a reinforced insulation at least 0.4 mm thick have no minimum spacing requirements for electrical voltages above 60VDC/30Vrms as long as these conductors pass the dielectric voltage withstand test defined in article 28 for 1 minute. Both the Flexibar and IBSB feature a third-party certified reinforced insulation as defined in clause 6.18; this insulation, of thickness 1.8 mm, has been tested at 20kV for 1 min according to section 7.5 of the very stringent EN 50264-3-1 railway cable performance standard, far above the requirements of UL9540. Using flexible conductors, such as the IBSB shown below in figure 10, therefore allows for the fabrication of extremely compact assemblies where conductors can touch each other as well as the exposed metal parts (enclosures,…).

Figure 10 – nVent ERIFLEX IBSB used in tight spaces

Along these lines, clause 14.1 mentions that "hazardous voltage circuits shall be insulated (…) through the following: a) Basic insulation and provided with a protective grounding system for protection in the event of a fault of the basic insulation that complies with 14.3; b) A system of double or reinforced insulation; or c) A combination of (a) and (b)." This clause strengthens the case for using power conductors with reinforced insulation by removing the need to design and implement time-consuming and costlier protective grounding measures.

Respect of clearance and creepage distance for uninsulated live parts can achieved using nVent's standoff insulators and modular busbar supports (CABS) which are both compliant to UL67 and UL891 (see figure 11 below)

Figure 11 – nVent ERIFLEX CABS modular busbar supports (left) and standoff insulators (right)

On the topic of grounding, clauses 14.3, 14.4 and 14.5 talk about the need for proper bonding of all metal parts according to the local North American electrical codes (e.g. Article 250 of NFPA 70) using the prospective fault levels as design basis. As mentioned in section 2.1, nVent ERIFLEX grounding straps (MBJ as shown in figure 12, CPI) are listed to UL467 and can be used to "ensure the continuity of the grounding system." (Article 14.5). It should be added that UL508A, listed in Appendix A1 of UL9540 as a reference standard, mentions that grounding (bonding) braids shall be listed according to UL 467.

Figure 12 – nVent ERIFLEX MBJ used for equipotential bonding according to NEC and UL508A

Finally, nVent ERIFLEX earthing straps of cross-section 25 mm^2 and 50 mm^2 have been shown to exceed the pullout force requirements of UL 486A-486B (Wire Connectors - table 27) by over 500% and the requirements of MIL-T-7928 for crimped connections by more than 200% which also leads to these straps being qualified for use in military-grade field energy storage systems.

Highlight #5: Performance Testing (Articles 26 through 40)

Article 26 through 40 deal with performance testing of the ESS with a focus on electrical testing in section 27 through 32.

Clause 27.4 states that during "the normal operations test (…) temperatures measured on components shall not exceed their specifications in accordance with Table 27.1." This means that for non-UL marked internal and external wiring, the maximum temperature of the wire should not exceed and be limited to only 75°C (167°F) while for UL marked conductors such as the IBSB and Flexibar Advanced conductors, the maximum temperature of the conductor should be that of the marking on the insulation (in the UL file). As previously mentioned, for nVent ERIFLEX conductors, that maximum temperature is 115°C (239°F) which leads to potential weight and cost savings over 75°C conductors of larger cross-section.

Article 28 specifies the requirements of the dielectric voltage test to be performed on the DUT (device under test) for 1 minute. As mentioned in highlight 4, nVent ERIFLEX Advanced conductors have been tested up to 20kV for 1 minute according to EN 50264-3-1. nVent ERIFLEX power and distribution blocks show in figure 3 have both been dielectrically tested up to 4250VAC for 1min for products listed to UL1953 and to 3000VAC for products listed to UL1059 (applicable for models listed at 1000VAC/1000VDC). Standoff insulators and CABS busbar supports have undergone similar testing (derived from UL508 mentioned in Appendix A1 of UL 9540) resulting in the nVent ERIFLEX CABS support being approved for use in power conversion equipment up to 1000VAC/1500VDC according to UL 508C, a standard that is listed in the article 5 normative references.

Article 30 addresses the equipment grounding and bonding test. It is indicated in this section, that "the impedance for all grounding and bonding circuits tested shall not exceed 0.1Ω". Both the MBJ and CPI facilitate compliance to article 30 and both solutions went through a current cycling test according to SAE/USCAR-2:2013 section 5.6.2. The definition of the test as exactly written in 5.6.2 is as follow "this test simulates actual operating conditions using temperature and humidity variations as aging mechanisms for evaluation of a connector system's electrical durability. High humidity and temperature can promote galvanic and electrolytic corrosion of the terminals which may cause electrical and mechanical degradation. Temperature

cycling promotes relative movement of the contact surfaces that can cause wear and fretting corrosion". Over a period of 8 hours, the braids were subjected to temperatures ranging from –40°C to 120°C combined with a humidity Rh varying up to 90%; the resulting measurement gave a braid resistance of much less than 0.1 mΩ for the MBJ braid and less than 20 mΩ for the CPI braid therefore making these solutions an ideal choice for the construction of safe and sound ESS (see figure 13 below).

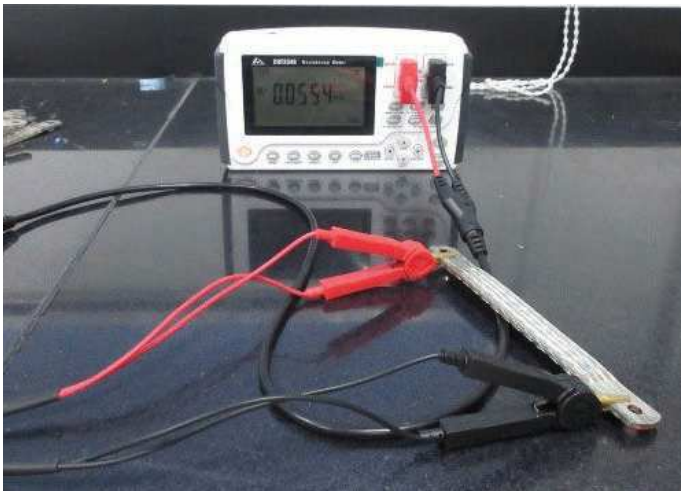

Figure 13 – Measurement of the nVent ERIFLEX MBJ resistance

Article 35 covers environmental testing with a focus on special applications such as outdoor (35.2) or Marine/near shore (35.3). Additionally, article 10.15 states that "electrical equipment (….) that will be subject to condensation, or the effects of condensation (…) shall be suitable for outdoor use or suitably protected against contact with water and protected against unsafe conduction of hazardous voltages". As mentioned several times across this document, the nVent ERIFLEX range of products is mostly made of tinned copper, tinned aluminum or stainless steel in order to improve corrosion resistance under stringent environmental conditions. Multiple nVent ERIFLEX products comply to Marine standards such as DNV-GL, ABS or BV. Additionally, the nVent ERIFLEX grounding straps (MBJ and CPI), which are traditionally more exposed to corrosion in a BESS than power conductors (typically located within an enclosures which is itself located with an ESS container or indoors) have been tested to GM14872 (Cyclic Corrosion Laboratory Test).

CONCLUSION

Shown throughout this document is the fact that the nVent ERIFLEX solutions do comply to the relevant and applicable UL and international standards listed in appendix A and article 5. Using nVent ERIFLEX flexible and insulated conductors (nVent ERIFLEX IBSB and nVent ERIFLEX Flexibar Advanced) allows for the construction of robust yet compact electrical assemblies that leverage the benefits of using a reinforced insulation. Using these solutions, as well as the nVent ERIFLEX power and distribution blocks, also makes it to easier to pass the various electrical tests listed the performance testing part of the standard. Implementing nVent ERIFLEX grounding straps (MBJ, CPI) facilitates compliance to the NEC grounding rules in article 14 about protective grounding, to article 30 (electrical performance testing) and to article 35 (environmental testing).

A closing comment should be added about UL9540A published in 2019 to address critical and potentially deadly thermal runaway battery fires. Article 6.1 provides a good overview of the standard scope as follow: "the tests in this standard are extreme abuse conditions conducted on electrochemical energy storage devices that can result in fires, explosions, smoke, off gassing of flammable and toxic materials, exposure to toxic and corrosive liquids, and potential exposure to hazardous voltages and electrical energy." As a reminder, nVent ERIFLEX power conductors are UL94 V-0 and IEC 60695-2-11 (Glow Wire Test 960 °C) rated as well as low-smoke, halogen-free and flame retardant. The nVent ERIFLEX power and distribution blocks are UL94 V-0 rated and halogen-free and so are the nVent ERIFLEX standoff insulators and busbar supports.

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