GTO thyristors poised to take control of dc traction

As higher voltage and current ratings become available, gate turn-off thyristors seem likely to displace forced commutation of choppers as well as camshaft control in multiple-units and locomotives operating on all dc voltages up to 3 kV

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WHILE the thyristor has been widely adopted as a means of regulating motor current in ac traction, the dc chopper has not always been accepted as more economic than the traditional camshaft switching of resistances.

With the introduction of the gate turn-off thyristor, this situation is changing rapidly. Until recently British Rail retained camshaft control for dc traction because an economic case could not be made for using choppers, but the latest EMU fleet to be ordered (Class 319) will have chopper control of dc traction motors using GTO thyristors as their principal elements. This is one of seven orders placed recently with GEC Traction Ltd for electrical equipment that incorporates GTO thyristors.

Admittedly, Class 319 is dual-system stock designed to provide through service across London from 1988 over the re-opened Snow Hill link. The 25 kV ac overhead supply used north of London will, however, simply be transformed and rectified to match the 750 V dc picked up from Southern Region's third rail (Fig 1).

Although electric braking was not justified in the case of the Class 319 stock because there are only four motored axles in a 16 axle unit, electric braking will be used on other EMUs and locomotives being equipped with GTOs by GEC, such as the 11 Docklands Light Railway cars and the 50 Class 10E1 locomotives which will shortly be delivered to South African Transport Services for use on 3 kV dc lines.

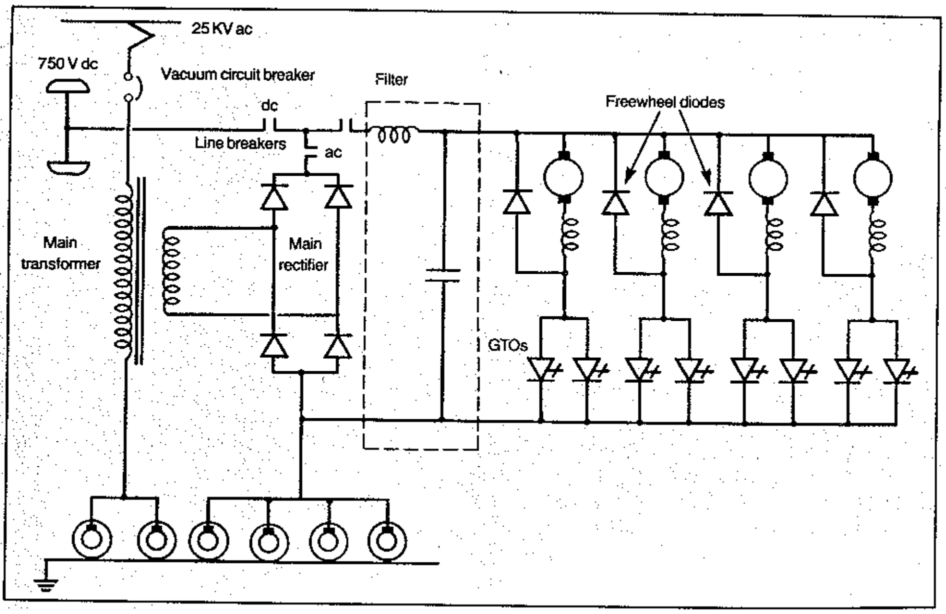
Before considering the influence of this new semiconductor device on the design of traction equipment, it is necessary to consider broader factors which led to the ascendency of chopper control.

Notwithstanding the present fall in the price of oil, the cost of energy continues to be a major factor in deciding between competing traction schemes. Railways are also very aware that if any changes are necessary to their depot and maintenance facilities as a result of the introduction of new stock, the cost can be high. Even in technically sophisticated countries, it has taken many years for railways to come to terms with the staff training and new maintenance procedures that the use of power electronics demands.

Nevertheless, a steadily increasing proportion of new orders have been for chopper-controlled stock, a develoment that has been helped rather than hindered by the advent of microprocessor-based control electronics. By automating to some extent the recording and analysis of faults, the microprocessor aids greatly the task of maintenance staff.

The GTO thyristor has increased the popularity of solid-state control on dc systems because of the changed constraints and additional freedoms which it offers. It is one step nearer to that dream of the power circuit designer: the perfect lossless solid-state switch. Like the ordinary thyristor, it is turned on by a small positive pulse at its gate, but whereas the ordinary thyristor needs a high power external circuit to force it off again at the right time, the GTO thyristor needs only a low power electronic circuit connected to its gate to provide the necessary negative pulse.

Fig 1. British Rail's Class 319 EMUs can take traction power at 25 kV 50 Hz or 750 V dc, allowing them to cross London through the re-opened Snow Hill tunnel from May 1988



DC traction motors

It is interesting to review the design of choppers with GTO thyristors currently being manufactured by GEC for BR's Class 319 EMUs, London Underground Ltd's prototype tube stock, the Docklands cars and the Class 10E1 locos. The first point to note is that all of them use dc traction motors, and not ac induction motors as might have been expected.

Compatibility and familiarity with known technology are two reasons why such a large fraction of the world's railways still use the dc motor. It might be thought that the GTO thyristor, by making the solid-state power switches simpler and more efficient, would speed the introduction of induction motor drives; but every advance which reduces the cost and complexity of the inverter needed to drive an induction motor at the same time reduces the cost and complexity of the chopper to drive a dc motor. Since an inverter (schematically at least) is made up of six choppers, the capital cost gap between the ac and dc drive options remains.

So there were sound arguments for retaining dc traction motors on these trains, and the choice in control gear was therefore between electro-mechanical and solid-state (chopper) equipment rather than between dc and ac motors. Nevertheless, GEC is manufacturing as a development project an induction-motor drive. The lower first cost and maintenance costs of the induction motor may offset the higher cost of the control equipment, if not at present then in the near future. It is therefore prudent to have this aspect of the technology developed so that it can be applied at short notice.

Protection

Chopper control gear is not entirely devoid of electro-mechanical switches. There is still the same need as ever to protect the system external to the train, and if possible the motors, from the effects of failure of the control gear.

breakers must perform this function.
on the list of desirable characteristics ion control equipment is electrical ess; the ability to withstand voltage sur- pled with sufficient current surge capa- e able to survive a high proportion of ults for as long as it takes the protective reaker to open.

TO thyristor enables the chopper to se criteria as well as, or better than, its ners in the field of semiconductors. The voltage previously obtainable in ordi- st-switching thyristors was 2·5 kV; yristors with repetitive voltage ratings V are readily available. With 1·5 kV dc one such device is adequate to d the normal vagaries of the traction and on LUL's and BR's 600/750 V dc a single GTO rated at 2·5 kV will suf- ries connection of devices is unneces- ept on 3 kV systems.

uld be pointed out that over-voltage on of one form or another is still l, since surges of four or five times the supply voltage are by no means non. The GTO thyristor also has a urrent rating similar to that of an fast thyristor of comparable rms rating, 16 kA for an 800 A rms device, nple. Thus no change in protection ue is called for.

nical robustness

nd requirement of traction equipment anical robustness and tolerance of the ment. The equipment must stand up to l and weather on the underframe of the d it must not be too delicate to handle way workshop. It must continue to reliably and to specification in all tem- s and humidities to which it is likely to ed, and it must not fall to pieces during ars of vibration and bumps. The ways ating equipment modules or cases, the of making cable connections and her techniques are carried over to the ture of chopper control gear from hard aught by previous experience.

ems in particular require special atten- e packaging of the printed-circuit boards of the control electronics, and the mounting and cooling of the high-power semi- conductors (GTOs and diodes).

All power semiconductors need to be cooled. In the Docklands equipment, for example, there is one GTO thyristor per traction motor (Fig 2); each GTO thus handles the peak motor current of 300 kW and in the process dissipates 500 W, which must eventually be rejected to atmosphere. GEC prefers naturally ventilated earthed heatsink assemblies, as used in the Class 319 and Docklands equipments, because they require no filtration of the cooling air and no fans.

The penalty to be paid for this simple, main- tenance-free heatsink is less thermal efficiency than can be obtained by oil or forced-air cooling, so larger semiconductors must be fitted. In Class 319, for example, Marconi DG506 thyristors have been used, a compar- atively large GTO rated at 1·4 kA peak turn- off current and 600 A rms. In Class 319 it is being utilised at only about 300 A, the penalty paid for naturally-ventilated heatsinks. When ambient temperatures and equipment rating permit, however, they remain the first choice, and are used on all the EMU chopper equip- ments GEC has supplied to BR as well as a much larger quantity of export orders.

In the choppers for LUL's prototype tube stock it was not possible to rely on natural ventilation because all axles are motored and space on the underframe is very restricted. It was therefore necessary to use forced-air cooling.

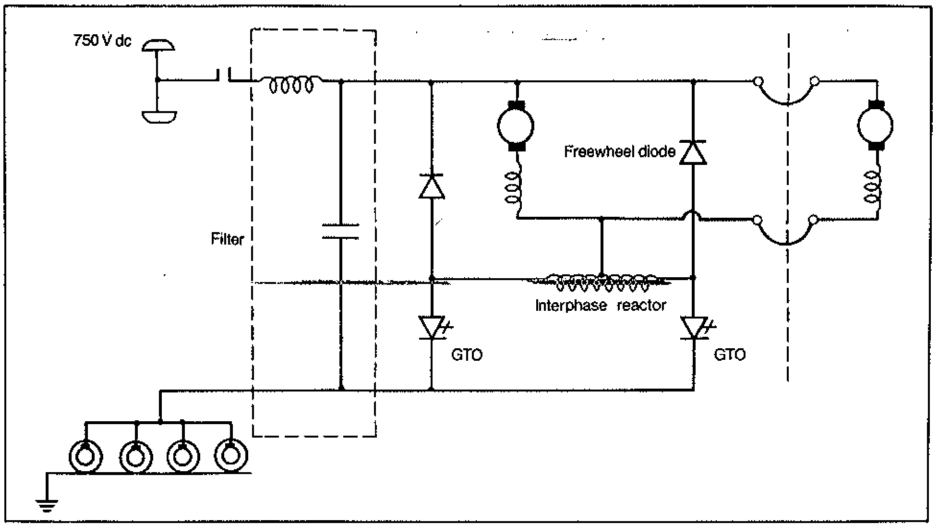


Fig 2. Simplified traction circuit (with braking connections omitted) for the articulated cars being built for the Docklands Light Railway

Interference

Third in the list of traction control gear features is the requirement that interference with signalling or telecommunications should be within acceptable limits.

The introduction of chopper control in the 1970s led to a much greater awareness of the electrical ambient in which the signalling sys- tem works. Measuring and recording instru- ments that until then had been comparatively rare on railways (tape and UV recorders, high- frequency shunts and oscilloscopes) became commonplace as a result of the power electronics engineer's involvement.

These insights are evident in specifications for new rolling-stock: the frequency at which the chopper operates, the permitted level of current ripple in the traction supply, the

thyristors GTO vont dominer la tion à courant continu. Au fur et à ure que des valeurs nominales plus ées de tension et d'intensité ennent disponibles, les thyristors raient déplacer la commutation e des hacheurs, ainsi que le rôle à arbre à cames des rames motrices et des locomotives tionnant sur toutes les tensions en ant continu, jusqu'à 3 kV. ndant, l'allure du développement semiconducteurs de puissance le accélérer à nouveau. Les stors contrôlés par champ et à ction statique qui arrivent sur le hé promettent des économies de et d'énergie encore plus grandes celles obtenues par les composants upure par impulsions de porte

Abschaltbare Thyristoren dominieren bei Gleichstrom-Triebfahrzeugen. *Bei den jetzt zur Verfügung stehenden höheren Spannungen und Stromstärken sieht es so aus, als ob abschaltbare Thyristoren die Zwangskommutierung der Zerhacker sowie den Fahrschalter in Triebwagenzügen und Lokomotiven für alle Gleichspannungen bis zu 3 kV ersetzen. Das Entwicklungstempo auf dem Gebiet der Leistungshalbleiter scheint sich jedoch wieder zu beschleunigen. Die heute auf den Markt kommenden Thyristoren mit Feldsteuerung und Statikinduktion versprechen noch größere Kosten- und Energieeinsparungen als die jetzigen abschaltbaren Geräte*

Los tiristores de desconexión por impulsos de puerta dominarán la tracción en cc. *A medida que va disponiéndose de tensiones e intensidades más elevadas parece probable que los tiristores de esta clase desplacen a la conmutación forzada de interruptores periódicos, así como al control por árboles de levas, en los trenes de unidades múltiples y locomotoras para todas las tensiones de hasta 3 kV en cc. Sin embargo, el ritmo del desarrollo de los semiconductores de potencia parece que está volviendo a acelerarse; los tiristores de control de campo y de inducción estática que están apareciendo ahora en el mercado parece que prometen ahorros de costes y energía aún mayores que los dipositivos controlados por impulsos de puerta*

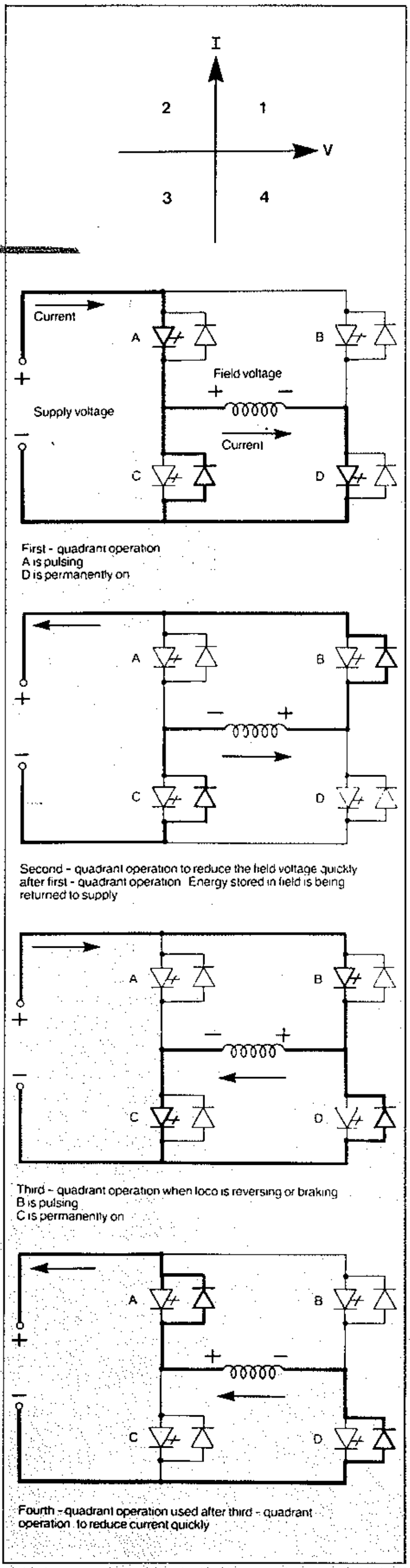


Fig 3. Four-quadrant operation is used in the Class 10E1 locomotives so that current in the separately-excited traction motor fields can be reversed rapidly; this gives the wide range of control which SATS considers essential when working heavy haul coal trains

psophometrically-weighted noise induced in adjoining telephone lines, and the input impedance of the equipment at 50 Hz are usually strictly defined.

It is in the design of the input filter of the chopper that such specifications have their greatest effect on costs and weight, and the GTO thyristor can do little to reduce their impact. This was particularly the case with Class 319 and the LUL tube stock, both of which have to be compatible with existing signalling since it would clearly be uneconomic to resignal lines solely to accommodate a minority of chopper trains.

In the case of Docklands, the signalling and traction control were designed to be compatible with traction choppers from the start, so the input filter on these cars is much smaller and lighter than on Class 319 stock.

Comfortable ride

A fourth desirable feature of traction control gear—and one where the GTO does have an impact—is that the train control should be completely unnoticeable to the passenger. In other words, there should be no jerkiness in acceleration or braking, as little noise as possible, and no interference either inside or outside the train with personal electrical equipment.

To turn off an ordinary thyristor used as a chopper requires a high power auxiliary circuit to reverse the voltage across the device. Such a forced commutation circuit needs to include a resonant circuit comprising a large capacitor and inductor. The resonant current flowing in this circuit during commutation of the thyristor has a high frequency and amplitude. This not only makes the engineering of the circuit difficult if it is to perform its primary function efficiently; it is almost impossible to prevent radiated electromagnetic interference and an annoying whine. The GTO thyristor helps in these areas by eliminating the commutation circuit entirely.

GTO drawbacks

As might be expected, the GTO brings with it some drawbacks as well as advantages.

The GTO switches off the current flowing through it in a few microseconds when a negative pulse of gate current is applied. In other words, the rate of change of current is extremely high. Unless stray inductance is kept to an absolute minimum in the cables leading to and from the filter capacitor and in the snubber circuit of the GTO, excessive voltage will be developed across the inductance by this rapidly-changing current.

The layout of the snubber circuit and of the main power circuit cabling thus become the subject of detailed engineering consideration. Some thought did need to be given to the layout of ordinary thyristor choppers, but not to the same extent. With GTO equipment, the designer does not have so free a hand as before in placing the equipment cases on the underframe of the vehicle.

These restrictions on layout are balanced by the fact that the GTO-based equipment is much smaller. In the prototype chopper which GEC produced for BR's Class 455 EMUs the two GTO thyristors controlling each pair of motors were both accommodated in one 800 mm long section of a standard underframe equipment case. It proved possible to install the choppers for four motors in much the same space as had been required for only two motors in a previous chopper prototype which used forced-commutated thyristors.

Two- and four-quadrant choppers

This reduction in size also means that it is now practical to consider the use of two-quadrant and four-quadrant chopper schemes. GEC first applied the four-quadrant chopper as a field controller in the Class 10E1. These locomotives have separately-excited motors in order to achieve the wide range of control required for hauling 10 000 tonne coal trains, and the close matching of tractive and braking effort needed when up to four units are working in multiple.

The field chopper controller works by varying the voltage applied to the field. When a higher braking notch is selected by the driver, the field current is increased by raising the conduction ratio—and hence the output voltage—of the chopper. Neither the current nor the voltage change direction, and this mode of working—which is the normal one for choppers—is known as first-quadrant operation.

It is sometimes necessary, however, to force the field current to change very quickly if the line voltage fluctuates rapidly. This is done by reversing the voltage on the field winding while the current is still flowing in the original direction, which is called second-quadrant operation (Fig 3).

In the Class 10E1 locomotive both the field current and voltage can be reversed independently by solid-state means. This is true four-quadrant operation, which permits field current reversal for switching between powering and braking, and field voltage reversal for fast field current control. In addition, the field current and voltage can be reversed simultaneously, which is normally the function of electro-mechancial reversing switches. Replacing the reverser would have been impractical using ordinary thyristors; the forced-commutation circuits would have been far too bulky to be accommodated even in a large locomotive.

High frequency

The working frequency of the chopper is usually specified by the operating authority. In most cases it is permissible to set the chopper frequency at one of the harmonics of the specified fundamental frequency as such harmonics will be produced anyway. Raising the chopper frequency has advantages: it may be possible to dispense with motor smoothing chokes, and the line current ripple will be reduced for a given size of input filter. A higher chopper frequency also allows faster control of the motor current in response to such conditions as wheelslip or sudden large changes in the line voltage.

The GTO thyristor invites operation of the chopper at higher frequency, not only because it is an inherently faster switch but also because there is no forced commutation circuit. A commutation circuit needs to be reset every cycle nd this takes a fixed time, thus placing an pper limit on the chopping frequency.

However, there are drawbacks to high freuency operation. GTO thyristors are not per-:ct switches; there is an energy loss associated ·ith each turn-on and turn-off of the device, nd consequently the power loss due to switch-ıg goes up in direct proportion to the chopping :equency.

Naturally-cooled heatsinks impose a strict mit on the GTO dissipation that can be hand-:d. The chopping frequency cannot be .icreased without either paralleling thyristors ›y one method or another, or making the emoval of heat from the GTO yet more effiient. Another possibility is to fit larger thyistors. In any event, extra cost is involved.

The GTO thyristor has been said to be able o work reliably at higher temperatures than ›rdinary thyristors, and perhaps even up to the ıormal maximum temperature for silicon liodes (150°C), but to date manufacturers have :rred on the side of caution and specified a naximum junction temperature of 125°C.

At very high frequencies it might not be pos-ible to take advantage of the increased speed ›f control response because the microprocessor vould have insufficient time to complete its ›rogram within the chopper cycle. This seems ınlikely to become a practical problem as faster ›rocessors are still being introduced.

It should not be thought that these disad-'antages of high frequency chopping prevent ts advantages being realised altogether. On the :ontrary, there is a well known method of ›btaining the best from both approaches: the requency is kept at the fundamental for most ›f the time, and only raised to two or three imes the fundamental during the relatively hort periods when the train is accelerating at naximum current. Fortunately, it is during ust these periods when the greatest benefit can ›e derived from the increased frequency in erms of reduced interference with telecomnunications or signalling.

Vhere next?

The GTO thyristor had been available in mall sizes for many years, but it remained in he background from the standpoint of the raction engineer until production of high-volage high-current grades began four or five vears ago. It has not perhaps led to such a major evolution in the industry as did the advent of ›ower electronic devices in the 1960s and 970s, but its introduction has enlarged the ange of practical and economic schemes in the raction engineer's repertoire.

The pace of development in power semi-:onductors, which at one time seemed to have lackened, now seems to be accelerating again. Field-controlled and static-induction thyristors ıre being brought to market which show ›romise of cost and energy savings even over he GTO thyristor.

The GTO thyristor itself is probably some vay from its ultimate commercial developnent. Higher voltage and current rating and asier gate drive requirements are foreseeable, ınd will encourage its use in every field of dc raction, in locomotives as well as multiple-unit rains and under 3 kV wires as well as on 1·5 :V and 750 V railways. □

Glasgow electrics reach Ayr

FROM September 29 a half-hourly service of Class 318 EMUs (above) will link Glasgow with Ayr, following electrification at 25 kV ac of the line from Paisley. Maximum speed will be restricted until the branch from Kilwinning to Ardrossan South Beach goes electric on January 20 1987, because a traction power feed from Ardrossan is needed to support 145 km/h running.

From May 1987 electric trains will be extended from Ardrossan to Largs, this section having been approved later than the rest of the £84m Ayrshire electrification. A further short extension of the catenary to Ardrossan Harbour is proposed to round off the project.

The Ayrshire scheme comprises 82 route-km and 173 track-km, including a connection to the EMU depot at Corkerhill in Glasgow. GEC-General Signal is equipping the lines with three-aspect colourlights controlled from a new panel in the existing Paisley signalbox. The double track between Paisley and Kilwinning has been signalled for bi-directional running at 90 sec headways to permit overtaking movements; pairs of facing and trailing crossovers can be traversed at 65 km/h.

Pirelli Construction has installed BR's standard MkIIIb catenary, as developed for the London – Bedford project completed in 1982. A feature of the line to Ayr is the very narrow right-of-way, which in places meant acquiring tiny plots of land to support the catenary masts. Almost 100 bridges had to be adapted to provide electrical clearance, and at Newton-on-Ayr a dead section of catenary proved necessary. Where the line runs beside the sea at Barassie, insulators with extra sheds ensure that salt pollution will not cause flashovers.

Basic half-hourly services from Glasgow to Ayr and Ardrossan, and hourly to Largs, will be provided by the 21 three-car EMUs now being delivered by British Rail Engineering's York works. Fast trains will cover the 67 km between Glasgow Central and Ayr in 49 min, and the 51 km to Ardrossan South Beach in 39 min. □