Application of Press-pack IGBTs in Traction Refurbishment

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***Abstract* – Press-pack IGBT technology has made significant advances in recent years. The availability of a wide range of products from multiple sources has now made this technology a realistic choice for both new build and refurbishment traction applications. Several case studies demonstrate the successful application of press-pack IGBTs in demanding traction applications including dc propulsion chopper drives for both Polish and RSA railways.**

I. INTRODUCTION

Whether it is an AC drive in a locomotive or an auxiliary power converter for the air-conditioning and lights in a passenger coach, all have evolved to use power electronic systems. This steady progress has proceeded over the last thirty years with ever more demands made on the heart of the system, the power semiconductors. Many older systems are now in need of either replacement or refurbishment. Often the project engineer is forced into the costly later solution due to the obsolescence of key components. Fast thyristors, Reverse conducting thyristors and GTO thyristors were the mainstay of AC drives and DC Choppers until they were replaced in new designs by the module IGBT. Now semiconductor manufacturers are often reluctant to supply these parts or charge high premiums to resurrect old production processes and the equipment owners demand upgrades with the latest technology. New power semiconductor technologies such as isolated base modules are not compatible with the mechanical systems, reduce the number of reusable parts and require extensive redesigns. An alternative is to take new silicon technology, such as the IGBT and package it in the form of the old (Figurers 1 & 2). It is the device, which follows this approach, the press-pack IGBT, that is the subject of this paper [1], [2] & [3].

Press-pack IGBT technology has evolved to a state where a wide range of products are available, from several manufacturers [4], [5] & [6], eliminating previously held concerns of the product being single source. While the characteristics of specific technologies may vary, the essential functionality and compatibility can be maintained within system designs. Devices are available with voltage ratings from 2.5 kV to 5.2 kV and current ratings from 160 A to 1.5 kA.

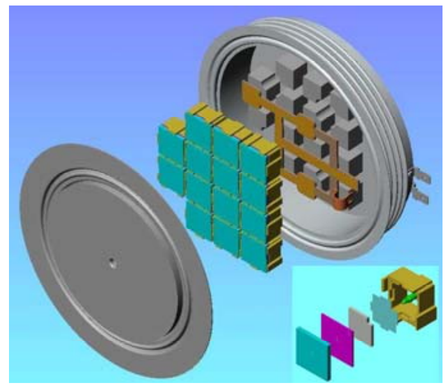

Figure 1, Construction of press-pack IGBT

Figure 2, Conventional press-pack outline

II. Press-pack IGBT technology

The press-pack IGBTs, used in the applications described in this paper, were designed for maximum reliability while maintaining simplicity of construction. Each IGBT or diode die is mounted in its own individual subassembly (lower right figure 1), offering total flexibility of package design. Contact to the die is made only through externally applied pressure, eliminating the need for wire and substrate bonds, thus minimising the stress and associated lifetime factors on the die. The subassemblies for each die are paralleled to give the required rating, figure 1 illustrates an exploded internal view of 900 A, 5.2 kV device, with an exploded view of a single die subassembly inset. Individual die gate terminals are contacted via a sprung pin, which is communally connected to the external gate terminal via a planar distribution board – this being carefully configured to ensure uniform series impedance to die and therefore good homogeneous switching. As the die subassembly is common for a given IGBT or diode die, different configurations are possible, such as the ratio of diode to IGBT, subject only to minor modifications to the package design. Projected ratings are only limited to what is practical both in housing manufacture and power circuit realisation [2].

Substantial environmental and accelerated life testing of the devices has demonstrated a very robust device, which out performs many alternative technologies [3]. Failure under thermal cycling has been identified as a reliability issue for some alternative packaging solutions, particularly under the arduous conditions required by traction applications. Elimination of stress, due to wire and substrate bonds, plus the relatively small size of the individual die give the press-pack IGBT thermal cycling performance in excess of even conventional thyristor technology.

Particular emphasis can also be placed on the impressive thermal properties offered by the press-pack design. A distinctive advantage over other packaging technologies is the ability to directly cool both dies of the die, almost doubling the effectiveness of the external cooling system. As additional performance enhancement is seen due to the direct cooling of the emitter contact, offering improved SOA and transient behaviour.

The hermetic package offers one additional option not seen in other packaging technologies, total immersion cooling. Particularly useful in the refurbishment of Freon™ and oil immersion cooled systems, the later of which is exploited in a an application described later in this paper.

III. Application of Press-pack IGBT technology

The press-pack IGBTs, described in this paper, was first developed for use in harsh applications such as Induction Heating, but have continued to evolve and now offer a new approach to the refurbishment of traction equipment. In the late 90's Westcode entered a development programme with a traction maintenance company in the UK to investigate using press-pack IGBTs to replace a now obsolete GTO thyristor. The twenty-year-old auxiliary power converters, which supplied heat and light to the passenger carriages in the high-speed electric trains, had started to exhibit unacceptable levels of failure. With one or two going out of service every trip, leaving the passengers in the dark, or still worse, failure of the electric doors forcing the carriage to be evacuated. The biggest problem for the owner of the equipment were the limitations imposed by the infrastructure owners on changes they could make to equipment operating on the track. A lot of on-site test measurements were made to characterise the system operation, with particular emphasis on conducted harmonics in both the line and load side (Figure 3).

Figure 3, In Coach testing of the auxiliary

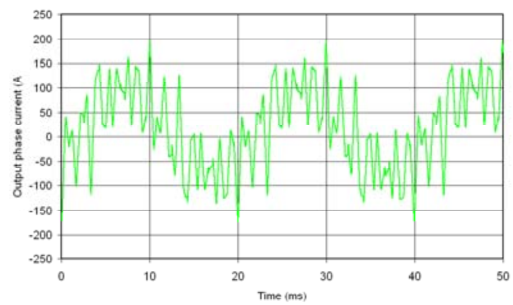

Figure 4, Live current output of auxiliary

Figure 4, shows output line current from one phase of the static converter, from this it can be clearly seen that this is less than ideal. With all this data a refurbishment proposal was placed with the Maintenance Company but ultimately rejected by the owners of the locomotives due to concerns for the unproven approach. Eventually the more expensive equipment replacement approach was taken, but not before a lot had been learned from the development project.

Undeterred by this failure, Westcode went on to use its new knowledge to further develop the press-pack technology, introducing higher voltage and current devices [7] & [8]. The next project, proposed and implemented by IEL (Instytut Elektrotechniki), was for a trial of the technology in a GTO thyristor propulsion chopper in a Warsaw tram. This project required the GTO thyristor plus gate drive to be replaced with a 2.5 kV, 500 A press-pack IGBT plus gate drive without altering either the mechanical layout or control circuits. After making the modifications, the unit was installed in a tram for operational testing on the network. After six months no problems were experienced and IEL felt confident to move on to a bigger project.

A new opportunity was presented by the need to upgrade five Polish Rail type E10 shunting locomotives. The locomotives run directly from the 3 kV DC supply line, which is fed to the chopper via a filter. The chopper unit drives four traction motors arranged in two groups of series connected pairs. IEL was awarded the contract to refit the locomotive's control system and power electronics, working with Westcode in the UK to replace the fast thyristor chopper units with new press-pack IGBT equipment (Figure 5 & 6). Westcode designed and supplied the power semiconductor assemblies, including cooling, snubbers gate drives and sharing circuits. The units were forced air-cooled and comprised of series connected pairs of 5.2 kV, 850 A press-pack IGBTs and extra low loss freewheeling fast recovery diodes, developed specially for the project. IEL's refurbishment scheme included: using the added functionality of the press-pack IGBTs to upgrade the locomotive's functions, to include both regenerative and rheostatic braking. To achieve this, the four fast thyristor assemblies (two chopper and two commutation), were replaced by three identical IGBT based assemblies (two for motor control plus one for DC link control and breaking). After extensive testing in the laboratory, the units were commissioned in the locomotives in April 2004 and have been operating without incident, the rail authority having expressed much satisfaction with the upgrade. Figure 7 & 8 show some examples of waveforms obtained during testing of the completed unit, when operating at a DC link voltage of 4 kV and a load current of 800A. Figure 7 shows an individual press-pack IGBT collector current and voltage while Figure 8 shows the voltage across two series connected press-pack IGBTs along with individual device voltages.

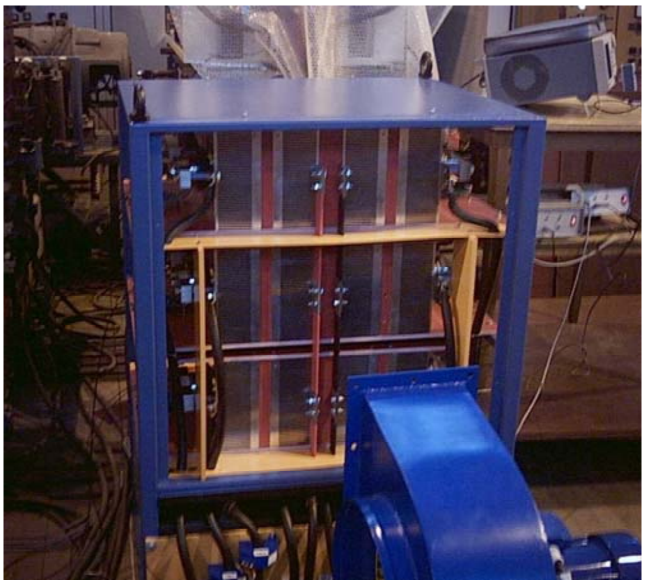
Figure 5, Chopper unit under test

Figure 6, Chopper unit installed into E10 Locomotive

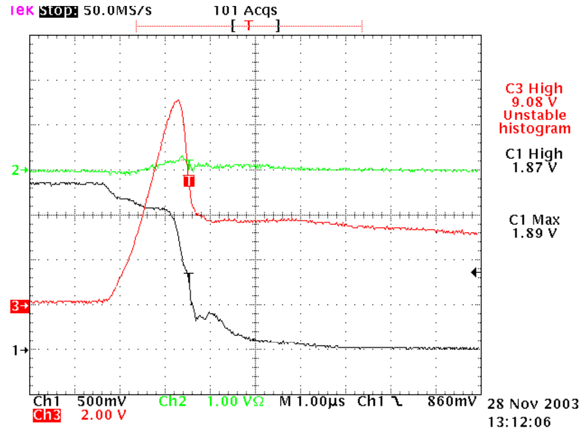

Figure 7, IGBT turn-off switching waveforms

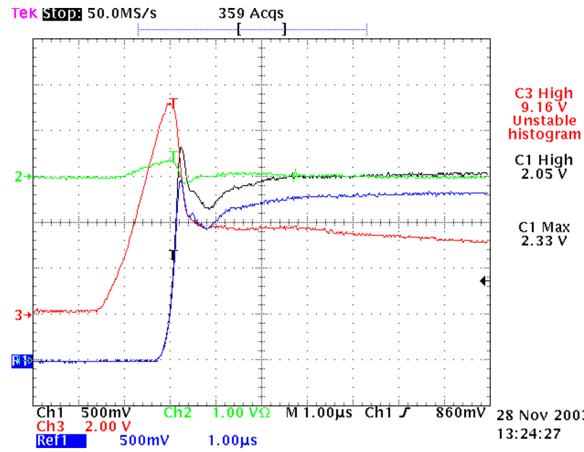

Figure 8, Chopper arm voltages

A further project is now underway to replace obsolete reverse conducting thyristor (RCTs) in the chopper units of Siemens Class 8E shunting locomotives operated by Spoornet in the RSA (Figure 9). The locomotive operates directly from a nominal 3 kV DC catenery, feeding the chopper via a DC link filter capacitor. The auxiliary resonant commutated chopper, comprising two series stacks each of four RCTs, feeds the main traction motors comprising two groups of two series connected, series wound DC motors (Figure 10). The RCTs are immersion cooled in an oil filled tank, which dictates the need for fully hermetic semiconductors making the press-pack IGBT an ideal choice for the upgrade.


Figure 9, Siemens Class 8E Shunting Locomotive

To determine the viability of the proposal, live testing of the chopper units under operational conditions was conducted on a locomotive in RSA (Figure 11). Figure 12 shows the chopper unit voltage and load current waveforms when operating at full power, rolling against the brakes. The chopper unit complete with its oil tank was then removed from the locomotive and shipped to the UK.

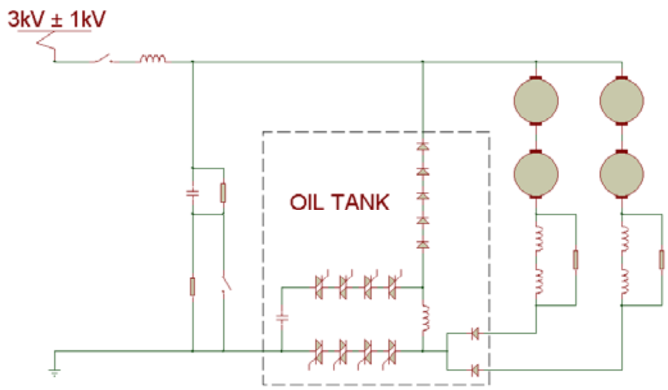

Figure 10, Original circuit diagram

Figure 11, Live testing of the chopper unit

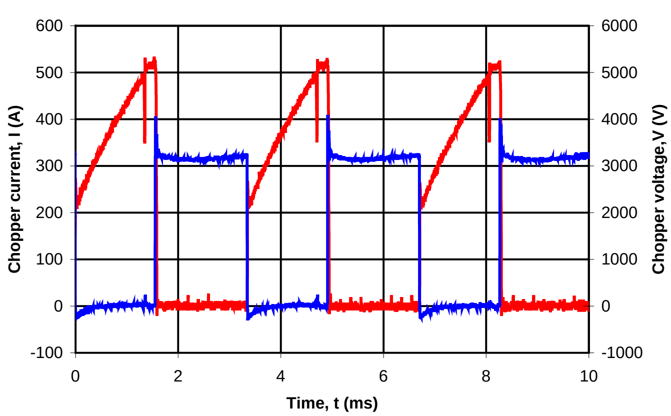

Figure 12, Live Waveforms (rolling against brake)

Figure 13, Chopper under test in UK.

Further testing and detailed characterisation of the chopper unit was completed in the UK (Figure 13) in parallel to a total redesign of the chopper power circuits. The two RCT stacks are replaced with a single press-pack IGBT stack comprising four 2.5 kV, 1500 A devices in series. As the IGBTs are gate-controlled devices, the commutation circuit was no longer needed so the bulky commutation capacitor was removed along with the commutation RCTs. The commutation reactor was initially retained to protect the freewheeling diodes from excessive di/dt at commutation. New cast aluminium pin-fin heatsinks were developed for this project. Extensive simulation was used to optimise the pin geometry, within the capabilities of modern manufacturing techniques, for application in oil immersion. Additionally the overall outline is optimised to requirements of the IGBT and best use of the available space. The IGBT pressure contacting and insulation systems are based around the original equipment such that the finished stacks are a form, fit and function replacement for the RCT stacks. Figure 15 shows one of the original RCT stacks to the left and a new IGBT stack to the right.

A new gate driver was designed to interface directly to the existing locomotive controls. Gate drive power supplies and timing signals are generated locally by the chopper unit from the original thyristor trigger and commutation lines. During the gate drive design process several new features were implemented to further take advantage of the IGBT - these include both short circuit shutdown and active voltage clamping.

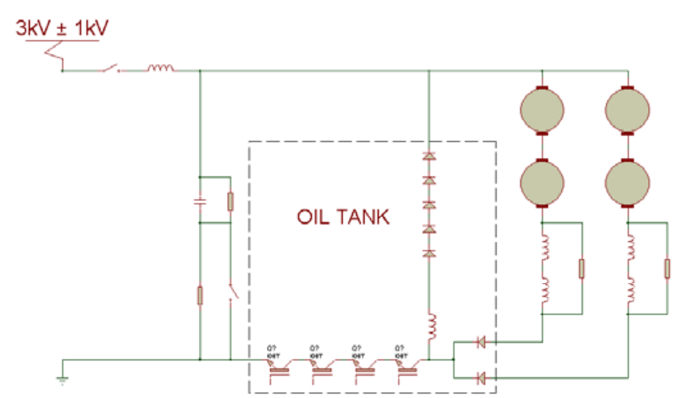

Figure 14, Upgraded circuit diagram

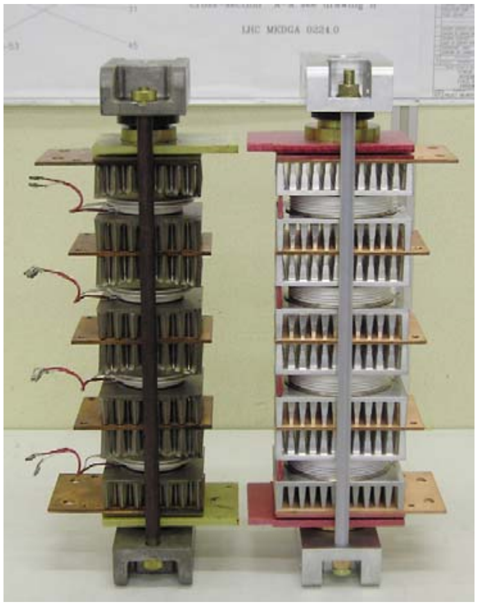

Figure 15, RCT and IGBT stacks

During initial testing of the prototype experiments were made with a new class of discrete extra fast recovery diode capable of repetitive inductive hard switching at over 3000 A/µs. These new diodes facilitated the disconnection of the commutation reactor. This not only reduces undesirable transient voltages induced but also significantly improves robustness and overall efficiency by further optimisation of the snubber circuits.

Final laboratory test focused on characterisation of the upgraded unit and verification of performance capabilities. Figure 16 shows the completed prototype switching at a current of 600 A into 3.2 kV, which is equivalent to the maximum operating condition where Ch1 is gate voltage, Ch2 is chopper voltage, Ch3 is chopper current .

Results of the characterisation compare favourably to the original design. Overall circuit losses (and hence temperature rise) are reduced to approximately 65% when compared to the original equipment. The volume of the chopper is less than 50% of the original unit and the weight reduced by around 20%.

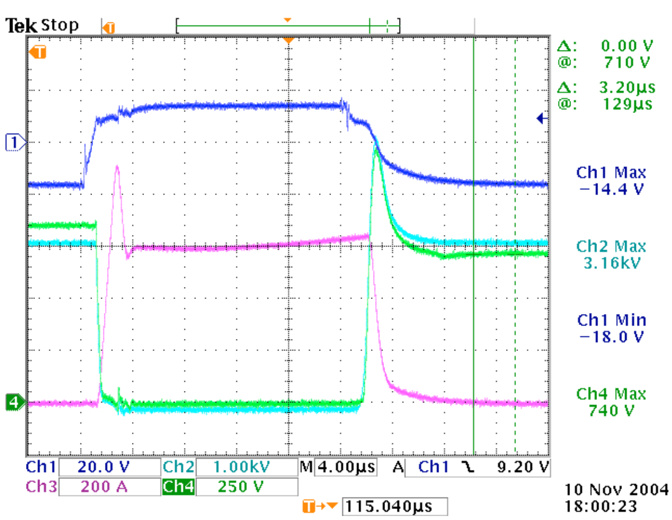

Figure 16, Final laboratory testing

To further capitalise on these savings, Spoornet are currently considering fitting a second, similar chopper unit into the space previously occupied by the commutation circuit to implement a field weakening controller. This could allow this class of locomotive to operate as a light haulage locomotive in mixed traffic.

Figure 17 shows the completed prototype unit removed for its oil tank including IGBTs to the right, gate drive in the center, snubber circuits to the left. The new freewheel and input diodes are mounted on the rear of the assembly. Subsequently, the prototype unit was shipped to Transwerk RSA for installation and commissioning into a Class 8E shunting locomotive, operated by Spoornet (Figure 18).

Figure 17, Completed prototype unit

Figure 18, Prototype installation

During the commissioning process the locomotive power was progressively increased while key parameters were monitored and recorded in real time. Testing culminated in a sustained stalled motor test, which the equipment passed successfully (Figure 19). At the time of writing the locomotive is undergoing further field trials in high temperature, high altitude conditions - to date no problems have been identified.

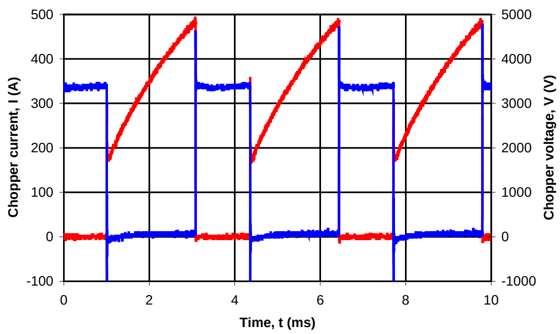

Figure 19, Live locomotive testing

IV. Conclusions

From the success of these projects, the press-pack IGBT has been demonstrated to be a viable alternative to complete equipment replacement, when the power semiconductors for a refurbishment become obsolete. This approach allows the retention of the mechanical system and often much of the control electronics, while introducing the advantages of the latest in power silicon technology. Traction has been the obvious target of this approach with so much equipment coming to the end of its serviceable life without major overhaul. Westcode is currently working on a number of projects including the replacement of GTO thyristors in AC locomotive main drives. However, the Press-pack IGBT is not limited to traction and similar projects are under discussion for medium voltage drives and utilities application, many of which have adopted this now proven technology for new designs.

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