
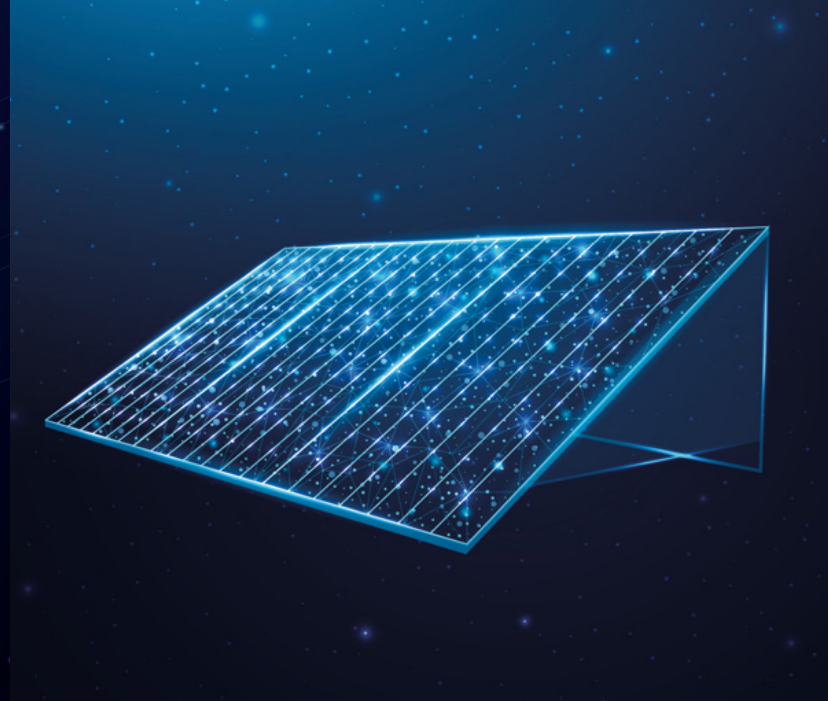

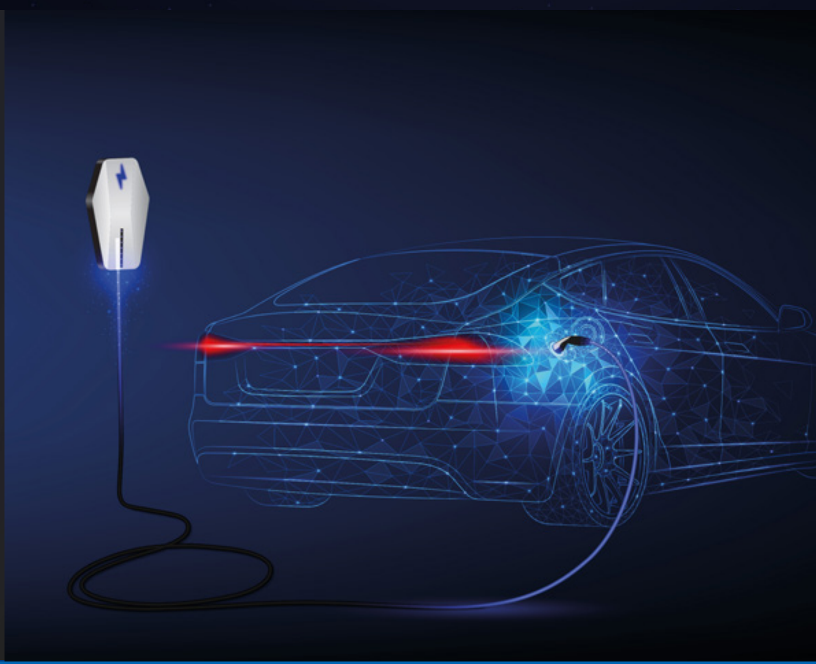

White Paper

Precision High-Voltage Switching:
Achieving Safety, Reliability & Repeatability

pickering

CONTENTS

Introduction 3
What is Driving the Need for High-Voltage Switching? 3
Why 500 V? 3
Benefits of Modular Test Systems for High-Voltage Applications 4
Safety, Reliability, Repeatability 4
Summary 7
The Advantages of Working With Pickering 8
About Pickering Interfaces 10

Introduction

Society continues to advance electrification technology into several emerging markets, with high-voltage buses exceeding 500 V. It is reasonable to conclude that testing products in these markets is driving an increased demand for high-voltage signal switching. This paper will examine how modular switching systems based on standards such as PXI and LXI are fulfilling the new demands for precision switching at elevated voltage levels in a safe, reliable, and repeatable fashion. It will also discuss methods to improve measurement performance and accuracy.

What is Driving the Need for High-Voltage Switching?

The electric vehicle industry is relatively new but has already achieved significant penetration and sales. And electrification is informing discussions on the future of personal and mass transportation. Some statistics worth mentioning:

- **In 2024, the revenue in the Electric Vehicles market is projected to reach a staggering US$623.3 B worldwide.**
- **The market is expected to demonstrate a steady annual growth rate (CAGR) of 9.82 % between 2024 and 2028, leading to a projected market value of US$906.7 B by 2028.**
- **Sales of EVs are anticipated to reach 17.07 M units by 2028.**

Currently, the most common automotive bus architecture is based on 400 V, but 800 V bus systems are increasingly being introduced to increase power and/or reduce current. Some car makers, as are producers of industrial and mass transit vehicles, are looking at even higher voltages, and battery stacks of over 1000 V are being designed.

Other new markets are also driving system voltages upwards. For example, renewable energy from solar installations demands a high-voltage capability during conversion, transmission, and storage. The medical industry increasingly relies on high-voltage equipment such as CT scanners, imaging, and X-rays. Of course, traditional high-voltage applications such as cable insulation, PCB isolation, and semiconductor testers all require high operational voltages.

Why 500 V?

Of course, the tipping point for when a system might be considered 'high-voltage' is somewhat arbitrary. However, equipment makers tend to agree on a number of at least 400 V. Why is this? Well, systems operating at 250 VAC—industry standard—will peak at roughly 350 V. Manufacturers of modular switching products often mandate that all NPIs above 500 V include a hardware interlocking feature to ensure safe operation. At these levels, suppression circuitry becomes necessary, and high-voltage connectors tend to be preferred. Therefore, 500 V seems reasonable for voltage to transition to 'high-voltage'.

At the upper end of the scale, reed relays—which, as will be discussed in detail later, are highly suitable for high-voltage switching—have an upper limit of >12.5 kV.

Benefits of Modular Test Systems for High-Voltage Applications

Before we delve deeper into the details concerning high-voltage switching, it is worth revisiting why choosing a modular platform based on commercial off-the-shelf technologies and standards will help reduce the cost of a test system, save development time, and deliver a system that does exactly what is required by any unique application. Such a system will also help reduce test time as it can be fully integrated and automated in both hardware and software, optimizing test routines, and potentially running multiple test routines in parallel.

PXI is an industry-standard, open-architecture test, measurement, and control platform maintained by the PXI Systems Alliance and supported by over 60 industry-leading companies manufacturing, selling, and integrating PXI-based hardware and software solutions. With so many suppliers offering compatible equipment, a system designer can pick and choose the most suitable building blocks from multiple companies depending on the application requirements rather than being constrained to using products from a single vendor.

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Using a standardized architecture also reduces the time required to configure a test system for new emerging products and requirements. Due to the flexible and scalable nature of a system based on PXI, both in hardware and software, as a test system's complexity grows, the modular system can grow with it. Modular elements—to increase functionality or capacity—can be added as required, keeping initial investment to a minimum but retaining the value of that investment since it will not go to waste when the test requirements outgrow it.

Best of all, the test team is not limited to a pre-configured system unique to a single vendor. Such solutions usually either fall short of the full system requirement or are too full-featured and complex, exceeding the current requirement with the associated cost implications. In contrast, a test system based on the PXI standard can be flexible without being cumbersome.

Safety, Reliability, Repeatability

Returning to the specific issue of high voltage—safety, reliability and repeatability are the three key pillars on which high-voltage switching systems must be founded. Let's examine these in detail.

Safety

With voltages up into the kilovolt range present, safety must be of prime concern. Therefore, high-voltage switching products should include a functional hardware interlock that can isolate their front-panel outputs by ensuring all on-board relays are de-energized. For example, a hardware interlock on a door switch could be used to disable relay operation if the test system cabinet door is open. Many configurations are possible on a card-by-card basis: multiple cards can be daisy-chained, or there can be one mastering hardware interrupt line, or separate ones. But predominantly, it's a door switch on a cabinet, and if the door is open the cards are inoperable in safe mode, even with 5 kV applied. Conversely, when the door is closed, and the operator cannot touch anything live, then the cards are put in enabled mode, and the system can be used normally.

The presence of high voltage also means that stray parasitics, interference, and spikes are more damaging, which can cause safety and reliability issues. Therefore, suppression circuitry must be included. We will discuss this more in the next section.

Of course, all equipment designed for use with high voltages must conform to international standards, such as IEC 62271-200.

Reliability

The reliability of high-voltage switching systems depends on the quality and selection of the components used. The switch itself is the most essential element to consider—most likely a relay. Although there are several distinct types of relays, reed relays have several advantages that make them a good fit for high-voltage applications.

In electromechanical relays (EMR), the contacts are open to the environment. This means that dust and other particles can pollute the surfaces of the contacts, adversely affecting performance. Reed relays, by comparison, feature a hermetically sealed switch, and the contacts operate in a vacuum. Therefore, the contacts are much less likely to suffer from degradation, and their performance will be consistently higher. Also, the tracking distance can be much less than that of EMR devices that operate in free air. And because the contacts are in a hermetically sealed vacuum, ionization, which occurs at high voltages, will not affect the reed switch performance.

Figure 1 – A typical electromechanical relay (left) and a high-voltage reed relay (right) showing internal construction.

High-voltage reed relays have a switching speed of 0.5-1 milliseconds, much faster than EMRs at three milliseconds. Lastly, reed relays suffer low mechanical wear because they have no moving parts apart from the small reed switch blades. If used correctly and within specified ratings, reed relays achieve a mechanical life of more than 1 billion operations (dependent on load). In contrast, EMRs can only be expected to last for 10 million operations.

Of course, there are many different types of reed relays for high-voltage applications – basically, the higher the voltage, the larger the device. Reed relays with a stand-off voltage (DC or AC peak) of 1500 V can be very compact, measuring – for example – just 12.5 x 3.7 x 6.6 mm. High-quality reed relays for use at these voltage levels will feature sputtered ruthenium contacts to give excellent performance at low current levels. Reed relays are available with voltage stand-offs of up to 15 kV. These larger devices have tungsten-plated contacts that provide resilience to hot switching at high power levels.

There are several factors to consider that affect relay performance and life. For optimum results, it is always best to cold switch—i.e., energize the relay contacts with no applied voltage. When hot switching is demanded, it is vital to ensure that the product of the voltage and current handled by the switch does not exceed the overall switching power rating of the relay. Hot switching, of course, will negatively impact relay life and reduce voltage stand-off as arcing occurs once plating degrades. For this reason, switching module datasheets specify a reduced operating voltage by as much as 40-50 % when hot switching is used.

Even if no user voltage is being applied to the relay contacts, switching may still not be 'cold'. The main reason high-voltage relays fail is that capacitance in the circuit is not adequately considered.

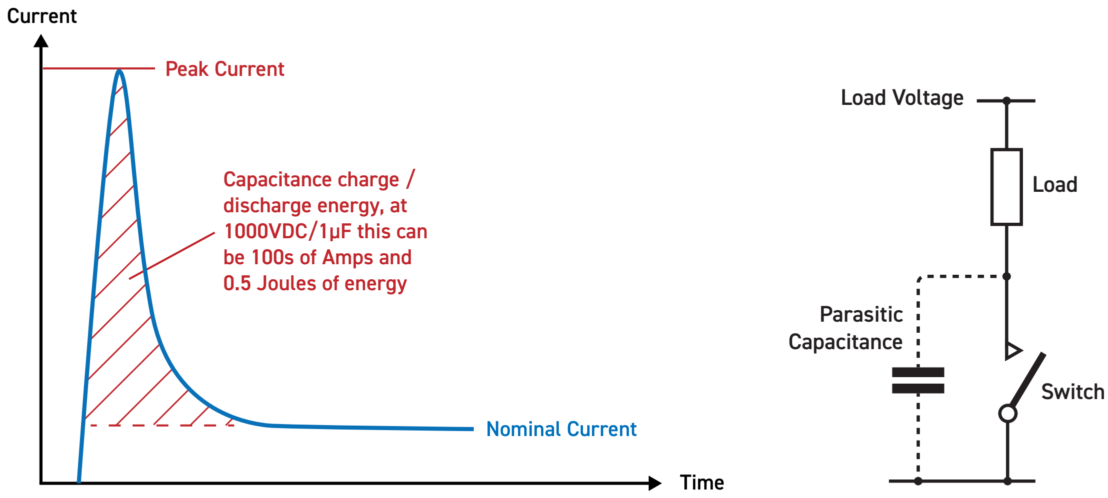

Figure 2 – Above shows capacitive inrush across the switch and a diagram of the circuit.

Consider Figure 2 above. If there is any capacitance in the circuit, this can charge up when high voltage is present. If the capacitance is across the switch with no limiting load, it will instantly discharge through the switch when it closes. Many high-voltage applications use capacitors to store the voltages. Even capacitors charged to quite low voltages can cause current inrushes of tens of amps when the switch closes, which can cause significant damage to relay contacts. So, either the nature of the capacitance in the circuit needs to be considered, or discharge protection must be included. This issue is discussed in greater detail in Pickering's Concise Technical Guide to Reed Relays.

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Manufacturers rate relays at a certain level of performance, but—especially for components >10 kV—pushing the device to its limits is inadvisable. When the part is new, it will perform as per spec, but throughout its life, especially if hot switching is employed, arcing and metal transference will occur between the contacts. This can cause a build-up on one contact, which reduces the contact gap and the voltage stand-off performance. By allowing a margin of at least 10 % on operating specs, the relay can be expected to perform reliably throughout its life.

Another advantage of reed relays in high-voltage applications is their high insulation resistances and much lower leakage currents in the nano-ampere region—orders of magnitude lower than solid-state devices (SSRs). The high leakage current of SSRs can make it difficult to measure milliampere current values.

The connector is another critical component requiring special consideration when evaluating modular switching products for high voltages. High-voltage D-type connectors rated for operation up to 1000 V are a readily available and economic choice. However, for applications above 1000 V, special high-voltage connectors such as those supplied by Redel must be used. These are, counterintuitively, smaller than the D-types, even though they work at higher voltages. These Redel connectors use plastic and lacquer insulation inside the connector to provide the necessary isolation to handle extremely high voltages.

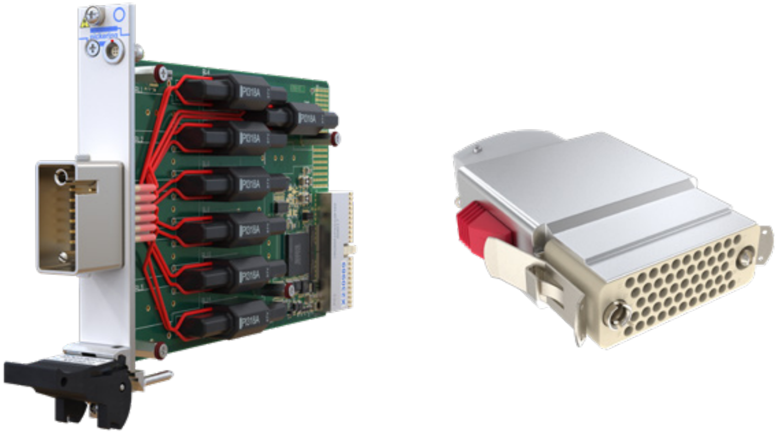

Figure 3 – PXI switching module from Pickering with 7 kV capability (left) and associated Redel high-voltage connector (right).

Another significant factor in increasing reliability is minimizing the effects of spikes, transients, and surges on modular switching cards. At high voltage, two types of suppression circuitry will be employed—one to protect the coil, which, if the relay is large enough, may be included within the relay housing, and additional suppression devices mounted on the LXI/PXI cards to protect the relay contacts from damage caused by spikes.

Repeatability

Best practices will ensure that test results are accurate and repeatable. For example, it is essential to ensure that the load is as purely resistive as possible, and does not include damaging capacitance and inductance elements. These can damage the plating on relay contacts and adversely impact their performance, even leading to failure. Therefore, avoid overshoot, inductance caused by cabling, and stored capacitance, which can lead to hot switching, even when power to the card is turned off.

Software errors must also be avoided. Automated signal routing software can help manage the safe timing and routing of signals within switching systems, considering discharge time, so hard-to-detect sequential errors and potentially damaging signal connections are avoided.

Of course, there are other techniques for improving measurement performance. Reducing voltage levels to manageable levels with voltage dividers is standard industry practice, and signal conditioning methods can also be used for more complex systems.

Summary

A thorough understanding of the considerations required when switching at high voltage has become of paramount importance, given the exponential increase in the demand, driven primarily by EVs but also by renewable energy systems and new generations of medical equipment, as well as more traditional high-voltage applications such as semiconductor, PCB, and cable test. Safety must always be the prime concern, and test system suppliers now routinely build hardware interlock functionality into their products. Reliability is assured when the most appropriate, high-quality components and standard design processes are used. And repeatability can be achieved when best test programming practices are followed. Stand-off voltage is a significant advantage of reed switch technology in high-voltage applications. Few applications switch high voltage if they can avoid doing so, and if they do, it will be low levels to preserve switch life. Having high stand-off voltage and low-contact resistance means that reed switches are increasingly chosen for applications where carry-current is the prime concern, especially if the current is pulsed. By using higher voltages, it can be easier to generate currents that are unaffected by circuit resistance changes and have 'cleaner' pulses (better pulse shape).

The Advantages of Working with Pickering

The Pickering Group comprises three businesses. Pickering Interfaces recently celebrated 25 years as a manufacturer of modular test systems built on the PXI standard. The company offers the industry's most comprehensive range of PXI and LXI products, including many products rated for use in high-voltage test equipment from 500 V to 7 kV. Pickering Electronics was founded over 55 years ago as a supplier of high-quality reed relays. Many of its products are now used to create compact, high-switching density, ultra-reliable modular test systems. Pickering Connect supplies custom cable assembly and connectivity solutions with quick turnarounds for any project size. Its innovative online Cable Design Tool and extensive in-house expertise ensure the highest performance interconnection products for all test and measurement applications.

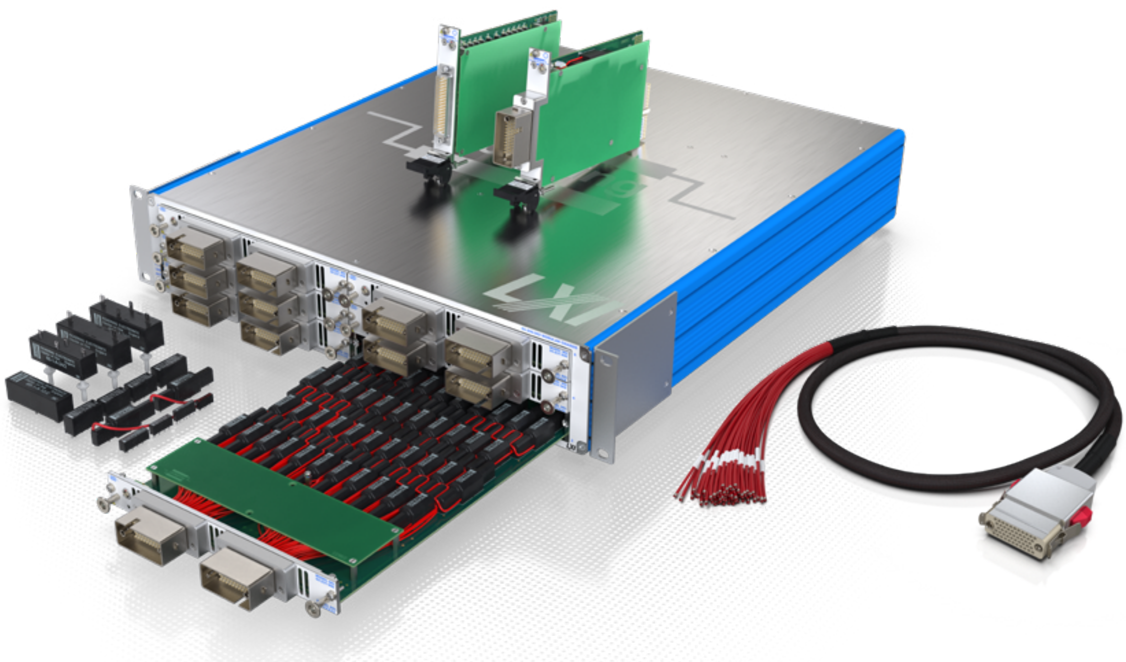

Figure 4 – High-voltage products from the Pickering Group.

Reed Relays

A reed relay may seem like a humble component, but as we have seen, it is a critical component in high-voltage switching systems. Pickering Electronics has introduced many innovations over the years that differentiate its product offerings. Examples include:

- A formerless coil construction is employed in Pickering reed relays, increasing the space available for coil winding by about 50 %, greatly improving magnetic efficiency.
- *SoftCenter*™ technology: Pickering reed relays are encapsulated using a soft inner material to greatly reduce physical stresses on the glass/metal seal of the reed switch capsule. This reduces damage to seals and distortion of the switchblade alignment, which will degrade contact resistance stability and life expectation.

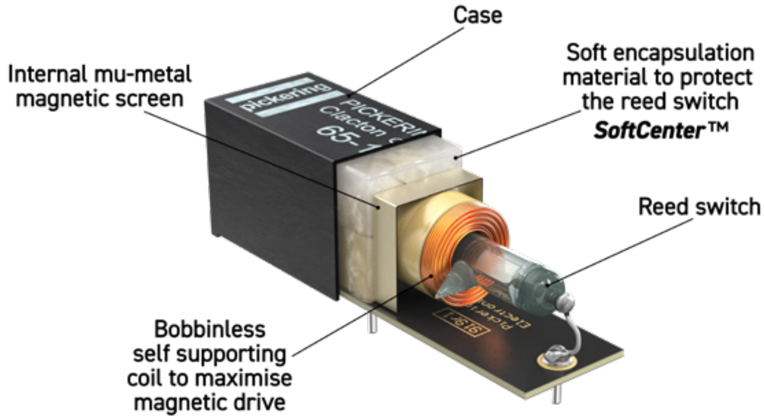

Figure 5 – Pickering high-voltage reed relay showing ***SoftCenter***™ internal construction.

- Mu-metal magnetic screening: Reed switches are operated by the magnetic field from a coil that is wound around the reed switch capsule. Without a magnetic screen, this field will spread some way outside the confines of the relay package and will de-sensitize other reed relays mounted alongside. Because Pickering's reed relays have this screening, they can be packaged very close together, forming very high-density switching systems.

- Custom design: Pickering Electronics offers a custom design service. One example is a variant of its Series 68 high-voltage product, which includes coil protection inside the relay housing, saving space and enabling potentially higher switching density.

Figure 6 – Pickering 68-series high-voltage reed relay designed for high-density applications.

PXI/LXI Switching Modules:

- Widest range: Pickering Interfaces offers the industry's most comprehensive range of high-voltage PXI and LXI switching modules with over 100 products in an ever-expanding portfolio.

- All high-voltage products introduced by Pickering in the last five years include hardware interlock functionality to ensure operator safety.

- Due to the expertise of its relay division, Pickering Interfaces offers high-voltage modules with an unmatched high switching density.

- Scalability: Pickering Interfaces' solutions are highly scalable: PXI and LXI modular chassis enable simple switching system expansion.

- Pickering's Switch Path Manager signal routing software speeds design and eliminates timing and routing errors.

About Pickering Interfaces

Pickering Interfaces designs and manufactures modular signal switching and simulation for use in electronic test and verification. We offer the largest range of switching and simulation products in the industry for PXI, LXI, and PCI applications. To support these products, we also provide cable and connector solutions, diagnostic test tools, along with our application software and software drivers created by our in-house software team.

Pickering's products are specified in test systems installed throughout the world and have a reputation for providing excellent reliability and value. Pickering Interfaces operates globally with direct operations in the US, UK, Germany, Sweden, France, Czech Republic and China, together with additional representation in countries throughout the Americas, Europe and Asia. We currently serve all electronics industries including, automotive, aerospace & defense, energy, industrial, communications, medical and semiconductor. For more information on signal switching and simulation products or sales contacts please visit: pickeringtest.com

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