

# Switchgear developments

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## SYNOPSIS

The purpose of this paper is to examine the significant developments in MV and LV switchgear technology over the last few decades and why they are only recently beginning to benefit the users. A recent development now has sufficient field experience to show how through innovative design it has been possible to vastly improve an auto-reclosing circuit breaker. The author believes that the same innovative ideas will soon be applied to all types of switchgear.

The next generation of military switchgear is likely to be developed for the Electric Warship. Irrespective of which distribution supply is used the next generation of switchgear should benefit from the new technology.

## INTRODUCTION

### Reliability

The main application of switchgear is in the protection of circuits against damage caused by faults and the restoration or preservation of supplies to as large a part of the system as possible following a fault. In this function they must add reliability to the system rather than contribute to system problems. Providing fault occurrences are rare then system disruption caused by the switchgear, either for maintenance or operational problems has to be very rare. Hence the main objective of any switchgear development must be to improve the reliability of the switchgear itself as well as its performance as a protective device.

### 1960's SWITCHGEAR

Oil and air circuit breakers dominate LV and MV switchgear markets.

#### Air circuit breakers

Air has been used as the insulator in switchgear across the entire voltage range from miniature circuit breakers at domestic voltage to air-blast circuit breakers at transmission voltages up to 800kV. For the purpose of this paper the term air circuit breaker will be used to describe a three-phase circuit breaker using air at atmospheric pressure as the insulator.

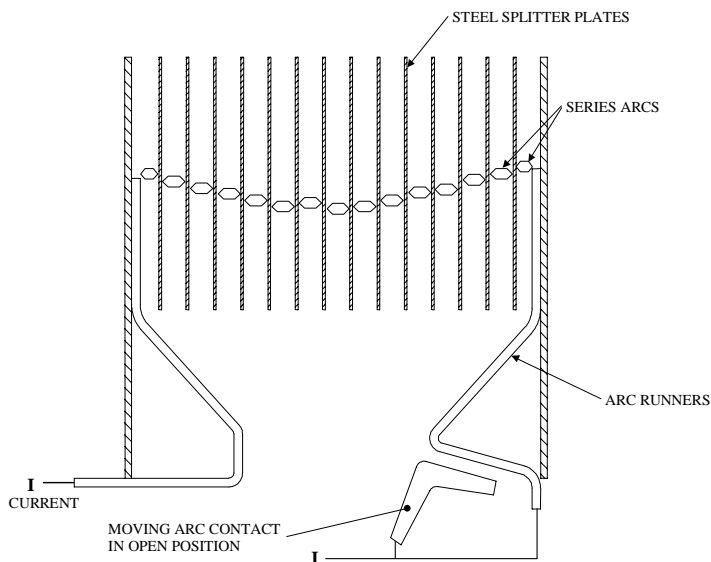
Early switches were plain-break which stretched an arc between a stationary and moving contact with no means of arc control. Arcing times were consequently long and voltage and current ratings limited. Performance was increased by the use of various arc control devices, probably the best and therefore the most commonly used arc control device is the arc chute.

Arc chutes comprise a number of bare metal plates arranged at right angles to the length of the arc chute with spacers between the plates to allow the arc to be split up into a number of series smaller arcs, increasing its resistance and extracting heat. Eventually the arc is no longer able to sustain itself. When interrupting high short circuit currents the anode to cathode voltage drop is approximately 30V across each pair of plates. In dc circuit breakers if enough plates are used in series the arc voltage across the chute can be greater than the system voltage, forcing the current down to zero and thereby interrupting the current.

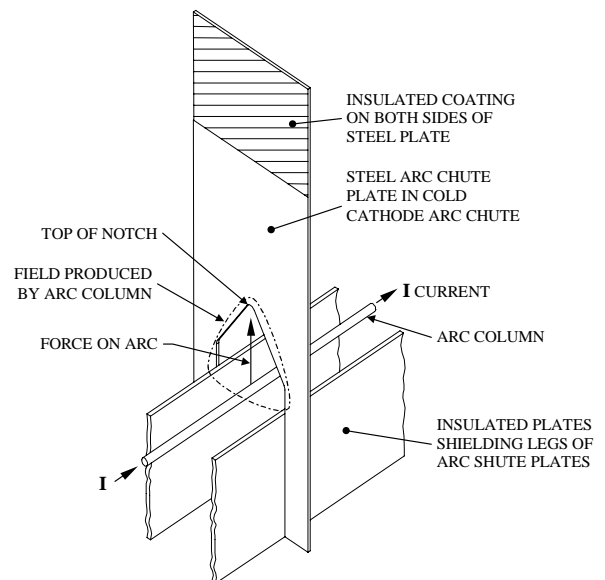
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### Authors Biography

Steve Lane is presently Engineering Director of FKI Switchgear Division a position he has held since 1992. Prior to joining FKI (Whipp & Bourne) he was Chief Engineer at GECAlstom Distribution Switchgear and before that RD&D manager at Brush Switchgear. He invented the principle of the modern day magnetic actuators in 1979 documented in a Thesis entitled 'A dc linear actuator with permanent magnet latching'. He was awarded The MacRobert Award by the Royal Academy of Engineering in 1997 for an outstanding contribution to innovation in engineering for the development of the GVR and also the Queens Award for Technology the same year.



**Fig 1(a)** Cross-section through arc chute



**Fig1(b)** Electro-magnetic forces on arc

Fig 1(a) Shows the arc in its final position in a typical arc chute. The arc is initiated at the point of contact separation between the fixed and moving contacts and is transferred into the chute by electromagnetic and thermal forces causing the arc to run away from the contacts along the arc runners. Arcing times are dependent upon current and voltage and can be relatively long.

In order to withstand the transient recovery voltage at the instant of interruption of an inductive current and also any transient over-voltages the contact separation in air is large. The same electromagnetic forces, which move the arc into the chute at high currents, also act on the contacts attempting to blow them apart. Large contact pressure springs are used to counter the forces.

The combination of the long contact travel and the compression of heavy contact pressure and opening springs during the closing stroke necessitated a powerful operating mechanism.

### Oil circuit breakers

Oil circuit breakers by the 1960's had also evolved from plain break interruption through to arc controlled interruption using the cross-jet explosion pot and now dominated the medium voltage distribution switchgear market. However, they had similar operating mechanism energy requirements, in this case due to the long stroke and the need to move heavy contacts quickly through oil. Regular maintenance was needed to changed carbonised oil and worn contacts after a few fault interruptions.

### Switchboards

The regular maintenance requirements of the circuit breakers necessitated that they were withdrawable, either horizontally on rails or vertically. The ability to withdraw the circuit breakers from the switchboard allowed easy provision of physical isolation, circuit earthing and cable test facilities at the cost of an increase in front to back dimension for isolation/earthing.

In order to make the withdrawal of the circuit breaker and the use of the other operational facilities safe, ever more complex interlocking and shuttering arrangements evolved which made the switchgear more complex and difficult to operate. Withdrawal, interlocking, shuttering and earthing arrangements became mechanisms in their own right with associated failures contributing to the reduction of reliability of the switchgear.

### Summary of 1960's Switchgear

- Oil and air interrupting technologies dominate LV and MV switchgear
- Interrupting devices require contact maintenance/oil change after a number of interruptions
- Powerful solenoid operating mechanisms with delicate trip latches required settings, adjustment and maintenance
- Withdrawable circuit breakers, added complexity and increased depth of switchboard
- Large and heavy switchgear, also large, heavy battery supply for high power solenoid mechanisms

## 1970's SWITCHGEAR

The major step forwards in switchgear in this decade was the emergence of firstly vacuum and later rotating arc SF6 circuit breakers. These technologies have the shared advantages of long contact life and low operating energy requirements.

### Vacuum circuit breakers

Vacuum interrupters became commercially available in the early 1970's. The vacuum bottle is sealed for life and cannot be maintained and is capable of more fault interruptions than would be seen during the life of the switchgear without wearing out. The dielectric strength of the high vacuum is such that a contact travel of only 6mm can be used at a rated voltage of 12kV.

The advantages of the new technology was immediately obvious to several manufacturers and signalled the end of any further development in oil or air circuit breaker technology at medium voltage. The cost of the early vacuum interrupters was substantially more than comparably rated oil or air interrupters, which is probably why they do not have a significant usage even today at low voltage.

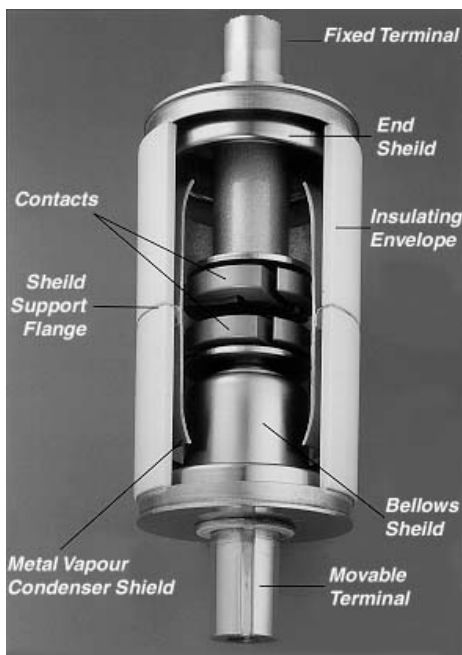


Fig 2 Typical Vacuum Interrupter

To off-set the additional cost of the vacuum interrupters to compete with oil circuit breakers three UK manufacturers produced fixed vacuum circuit breaker designs in order to reduce complexity, costs and size. The fixed design was made possible by the maintenance-free interrupters. However, the operating mechanism still demanded lubrication, occasional checks and resetting. Being too complex to rely upon for life it had to be housed in a separate low voltage compartment, connected to the three vacuum interrupters by a number of operating shafts, links, pivot points and insulators.

The first fixed designs failed to gain universal approval, mainly due to the leap of faith required in accepting manufacturers claims that vacuum interrupters would prove to be truly maintenance free and would not lose their vacuum integrity after a period of time. Eastern Electricity who installed a large number of this type of switchgear from 1973 into primary substations claim that their operational experience has been trouble free.

### Rotating arc SF6 circuit breakers

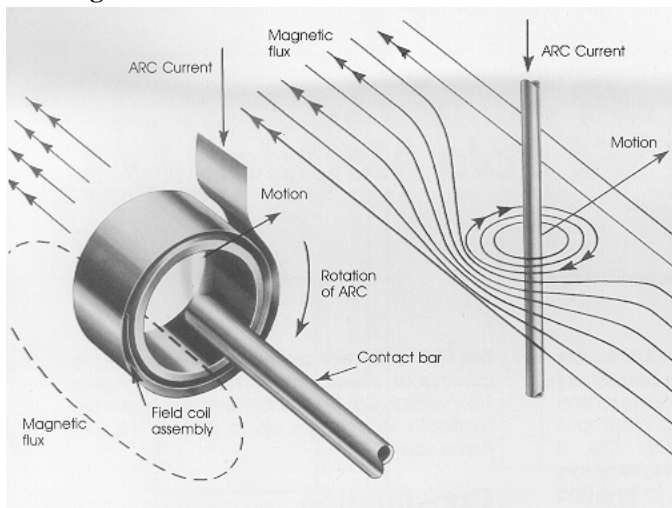


Fig 3 Rotating arc principal

This technology was developed by South Wales Switchgear. The rotating arc interrupter is as inexpensive as oil or air arc control devices with almost the reliability and performance of a vacuum interrupter.

SF6 is a highly insulating, heavy, non-toxic gas which decomposes during the arcing process but very quickly recombines at current zero regaining its dielectric properties. Fault currents up to 20kA can be cleared at 12kV with a 50mm gap (approx) at a gas pressure of a 2.0 bar. The arc current is transferred during contact separation through a solenoid of a few turns of copper strip generating a magnetic field causing the arc to rotate around the inner ring of the solenoid. The rapid movement of the arc through the SF6 gas causes cooling and enables extinction at the first current zero at high fault currents.

### **Summary of 1970's switchgear**

- Vacuum and rotating arc SF6 interrupters enable low energy, maintenance free interrupting devices
- Reduced energy solenoid operating mechanisms designs still require settings, adjustment and maintenance
- Fixed vacuum designs introduced but did not catch on due to lack of service experience with vacuum interrupters

### **1980's SWITCHGEAR**

No new interrupting devices have become commercially available in MV or LV since the advent of vacuum interrupters and rotating arc SF6. During the 1980's the main thrust of development activity was to provide better, more cost-effective circuit breakers using the new technologies. Vacuum interrupters have become smaller for a given rating and less expensive. Nearly all new circuit breakers developed during this period were withdrawable designs.

To reduce the size of substation batteries and chargers that provided the power source for opening and tripping of the circuit breakers, motor-wound spring mechanisms became standard equipment on all medium voltage and low voltage circuit breakers. A spring is charged by an electric motor drawing a few amps over a period of a few seconds in place of the earlier closing solenoid that took a current of many tens of amps for a fraction of a second. The spring energy is released by a smaller solenoid releasing a latch. As the spring relaxes it drives the mechanism components, compressing the contact pressure and opening springs and forcing the moving and fixed contacts of the interrupter together.

Whilst the substation battery (until the widespread use of electronic protection relays) could be reduced in size the mechanisms became even more complex compared to solenoid mechanisms. Despite claims from some manufacturers users were experiencing an increase in switchgear problems

### **Summary of 1980's switchgear**

- Oil and air circuit breakers go out of production, vast majority of new switchgear put into service are vacuum or SF6
- Emphasis on production engineering to produce cost reduced designs
- Motor-wound spring mechanisms and withdrawable designs become the order of the day

### **1990's SWITCHGEAR**

Vacuum circuit breakers have emerged during this decade as by far the most preferred technology for primary substation medium voltage switchgear as field service experience shows almost zero failure rate of vacuum interrupters and interrupter prices fall.

The fixed switchgear concept has made a comeback with SF6 insulated vacuum switchgear and air insulated SF6 switchgear with conventional mechanisms in the low voltage compartment driving the interrupters through linkages.

The most significant advance in switchgear technology in many years has come with the introduction of the GVR pole mounted auto-recloser which included a magnetic actuator mechanism and other radical innovations which are presently shaping new developments in medium voltage switchgear. The operating mechanism is now as reliable as the interrupter.

### **What is an auto-recloser?**

Essentially, an auto-recloser is a pole-top mounted reclosing circuit breaker which is used to protect sections of the overhead line supply network, usually in remote locations. An electronic control unit operates a mechanism which opens the main circuit contacts when it detects fault current on the overhead lines, which it monitors. If the fault is still present the auto-recloser will open and close up to two more times before finally locking out. If the fault has cleared during a dead time the auto-recloser sequence ends with the main contacts closed and the supply re-established to the customer.

Why is it so important for auto-reclosers to be highly reliable and require little or no maintenance ?

- Auto-reclosers are intended to enhance the reliability of the distribution network.
- Unlike other forms of switchgear which are used as a protection device and very rarely operate (like fuses), an auto-recloser's normal duty is to operate many times under short circuit (fault) conditions.
- They are installed far out into the network in remote locations

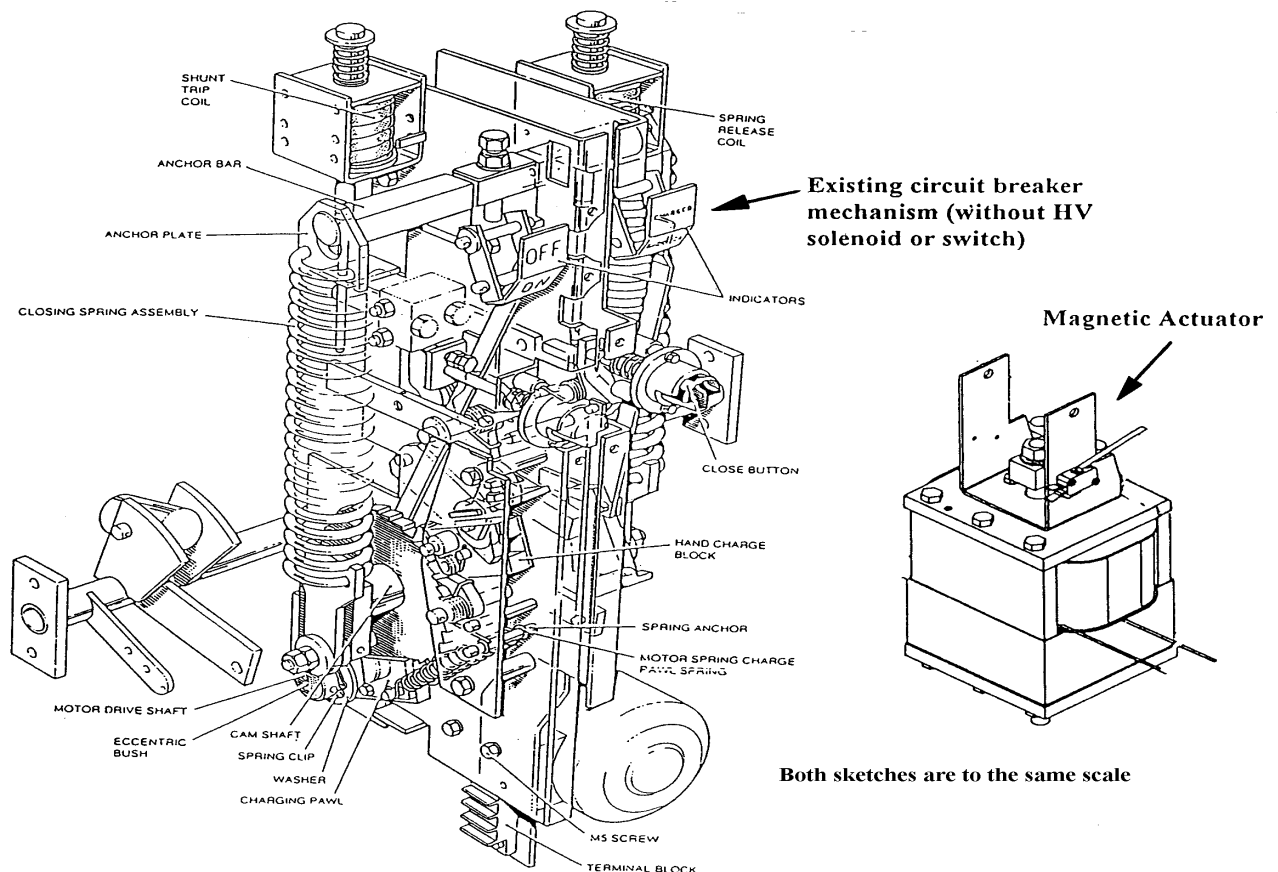
In 1993 when the development of the GVR began there were several well-established manufacturers of auto-reclosers. Other switchgear companies were considering entering this market which is growing, especially in the UK as the electricity regulator OFFER is demanding that the privatised electricity companies (REC's) increase the quality of supply on the overhead line networks. However, the REC's were reluctant to place large orders due to the problems that existed with the available auto-reclosers and were looking at other alternatives, such as insulated overhead lines.

An auto-recloser has without doubt the most arduous duty of any circuit breaker, in some areas of the world they can clear more than 1000 transient faults per annum! In order for any new auto-recloser to be successful the concept had to be a radical departure from the existing designs and had to meet the "fit and forget" criteria. This was achieved by the development of a number of innovations and with around 20,000 GVR's in service field experience has confirmed the maintenance-free aspect of the design.

The main innovation was the use of a magnetic actuator operating mechanism, which is at least as reliable as the vacuum interrupters but there are less obvious innovations and good design practices that contribute to the product reliability.

### Magnetic actuator

The magnetic actuator is basically a solenoid containing powerful rare earth (neodmium iron boron) permanent magnets which have been commercially available for about 10 years that latch the armature at either end of it's stroke holding the interrupter contacts open or closed. A single moving part replaces over 100 moving parts contained in a conventional circuit breaker mechanism linkage. Figure 4 shows a comparison of a typical motor-wound spring mechanism and a magnetic actuator on the same scale.



**Fig 4** Comparison of typical motor-wound spring mechanism and magnetic actuator

The force/travel characteristics of the magnetic actuator match closely the requirements of a circuit breaker, particularly when closing onto fault currents. With good design the actuator can provide a direct drive to the moving contact system without the need for complex linkages and is highly efficient reducing the current pulse drawn from the substation battery to manageable levels.

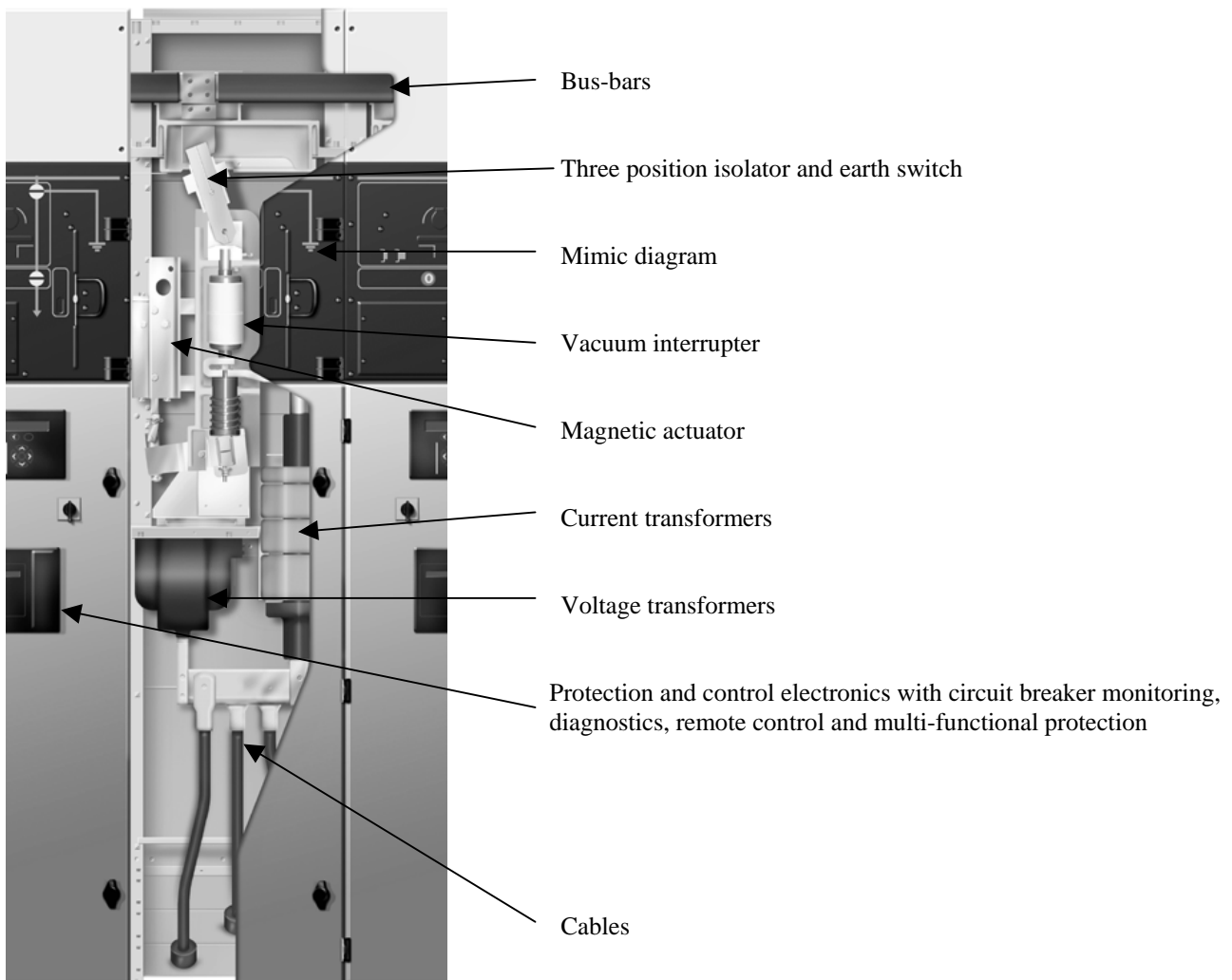
The success of the GVR auto-recloser has sparked a new wave of developments in the MV switchgear industry. It is now almost impossible in most parts of the world to sell an auto-recloser that does not use a magnetic actuator. Most leading manufacturers are also fitting magnetic actuators in place of the existing mechanisms in their circuit breakers used in their current designs of primary switchgear, which are horizontally withdrawable.

The lessons of the past show that it is not effective to simply fit a better technology component to an existing design concept.

### THE 2000's

New designs of switchgear will evolve, designed from scratch with every component as simple and reliable as possible to capitalise on the potential of the magnetic actuator mechanism to be as trouble free as the latest interrupter technology. This concept should be applied to low voltage switchgear, finally replacing the old technology air circuit breakers at this voltage and perhaps later to EHV switchgear.

A medium voltage switchgear of such a design is the Eclipse (below)



**Fig 5** Eclipse – fixed vacuum air insulated switchgear with magnetic actuator drive

This minimalist design is the lightest and dimensionally smallest in its class, for military use there may be no need to two-tier the circuit breakers within the cubicle. Some preliminary investigational shock tests have been carried out on this switchgear.

## **SHOCK WITHSTAND**

The intrinsically simple design of the Eclipse circuit breaker and magnetic actuator, lend themselves to being easily adapted to meet shock requirements.

### **Comparison with conventional circuit breakers**

A conventional circuit breaker mechanism incorporates catches for tripping and for closing spring release (in the case of a stored energy mechanism). In addition anti-rebound latches to prevent main contacts closing during shock are incorporated. All of these features need to be balanced for good shock performance further adding to the complexity of the mechanism. The magnetic actuator, as previously described, provides a robust operating mechanism with a single moving part. As the solenoid plunger is magnetically latched in both the closed and open positions the need to provide for anti-rebound catches and balancing features is eliminated.

The use of the "fixed pattern" philosophy further provides increased reliability and durability. Incorporating an integral isolator has allowed the circuit breaker carriage to be rigidly fixed within the cubicle reducing the complexity of interlocking and isolating features. Rigidly fixing the circuit breaker eliminates the relative motion between circuit breaker and cassette during shock particularly when subjected to a sinusoidal shock wave as experienced on the deck shock machine (DSM).

Again the fixed pattern philosophy brings improvements in reliability through the elimination of wiping secondary connections which would require particular detail to prevent contacts parting during shock.

### **Test experience**

During June of this year an Eclipse circuit breaker was shock tested in accordance with BR8470 on the DERA West Drayton DSM the tests were investigational and in co-operation with MOD(N) ME242. With very little modification to the commercial design currently being developed shock levels of 30g vertical, horizontal side to side and horizontal back to back were attained with little damage being sustained. A shock level of 58g in the vertical direction was reached before the circuit breaker sustained irreparable damage.

The results of these tests and subsequent examination of the tested equipment show that a 70g "commercial of the shelf" design is feasible with some modifications. If a 30g maximum shock level was chosen for future warships than a design is immediately available.

## **CONCLUSIONS**

The combination of magnetic actuator and vacuum interrupters has enabled maintenance-free for life circuit breakers. Switchgear can now be made more compact, simple and reliable by bolting the circuit breaker into the high voltage compartment.

The concepts already developed can be applied to any form of switchgear likely to be used in the Electric Warship

## **REFERENCES**

1. J Rye, L J Makay, J C Tobias, ' The advantages of fixed circuit breaker switchgear', Fifth International Conference on Trends in Distribution Switchgear