The growing need for higher voltage photorelay devices in next generation automotive applications

Introduction

With growing concerns about the environment and the impact of global warming now being seen regularly, steps are needed to address these challenges. Pivotal to this will be the migration away from internal combustion engine (ICE) vehicles to alternatives that rely on electrical propulsion. Due to large-scale government investments in infrastructure, many countries are now seeing a considerable uptake in electric vehicles (EVs).

According to projections from the International Environment Agency (IEA), by 2030 the number of EVs on our roads will have increased at least ten-fold, reaching a total of around 145 million[1]. A further study, conducted by Bloomberg New Energy Finance, expects EVs to make up 58% of all passenger vehicle sales by 2040[2]. If these deployment levels are to be achieved, then EVs must become more attractive to car buyers.

One of the primary buyer concerns is the distance that EVs can travel between charges. This must be extended to avoid so-called 'range anxiety'. Improvements in battery technology and efficient operation mean that some EVs are now available with the capacity to travel over 500 miles before needing to be recharged.

Additionally, the number of charging points available, both en-route and at destinations (homes, offices, shopping malls, airports etc.) must continue to increase. Initiatives have been undertaken throughout Europe, bringing the number of public charging points currently in operation across the continent to around 285,000[3]. However, this deployment needs to go even further - significantly growing this number before the end of this decade.

Also, the time taken, especially for mid-journey recharging must be shortened significantly - bringing it as close to the time needed to refill a petrol tank as possible. The latest fast charging equipment is now enabling charge periods to be cut down to around 20 minutes.

One way vehicle manufacturers are improving the charging performance and efficiency is by migrating from the current 400V-based systems to ones that have an 800V rating. These higher voltage systems will allow recharging to be completed within a much shorter time. They will also mean that significantly lower charging currents can be utilized - resulting in less heat generation, which will, in turn, translate into reduced energy loss. As a result, more usable energy can be retained, and the range that vehicles can travel between charges will be significantly extended.

Finally, so that the initial investment in an EV can be more easily justified, the lifespan of the battery packs - which are the biggest single contributor to such vehicles' overall bill-of-materials (BoM) costs - must be extended as much as possible. Through the use of more sophisticated and effective battery management system (BMS) implementations, the health of battery packs (and each of their constituent cells) can be more closely monitored. Not only will this mean that potential safety issues may be identified far earlier, but furthermore, better cell balancing will lead to prolonged battery operation - thereby lowering EVs' total cost of ownership (TCO) and making them more commercially appealing.

This white paper will show how the use of advanced optoelectronics has a role to play in ongoing EV powertrain innovation. It will describe how there is a shift away from conventional electro-mechanical relays, in favor of more reliable, longer-lasting and convenient semiconductor-based alternatives which can enhance vehicle performance and reliability.

Issues with mechanical relays

Mechanical relays offer certain operational characteristics that are of real value in an EV context, because they are able to deal with the high voltages present. However, the risk of contact sticking is of great concern. If the device sticks forming welds on the contacts, then it will be impossible for the charge/discharge circuit to be turned off - and that could clearly be extremely dangerous.

Semiconductor-based relays (such as photorelays) do not have any risk of sticking, giving them clear advantages from a safety perspective. They can also be used in a broader variety of applications (which will be described later).

Photorelay function

The basic construction of a photorelay is fairly simple to understand. On one side there is a light emitter, which will be illuminated when current is passed through it. This will be complemented by a light receiver that detects the light coming from the emitter, initiating the switch of the output MOSFETs. In many cases, the emitter device will be an infrared light-emitting diode (IR-LED) with a corresponding photodiode array (PDA) receiving the signal. The two serial output MOSFETs will be turned on by the charging of their gates. If the current to the IR-LED falls below a certain level, the photovoltaic power of the PDA will not be sufficient to charge the gates of the MOSFET, resulting in an off-state.

Key photorelay attributes

Though photorelays currently cannot control loads that are as large as their electro-mechanical counterparts, they have a multitude of important operational advantages that engineers should be aware of. As they are solid-state, they are not prone to physical wear. This means that they can function over a much longer period than their mechanical counterparts, with no reliability concerns arising. These devices thus have a lower TCO associated with them, as they do not need to be replaced on a regular basis. In addition, they have much smaller physical dimensions, so they will take up a lot less space.

Raising voltage levels

Many of the applications in EVs are requiring higher voltage operation, due to the move from 400V to 800V architecture. This is driving a need for higher voltage photorelays to implement these applications. Some of those applications will now be briefly described.

Given the high-voltage batteries incorporated into EVs, measures must be taken to prevent them from harming vehicle occupants. Photorelays with enhanced voltage performance could be used for ground fault detection purposes. It will thereby be possible to safeguard against the risk of electric shocks through ground faults or short circuits occurring.

The ability of a BMS to determine the performance parameters of each cell within the EV’s battery resource will be vital if long-term operation is to be secured. Voltage monitoring may be called for, whether the EV is running or stationary.

Mechanical relays are unsuitable for this task, because of their open/close contact limitations and their relatively slow switching speeds. Also, if voltage monitoring is to be accurate, then the absolute minimum amount of current should be drawn.

Automotive applications for high voltage photorelays

Photorelays are of particular use in the BMS within EV applications. Specifically, they are used in mechanical relay welding detection, battery voltage monitoring and ground fault detection where it is often necessary to switch high voltages.

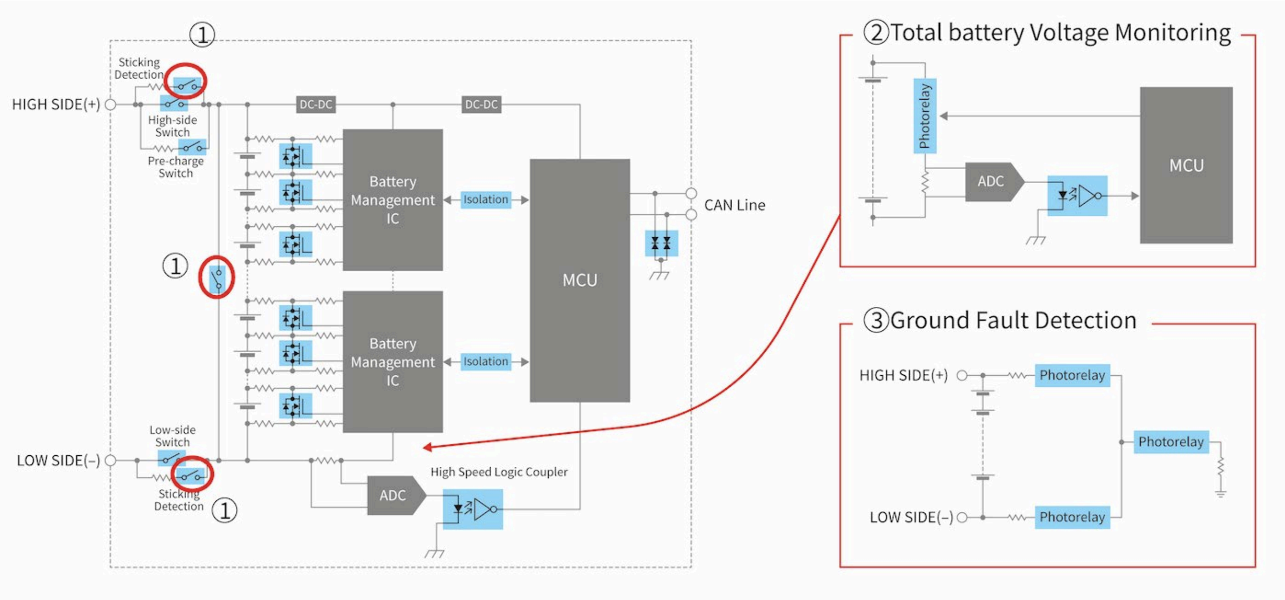

Figure 1: Applications for photorelays within an automotive BMS

Mechanical relays are often the only choice for high-energy automotive applications where hundreds of volts and hundreds of amperes have to be switched. While mechanical relays are ideal for this type of application, there is a risk that the contacts may stick and then weld together which would lead to a potentially dangerous situation where the power cannot be removed from the load.

For this reason, it is necessary to check for contact welding of mechanical relays. As this does not require a huge current flow, it is an ideal application for a high-voltage photorelay with no risk of sticking.

As EVs and hybrid vehicles use their batteries for traction power, then (especially when starting and accelerating) they require very high levels of electrical power. Therefore, it is important to know the individual battery cells and the total voltage status of the entire in-vehicle battery, and it is desirable to monitor them.

Voltage monitoring is required whether a vehicle is running or stopped and, for this reason, mechanical relays with limitations on contact opening/closing and slow switching speeds are generally unsuitable.

In voltage monitoring, it is common to measure using a high ohmic shunt resistor meaning that only a minimal current is applied. As a result, a photorelay is ideal as an ON/OFF switch for this circuit.

In general, the electrification of all types of vehicles, including EVs is enhancing, vehicle drivability and in-vehicle comfort. However, high voltages require higher levels of equipment safety, including ensuring that the battery voltage cannot flow into the chassis. In particular, there is a significant risk of electric shock to vehicle occupants in the event of a ground fault or short circuit. For this reason, a ground fault detection circuit is required for vehicles equipped with high-voltage batteries.

The presence or absence of this ground fault is checked at various events, including when driving, stopping, charging, etc., and between events. However, if the switch in the ground fault detection circuit remains in the ON state, normal detection cannot be performed. For this reason, it is common to use a high withstand voltage photorelay that is free from contact wear and welding risk.

A modern high-voltage photorelay

Leveraging advanced power engineering technology, Toshiba’s TLX9160T high-voltage photorelay is set to be an integral part of next-generation EV systems. It has been developed to handle elevated voltages that would normally require a mechanical relay, while still having the compact construction, rapid responsiveness and strong operational reliability which are synonymous with optoelectronic technology. This AEC-Q101-compliant normally-open 1-Form-A device has a maximum turn-on/off time that is less than 1ms.

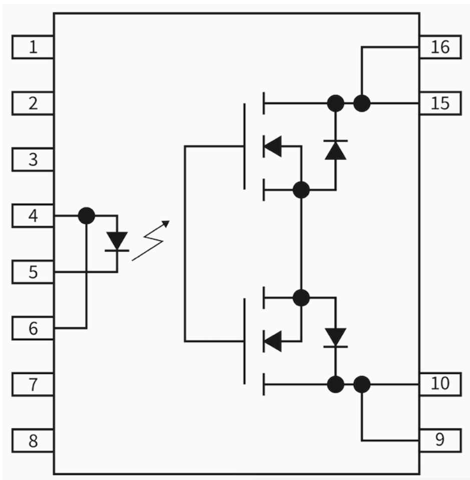

Figure 2: Pinout and internal structure of the Toshiba TLX9160T photorelay

The light-receiving element of the TLX9160T has a much higher voltage MOSFET situated between the output terminals of the PDA than can be found on other photorelays. This allows it to accept battery voltages of up to 1kV, thereby offering compatibility with the vast majority of traction batteries used in modern EVs. When operating at such voltages, a 5mm creepage distance is maintained on the PDA side. This means that the device delivers a 5kVrms isolation voltage.
Toshiba’s TLX9160T is highly optimized for use in EV BMS implementations, as well as for ground fault detection and mechanical relay weld detection activities. It is housed in a modified SO16L-T package that is made from an IEC60664-1 authorized material. An operational temperature range of -40°C to +125°C is supported.

Summary

The growing demand for EVs, and especially for EVs with greater range, faster charging and improved efficiency is posing several significant challenges for power designers, especially as battery voltages double to reduce currents and enhance efficiency. Mechanical relays have long been the switchgear of choice in high-energy automotive applications and, due to their current handling, they remain popular. However, their ability to 'stick' or weld their contacts is a concerning failure mode that could prevent a load from being switched off. This issue is sufficiently concerning that it is necessary to implement small circuits to check for this condition. Here, small high voltage photorelays are particularly useful. In fact, these devices are proving their worth in automotive applications and are being used extensively within the BMS.

References

1. IAE Global EV Outlook (April 2021)
2. Bloomberg New Energy Finance EV Outlook Report (May 2019).
3. Statista - Number of Electric Vehicle Charging Stations in Europe (2010-2021)

Contact us to discuss incorporating our products and solutions into your design:
https://toshiba.semicon-storage.com/eu/contact.html

toshiba.semicon-storage.com

TOSHIBA

Restrictions On Product Use

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as “TOSHIBA”.
Hardware, software and systems described in this document are collectively referred to as “Product”.

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA’s written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.
- PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE"). Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signalling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT. For details, please contact your TOSHIBA sales representative or contact as via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.