In all renewable energy generating equipment, such as solar cells and wind turbines, power electronics in the form of converters and inverters provide stable and sustainable energy. These power modules have to be able to dissipate considerable amounts of heat. Hence, they are often liquid-cooled. These days, Hitachi manufactures and sells custom-designed sealed water-cooled power module units (Figure 1) for not only renewable energy plant but also electric cars. A big challenge to the design of these power modules is producing a robust power electronics box with water-cooled heatsink underneath it, which also removes sufficient quantities of the heat generated to prevent it from overheating.

The problem we are faced with in our design process for these Power Modules is illustrated in Figure 2 by way of a rendering of a complete CAD geometry of such a unit. The schematic thermal measurement points through the IGBT and sealed water-cooled unit in terms of key junction to case temperatures, that can be measured. It is just not easy to measure the case temperature, $T_c$, properly with thermocouples.

Ideally, Hitachi wanted a new temperature measuring method that was non-invasive but as accurate as conventional thermocouples (or better), especially since the power densities have increased by up to eight fold in the last 18 years while power modules have had to be reduced physically in size by almost 100% for space and weight considerations. Thermocouples have inherent measurement weaknesses too, such as the flow over them affecting the accuracy of the results being taken, and possible leakages from the power module unit during operation with a thermocouple in place.

We researched several methods of measuring non-invasively temperatures in our power modules and from these we devised a three step measurement process based on using an Electric Furnace for calibration to determine the voltage drop, $V_{ce}$, across the unit, and the Mentor Graphics MicReD T3Ster® transient thermal tester (Figure 3). The T3Ster determines “structure functions” via R-C (resistance-capacitance) ladders which ultimately yield valuable thermal path data across the unit as well as temperatures through the many thermal layers in the module. In particular, this approach allows us to measure the Case Temperature, $T_c$, indirectly and because we measure water inlet and outlet temperatures we can use the T3Ster structure functions, for high to low water flow rates.
The graph in Figure 5 shows the derived Structure Functions from T3Ster for the study shown in Figure 4. It is clear that we can deduce the Case Temperature from this approach and assess the impact of various water cooling rates through the module. However, it is still hard to see the details of the inflection point and to estimate what minimum liquid flow rate we can get away with. Hence, in Figure 6 we took the T3Ster structure functions and looked at their differential values in finer detail to pinpoint the best inflection point. The graph clearly shows that 7 litres/min. cooling water could be just as effective as 10 litres/min.

Finally, as a cross-check verification of our new approach to case temperature, Tc, measurement, we devised a simple experiment using our tried-and-proven in-house engineering simulation tools. Figure 7 shows an in-house FEA thermal prediction of heat transfer inside the metal of the power module plate for three IGBTs operating. The proposed measurement method shows that it is possible to obtain case temperature (Tc) non-intrusive, accurately and the experimental results agreed well with the FEA temperature differential predictions, inside the metal component averaged over a 45° heat spreading area for three dies on the module.

In conclusion, Hitachi has developed a non-invasive technique, based around the MicReD T3Ster equipment, to measure our Inverter Power Module case temperatures as accurately as with thermocouples. Crucially, because the approach is non-invasive we can increase the productivity of our development efforts and look at many more customized power modules, weeks faster than before. We also gain extra thermal information about what is happening inside our IGBTs, plus the methodology also helps in the water-cooling design process when coupled with our in-house FEA and CFD simulation tools. In the future we would like to look at diagnostics of failure modes during power cycling of these power modules.