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High-voltage heaters with IGBTs

IGBTs – A key technology for air conditioning of electric vehicles

With the RGS series ROHM offers a wide range of AEC-Q101 compliant IGBTs in 1,200 V and 650 V versions. The series achieves market-leading low conduction losses that increase the efficiency of applications and minimize their size. They are ideal for inverters in electric compressors and for use in high-voltage heaters.

Felipe Filsecker

Electric vehicles are much more efficient than conventional vehicles with combustion engines. One consequence of this is that the waste heat from the motor no longer suffices to heat the interior of the vehicle. In this case, part of the energy stored in the battery must be converted into heat.
In order to enable an adjustable heating power without dependence on the operating temperature or battery voltage, power semiconductors are used in the new generation of high-voltage heaters. They control the energy flow from the battery to the heating element. The heating element heats the coolant, which is connected to the vehicle's air conditioning system via a heat exchanger. A blower transports the warm air into the interior.

This is shown schematically in Fig. 1.

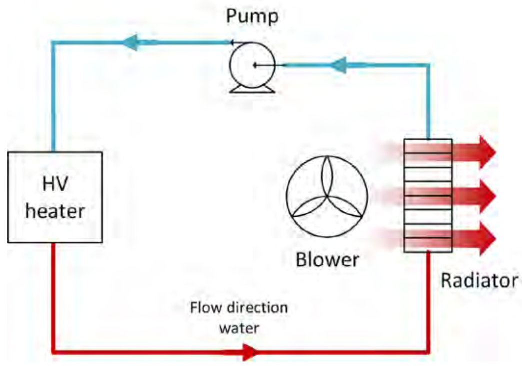

Fig. 1 Mode of operation of a HV heater in an electric vehicle

A normal electric vehicle needs a heating power between 5 and 7 kW to cover the heat demand. If the car is heated exclusively by a resistive load (heating element), the range decreases accordingly. Alternatively, there are also systems that do not rely solely on resistors to generate heat. They use the heat pump concept: thermal energy is transferred from a cold source (environment) to a warm source (interior) by means of externally supplied energy. The energy balance of a heat pump is better than heat generation by an ohmic load and the range is affected less.

However, with this system, the costs of the vehicle increase and its availability is determined by the ambient temperature. In regions with a very cold winter, these systems cannot generate enough heat. Classic resistive heaters are indispensable there.

Heating systems not only ensure the comfort of car occupants, but also have important safety functions: for example, they defrost windows or dehumidify the interior to give the driver a clear view of the outside world. The battery requires a certain operating temperature. The heater ensures that the battery is always in the green temperature range. The heater can also act as a discharge resistor in the event of high voltage peaks. If there is an unwanted increase in the voltage of the vehicle's electrical system, the device is able to absorb this energy and thus limit the amount of overvoltage. This protects the battery and other systems connected to the vehicle electrical system.

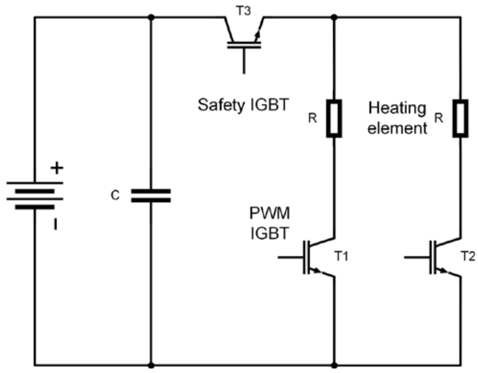

Fig. 2 Basic circuit of a high-voltage heater with two heating elements

The simplest form of a resistive heater is shown in Fig. 2: the switch is operated with an adjustable duty cycle so that the power output always matches the setpoint. To distribute the heat better, several branches are connected in parallel, usually two or three. In order to be able to switch off the heating system safely in the event of a fault, safety switches which are switched on permanently during normal operation are required. Should a fault occur, these switches switch off and thus disconnect the heating elements from the high-voltage vehicle electrical system.

ROHM's RGS IGBT product range with AEC-Q101 qualification

The circuit breakers used in this case are exclusively IGBTs. This technology offers very good conduction characteristics for high currents. The higher switching losses compared to MOSFETs are not relevant, as the switching frequencies are usually between a two-digit Hertz range up to a few kilohertz. Furthermore, these components are available in voltage classes of 650 V and 1200 V. Both classes are required for common heating systems. ROHM offers IGBTs of the RGS series with AEC-Q101 qualification in discrete packages, see Table 1, which are well suited for this application. These rugged IGBTs meet the typical requirements of a heater, which are discussed in more detail in the following sections.

BV	Gehäuse	FRD	15 A	20 A	25 A	30 A	40 A	50 A	75 A
650 V	TO-247	nein				✓	✓	✓	*
		ja				✓	✓	✓	*
	TO-263	nein	*	*	*	*	*		
		ja	*	*	*				
1200 V	TO-247	nein	*		✓		✓		
		ja	*		✓		✓		
	TO-263	nein	*						

* under development

Most of the systems are designed for 400V batteries for which 650V IGBTs are typically used. However, a trend towards 1200 V solutions has been observed recently to ensure an increased overvoltage capability of the heater. If the power supply from the battery to the heater is interrupted abruptly, the wires in the vehicle electrical system can cause significant overvoltages that could damage the switches. A higher breakdown voltage of the power semiconductors will thus prevent destruction of the heater. The 800 V systems are realised with 1200 V IGBTs. Here, series connection can provide an increased overvoltage load capacity.

Another feature of this application is the switching speed (dVCE/dt, dIC/dt), which is specified by the system. This is usually limited to a low value, in contrast to almost all other applications where the aim is to switch on and off as quickly as possible. This is due to EMC limitations and the aim to operate without filters or reduce them as far as possible to save costs. A simple way to achieve this is to slow down the IGBTs during switching to reduce the high-frequency content of the switching edges. This solution causes higher losses in the IGBT during switching, but does not require any additional components. The increased losses can be compensated by reducing the switching frequency. The switching times are in the range of single-digit microseconds. In rare cases, times in the lower two-digit range are achieved. Fig. 4 shows an example of the turn-on process of an IGBT with a gate resistor in kiloohm range. Since the load is resistive, and not inductive as usual, the voltage and current curves cross in the middle of the switching process.

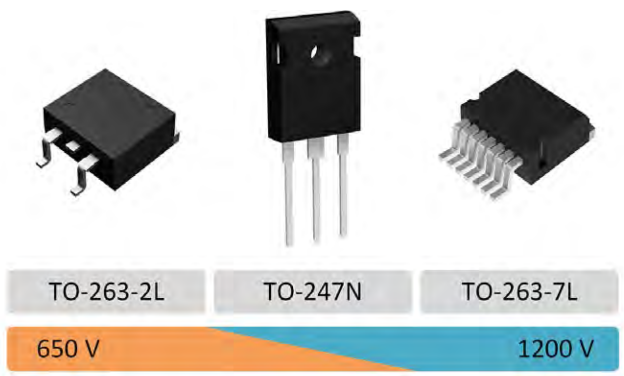

Fig. 3 IGBT package of the RGS product series

Although this way of operating IGBTs may look unusual for experienced designers, this approach is not prohibited. However, one should not slow down the switching times too much. It should be avoided that the IGBT experiences excessively large temperature spikes during each switching operation so as not to impair the power cycling capability. In addition, extremely slow switching times could be dangerous for the IGBT since it is operated at a lower gate voltage during switching. ROHM's own experience indicates that moderately slow switching does not cause problems. Due to the experience gained from various projects, ROHM is able to advise its customers competently in these decisions in order to find the best possible solution.

Another feature that should not be neglected is the short-circuit withstand capability of the IGBTs in order to ensure shutdown in case of a fault. Usually, the short-circuit detection needs a few microseconds to react. The IGBTs of the RGS series have a short-circuit withstand time of 8 µs for the 650 V voltage class and 10 µs for 1200 V. This allows any error handling strategy to be implemented successfully.

A further aspect in the selection of power semiconductors is the package. In this application, through-hole technology (THT) components are mainly used. These allow easy cooling by attaching them to an external heat sink. This technology, on the other hand, has a disadvantage in production, as through-hole technology requires additional steps. Surface mount technology (SMT) components, such as the well-known TO-263, can be soldered together with other components in one step, thus offering a cost advantage. Even though cooling becomes more demanding as the heat must be dissipated through the PCB, this does not prevent some manufacturers from considering this technology today. ROHM is closely following these discussions to be able to react in time. An expansion of the RGS IGBT portfolio for SMT components is currently under development. Fig. 3 shows the different packages for the RGS series of ROHM IGBTs. Transistors for surface mounting in TO-263 are currently being planned in two versions, depending on the voltage class. The 7-pin version for 1200 V offers an increased creepage distance to meet the requirements of the automotive industry.

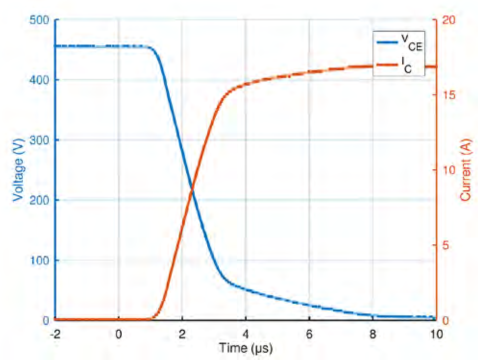

Fig. 4 Switch-on process of an IGBT (RGS80TSX2DHR) with resistive load and RG = 1.1 kΩ

There are, of course, in addition to the IGBT, other products from the ROHM catalogue that can be used in high-voltage heaters. These include gate driver ICs, shunt resistors, comparators, op-amps and voltage regulators. In the field of IGBTs, ROHM is the only manufacturer to offer a complete portfolio of AEC-Q101-qualified IGBTs. These are available with rated currents from 30 to 50 A, with and without integrated diode, in TO-247 packages. In addition, the RGS series will be extended to SMD components in 2020: 15 to 40 A IGBTs with or without integrated diode in TO-263-3L packages for the 650 V voltage class and 15 A in TO-263-7L packages for the 1200 V voltage class. A further addition to our portfolio are larger IGBTs in TO-247 packages: the 650 V voltage class will be extended from a rated current of 50 to 75 A. Due to the wide selection, the components can be adapted optimally to the operating conditions of the heater.

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