# Isolation and Partial Discharge testing of DC-DCs for gate drive applications

Paul Lee, Director of Business Development, Murata Power Solutions, UK

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## ABSTRACT

*DC-DC converters designed to power 'high side' gate drives must have characterised isolation and partial discharge performance for guaranteed long-term reliability. Details are given of comparative test results for different insulation types.*

## ARTICLE

DC-DC converters are often used to provide power for IGBT or MOSFET gate drive circuits in 'high-side' applications where the barrier of the converter sees a continuously switched high voltage. See Figure 1. For IGBTs, voltages for low and medium power systems can be over 1 kV at typically 10 KHz with edge rates (dV/dt) of around 30 kV/µs. For MOSFETS, both silicon and silicon carbide, frequencies can exceed 100 kHz with dV/dt rates up to around 80 kV/µs. While general purpose DC-DC converters may be 'flash tested' at high voltages, they are not necessarily guaranteed to withstand these values continuously. Because the voltage is switched at high frequency, undesirable displacement current is forced through the DC-DC barrier capacitance which can cause EMI and at worst short or long term failure of the barrier material. DC-DCs for high side drives therefore need to be designed and qualified for the application.

Various methods can be used to construct a DC-DC transformer barrier, trading-off size, cost and complexity. While an air-spacing would give confidence of effective isolation, the distance required even for low working voltages can be impractical. Alternatives are substantial solid material or multiple layers of thinner material. If the barrier needs an agency safety rating, the relevant standard defines the material type and thickness for different grades of isolation, working voltage, over-voltage category, pollution degree and altitude.

DC-DCs with defined creepage/clearance and solid insulation have recently been released by Murata Power Solutions for these applications and to build confidence in their isolation performance they have been put through a programme of stress testing in typical application circuits under controlled conditions. The typical application however may be a 10-100 kW inverter so Murata has teamed up with the Power Electronics Department of the University of Nottingham, UK, to evaluate DC-DC converters in their test rigs, normally used for research into latest technology high power drives.

A selection of power devices, 'DC link' voltages and test frequencies were chosen with dV/dt rates maximised for the devices used. The appropriate DC-DC converter from the Murata range was used as the supply for the gate driver circuitry and its barrier evaluated for integrity during and after long term testing using 3D X-ray tomography. A summary of the test conditions is given in Figure 2. No failures were observed, with long term tests ongoing.

Although the DC-DC parts have accumulated many thousands of hours of extreme stress testing, there is still the possibility that there is very slow degradation of the insulation barrier that might manifest over longer time periods. For high value applications, a user might expect reliable operation over more than ten years so a way is needed to give confidence that this is achievable.

The main mechanism for slow degradation of insulation barriers is 'Partial Discharge', the breakdown of micro-voids in the barrier material. Occasional discharge events have insignificant long term effect but continual discharges, even though measured in picocoulombs, can lead to carbonisation of the barrier material with voids effectively becoming short circuits, progressively reducing the overall insulation thickness until total breakdown occurs. Partial discharge only occurs at high applied voltage with specific inception and extinction values which are affected by void size and local air pressure in the void according to the non-linear 'Paschen' equation, curve A in Figure 3.

Considering a typical agency-specified insulation of 0.4 mm solid and a minimum inception voltage requirement of say 4 kVDC for long term reliability, a voltage stress of 10 kV/mm results, shown as line B in Figure 3. Where plots A and B intercept is the border in void size where discharges will occur or not, voids above 200 µm breaking down. It is relatively easy to specify plastic moulded material or layers of fibreglass in PCBs of planar transformers to have void sizes of less than 200 µm. Multilayer insulation however usually has much smaller overall thickness, the safety agencies typically allowing three layers of appropriate film amounting to 150 µm as equivalent to 0.4 mm solid. Now the material has a voltage stress of about 27 kV/mm shown as line C intersecting the Paschen curve at about 15 µm. Voids of this size or more between the layers are virtually guaranteed so this type of insulation system, while withstanding the voltage as a short production test without gross failure, will be experiencing multiple partial discharges, slowly degrading the areas around the breakdown.

Tests showing the inception voltage to be higher than the typical working voltage of a barrier material are therefore a good indicator of long term reliability. Specialised test equipment is used for this which can register the tiny current pulses representing the picocoulomb discharges.

To illustrate the partial discharge performance of different insulation systems, inception voltages were measured for different Murata DC-DC converters utilising insulation systems with the following characteristics:

- MGJ2 series, creepage/clearance 2mm in pollution degree 1 encapsulation, rated 'basic 200 VAC', functional 1.5kV, 5.2 kVDC hipot
- MGJ3 series, solid 0.4mm, rated 'reinforced 250 VAC', functional 3kV, hipot 5.2 kVDC
- NXJ series, double layer each 0.077 mm, rated 'reinforced 200 VAC', hipot 4.2 kVDC
- NCM6 series, commercial triple insulated wire each layer 0.04 mm, rated 'reinforced 250 VAC' hipot 5.2 kVDC
- NDS6 series, wire on enamelled wire rated 'functional', hipot 1.5 kVDC

Multiple units were tested and worst case results were recorded as shown in Figure 4. Parts MGJ2 and MGJ3, designed for high side gate drive applications showed very good results with partial discharge inception voltages substantially over their 'functional' working voltages. NXJ series with its monolithic construction also showed good results while the NDS6 with only wire enamel insulation showed the lowest inception voltage rating, reinforcing the guidance that parts of this type should only be used for low voltage functional isolation applications. Interestingly, and perhaps understandably, the NCM6 with its bought-in triple insulated wire shows relatively low inception at around 2 kV showing its unsuitability for the high-side drive application. The wire is rated for a test voltage of 4 KVAC so under this condition it is certainly experiencing significant partial discharges and degrading to some extent. This justifies the warning that DC-DC manufacturers such as Murata Power Solutions put on their data sheets that unnecessary repetition of hi-pot testing of insulation barriers leads to degradation and is not advisable.

In summary, for best partial discharge immunity physical spacing between transformer primary and secondary is best, followed by a single solid barrier with tight control of voiding. Over-sized solid insulation is beneficial as it reduces the field strength in the bulk of the material increasing the void size over which breakdown might occur according to the Paschen curve. Multi-layering of thin insulation is not recommended.

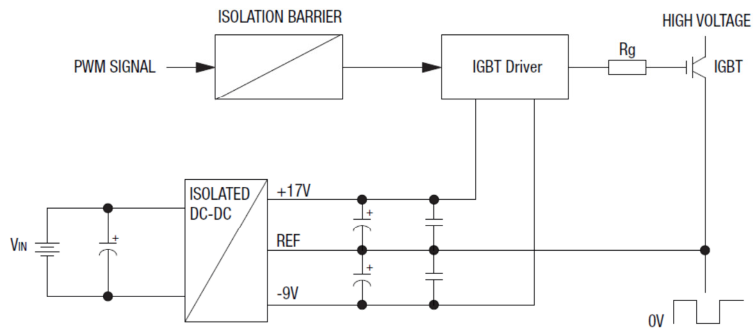


Figure 1. DC-DC in ‘High-side’ drive application

| DC-DC Converter | Switch Devices | Type | Inverter Frequency | DC Link Voltage | dV/dt | Test Duration |
|---|---|---|---|---|---|---|
| MGJ2D121509SC | CREE-C2M1000170D | SiC | 100 kHz | 1600 V | >65 kV/us | >2200 Hours |
| MGJ3 | IXGH6N170A | IGBT | 20 kHz | 1600 V | >80 kV/µs | >2200 Hours |
| MGJ3 | CREE-C2M1000170D | SiC | 100 kHz | 1600 V | >60 kV/µs | >2200 Hours |
| MGJ6 | IXGH6N170A | IGBT | 20 kHz | 1600 V | >80 kV/µs | >1000 Hours |
| MGJ6 | CREE-C2M1000170D | SiC | 100 kHz | 1600 V | >60 kV/µs | >2200 Hours |
| MGJ3/6 | IXEL40N400-ND | IGBT | 20 Hz | 3000 V | >30 kV/ µs | >1000 Hours |

Figure 2. DC-DC converter reliability test conditions

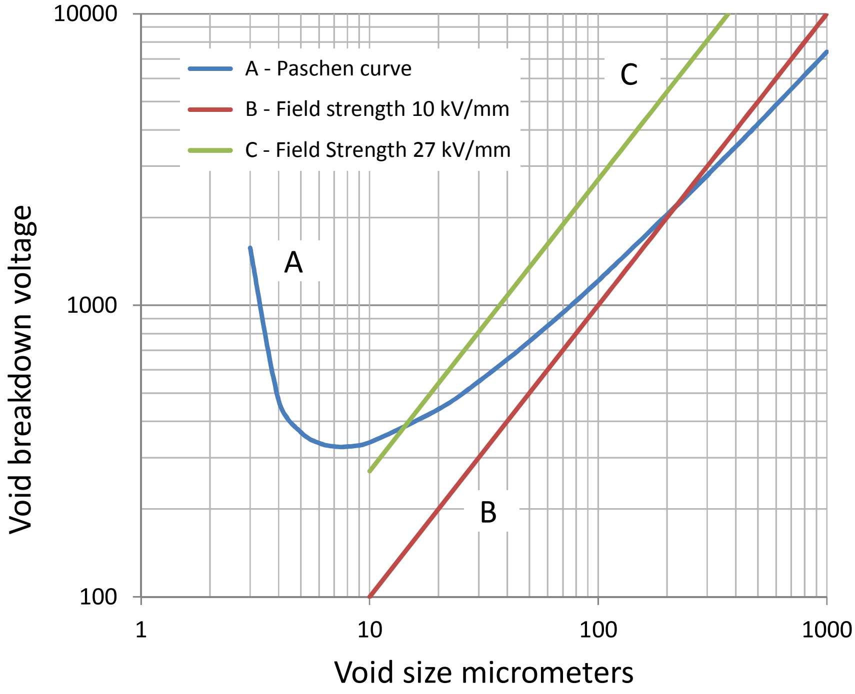


Figure 3.
Paschen curve for air at standard pressure and temperature with two field strengths

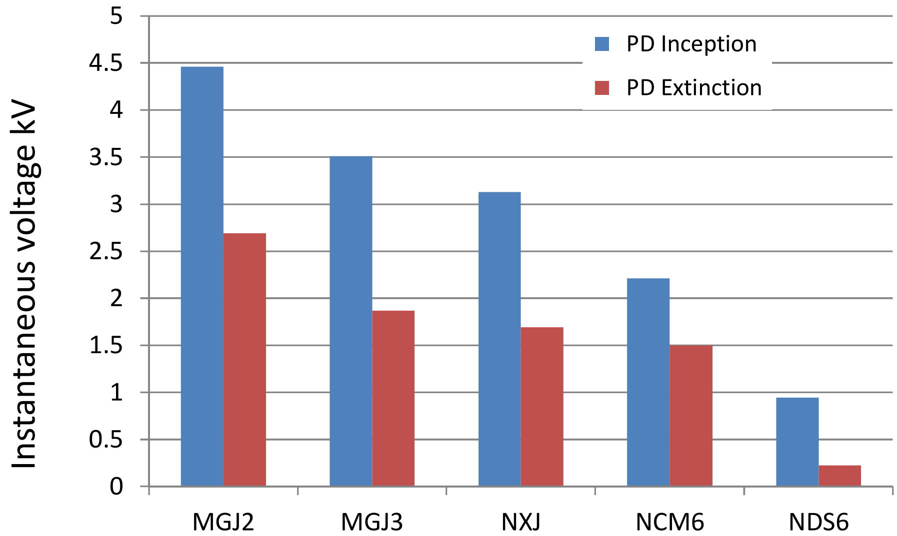


Figure 4.
Partial Discharge inception and extinction voltages for various Murata DC-DC converters