Technical Article

How solid-state relays simplify insulation monitoring designs in high-voltage applications

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In electric vehicles, solar panels and energy storage systems, high-voltage power achieves faster charge times, minimizes power losses, and improves design reliability. High-voltage currents have the potential to be dangerous or even deadly, however, so designers use insulation monitoring systems to send an alert or disconnect the power supply to prevent harm to the application or users. Quickly and accurately detecting faults in insulation is vital for maximizing user safety and minimizing damage or fire resulting from a catastrophic loss of power.

Common applications with insulation monitoring include battery management systems, energy storage systems, string inverters, DC fast chargers, DC wall-box chargers, solar panels, motors and planes. But accuracy and withstand voltage test requirements can make insulation monitoring challenging to design. TI has both reference designs and devices designed to simplify the design process.

Navigating the design challenges of insulation monitoring

Insulation monitoring, also known as insulation check, isolation monitoring, isolation check, ground fault detection or ground fault sensing, monitors the amount of insulation between high-voltage terminals and protective earth/chassis ground. Figure 1 illustrates one configuration for insulation monitoring. The basic operation of an insulation monitoring circuit involves switching in known resistances (RDIV1/2, RDIV3/4) and solving a system of equations in order to find the unknown insulation resistances (R_{ISOP}, R_{ISON}).

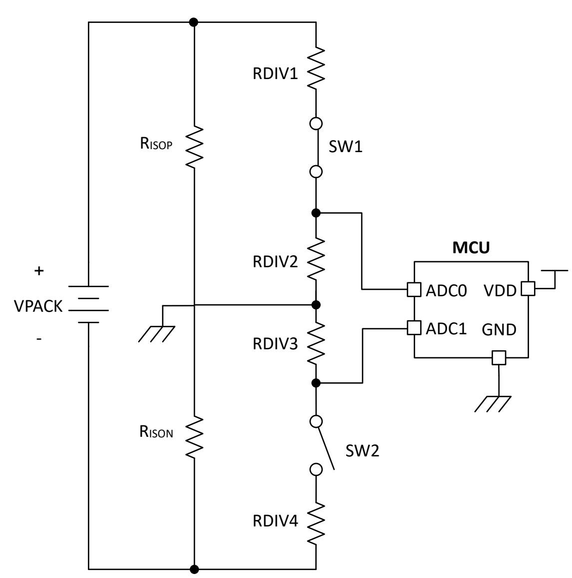

Figure 1. Insulation monitoring configuration

Addressing strict safety requirements

Safety standards require that manufacturers evaluate the effectiveness of a given electrical or electronic device's insulation for safety by performing a dielectric voltage withstand test (also called a high-potential test). The dielectric voltage withstand test applies high voltages across the insulation barrier for one minute. A measured insulation post-test that meets the manufacturer's requirement threshold is considered a passing grade.

According to International Electrotechnical Commission (IEC) 60950, the withstand voltage test for basic insulation is 2U + 1,000 V_{RMS}, where U is the maximum operating voltage of a system. A manufacturer may need to apply a 4,242-V withstand voltage test when designing an 800-V system based on Equation 1:

2 x 1,000 V (added battery charge margin) +1,000=3,000 V_{RMS}=4,242 V_{DC} (1)

Figure 2 illustrates this withstand voltage test, taking the previous insulation monitoring configuration, removing the high-voltage battery, and applying 4,242 V across a terminal and chassis ground.

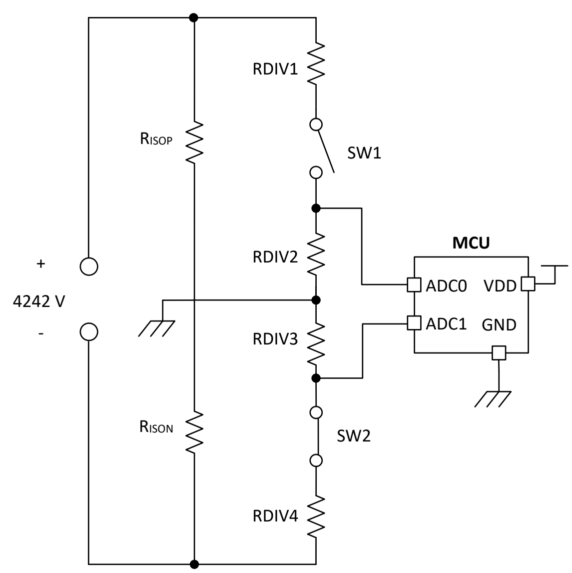

Figure 2. Insulation monitoring high-potential example

Since the switches (SW1, SW2) are often solid-state relays or photo relays with integrated metal-oxide semiconductor field-effect transistors, you must make component considerations to ensure switch survivability. These switches are typically rated for a limited amount of avalanche current (Iava) over a span of time, so for example, during component selection you may need to choose series resistors that can adequately limit the avalanche current, or add an expensive reed relay to ground in order to prevent avalanche current flow altogether. Unfortunately, having a large series resistance can negatively impact measurement accuracy, so selecting resistors with resistances similar in value to the insulation resistance will maximize accuracy.

The advantages of solid-state relays

You can use photo relays, but there are drawbacks in comparison to solid-state relays in terms of avalanche current, speed, reliability and solution size. The TPSI2140-Q1 supports up to 2 mA of avalanche current, compared to 0.6 mA in a generic photo relay. A generic photo relay is also typically limited in switching speed by its LED and forward bias requirements. Photo relays suffer from photo degradation over time and in size, requiring additional components to create drive circuitry.

Figure 3 shows the TPSI2140-Q1 functional block diagram.

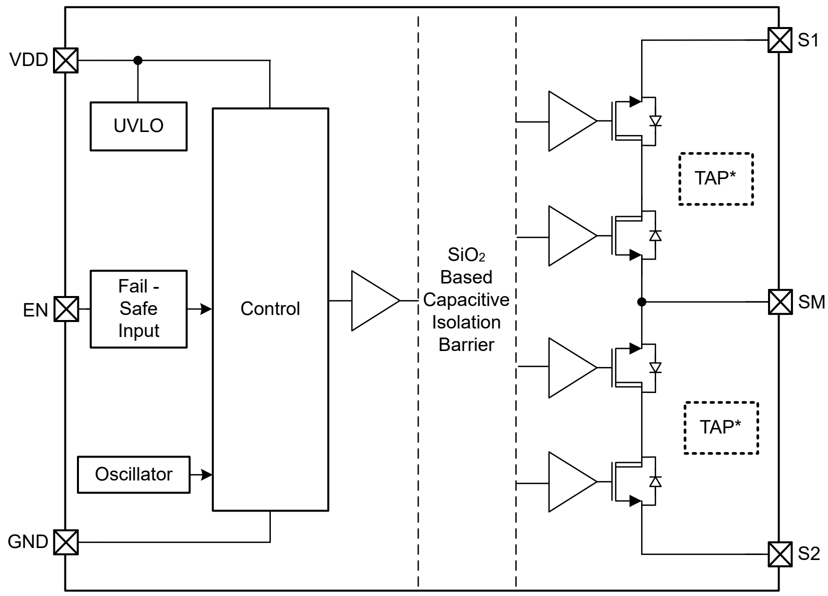

Figure 3. TPSI2140-Q1 functional block diagram

Depending on additional system requirements, you may wish to consider a configuration using an intelligent battery junction box such as the BQ79731-Q1 battery pack monitor to measure voltage, temperature and current.

The AFE for Insulation Monitoring in High-Voltage EV Charging and Solar Energy Reference Design and Automotive High-Voltage and Isolation Leakage Measurements Reference Design both use the TPSI2140-Q1 solid-state relay for switching in known resistances.

Designers sometimes opt into purchasing insulation monitoring modules in order to avoid the challenges of factoring in withstand voltage test design considerations. Both reference designs use different topologies to address insulation monitoring, featuring good accuracy for fault detection, support for safety standards, scalability and more.

The AFE reference design is capable of accurately and reliably monitoring the insulation resistance, maintains insulation during insulation resistance measurements, and supports IEC 61557-8 and IEC 61851-23.

Figure 4 depicts the AFE reference design block diagram.

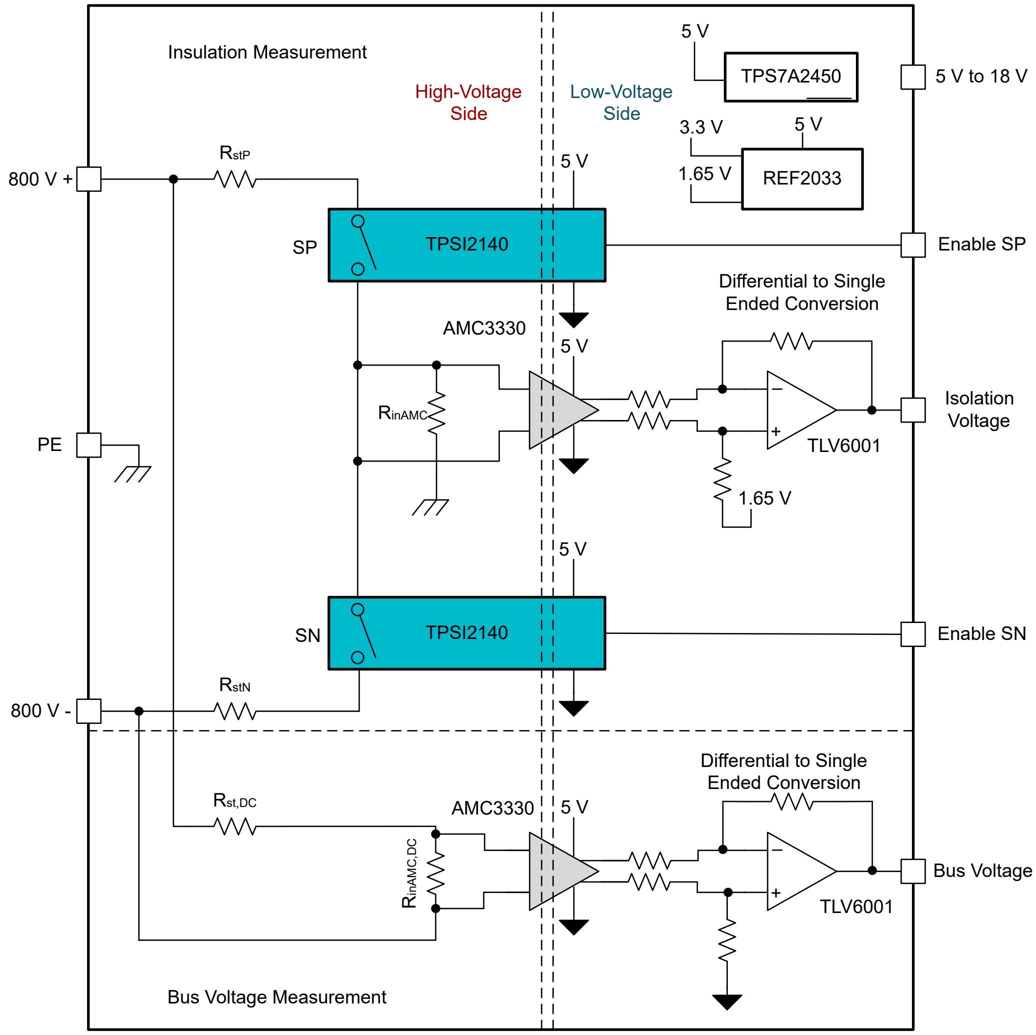

Figure 4. AFE reference design block diagram

Figure 5 depicts the block diagram for the leakage measurements reference design.

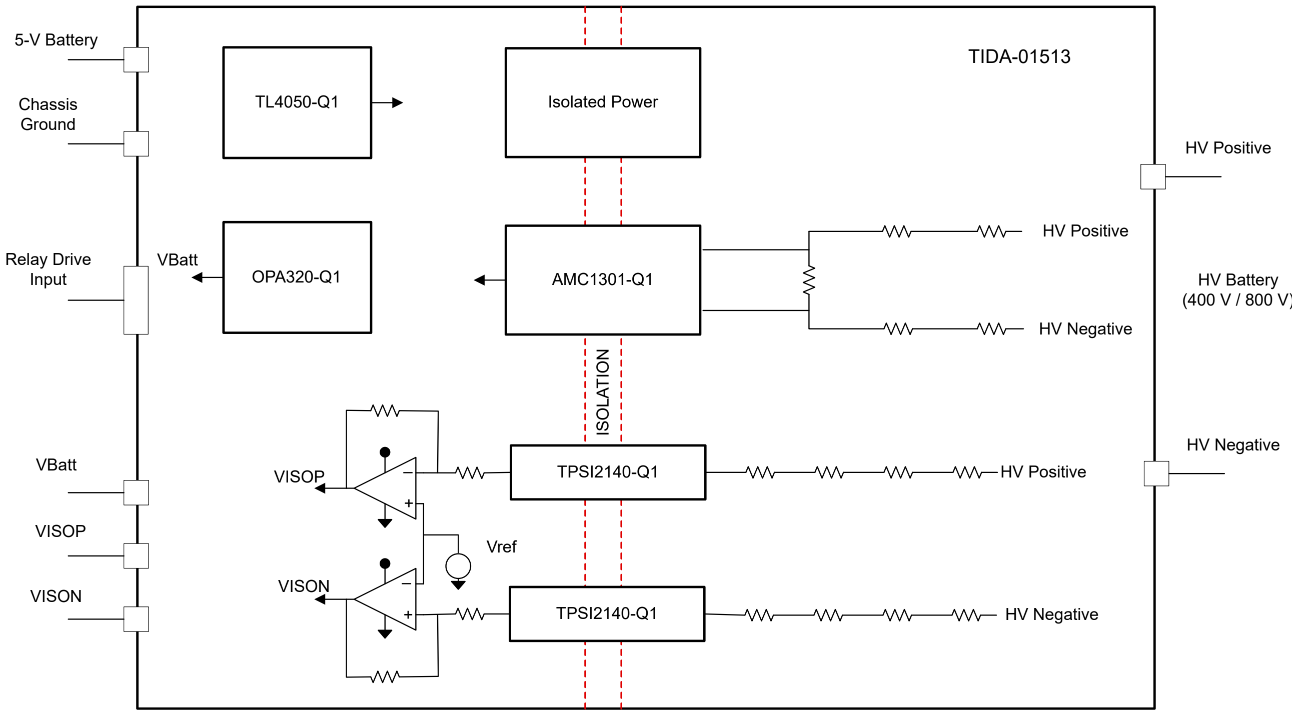

Figure 5. Leakage measurements reference design block diagram

Conclusion

The shift to higher voltages to minimize charging times – such as EVs trending from 400 V to 800 V and solar energy shifting toward higher voltage systems – increases the need for reliable safety and insulation monitoring methods. Insulation monitoring detects insulation resistance by monitoring the leakage current from high-voltage terminals to protective earth/chassis ground. Since currents above 10 mA can be fatal, insulation monitoring systems must provide warnings upon the detection of faults in the insulation.

TI's solid-state relays provide the highest operating temperature and highest dielectric strength at the highest speeds while being cost-effective. They also provide reliable switching contained in a small package. Discover more about how to optimize your design using our isolated switches and drivers in the additional resources below.

Additional resources

- Watch "Introduction to Isolation" in our TI Precision Labs training series.
- Check out our solid-state relay portfolio.
- More information, read the technical article, "How to achieve higher-reliability isolation and a smaller solution size with solid-state relays."

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