Introduction

Retrofit breakers have been developed in the UK over the last two decades to replace old or under-rated air and oil medium voltage circuit breakers and, more recently, some of the early vintage SF6 and vacuum breakers, which are now also reaching the end of their useful lives.

Most of the breakers being replaced were manufactured in the 1960s and 1970s although many were supplied before that. Type test standards have evolved continuously over this period. Most developed counties used their own testing standards until the end of the 1960s when it was generally agreed a universal standard should be adopted at which point IEC56 was introduced for high voltage circuit breakers. National standards such as BS5311 were introduced as direct copies of this. This has gradually led to more standard switchgear designs and the ability to adopt common practices over many parts of the world.

This allowed more commonality in testing, but the testing requirements have gradually been increased and become more onerous over the years since. Some of the changes were based on hard won service experience and some were based on a better understanding of potential power system performance, especially at higher system voltages.

Many of the circuit breakers still in service today were tested to British Standard BS 116 from 1952 with type test requirements bearing little resemblance to the more onerous requirements today. Since the vast majority of the breakers have performed satisfactorily in all sorts of practical conditions for over 40 years, it might be argued that much of the change in the testing standards is not entirely necessary, at least for many medium voltage applications! The latest version of the circuit breaker standard, IEC/BSEN 62271-100 comprises well over 300 pages, with more than three quarters of this devoted to testing and the IEC technical committees are currently preparing a guide to help understand and interpret this and its related standards.

Generally, new medium voltage indoor switchgear ranges, i.e. the breaker and its cubicle are tested together during their development. IEC62271-1 (previously IEC 694) and IEC 62271-200 (previously IEC 298) are the relevant standards related to IEC 62271-100 mentioned above, which bring the whole switchgear design together. This testing occurs on new ranges of switchgear, developed now by successively fewer but larger organisations as the number of smaller or medium sized UK manufacturers have been bought up and incorporated, or closed, by the few global switchgear companies who remain. Each of these huge companies has worked to reduce the variety of similar switchgear designs, to reduce development and design support costs and to achieve economies of scale in manufacture. This means although the requirements of type testing have become much broader, more complex and generally much more onerous; and the costs of this have increased hugely, the number of ranges of similar switchgear they support has reduced.

When it comes to upgrading or replacing existing switchgear there are a number of choices faced by the switchgear owner. In some cases the whole switchgear is replaced with new equipment, tested to the latest standards. However, this can be an extremely and unnecessarily expensive option, when it is possible to simply replace the moveable portion which does all the switching work, since usually only this part is beyond economic repair. In many cases the fixed part is good for another 25 years life.

Generally, the new switchgear designs mentioned earlier are intended for high volume manufacture, thousands per annum, usually for adoption in several factories to supply to a range of countries worldwide. High development and testing costs are therefore recovered over a large production volume. Retrofit or replacement breakers are aimed at much smaller volumes with some designs aimed at some tens of breaker units and others, at best, a few hundreds.

This leads to the question of what is a sensible approach to type testing circuit breakers being introduced to replace or retrofit the existing designs.

It is not feasible, either practically, technically or commercially, to fully type test every variant of new circuit breaker in every previous design of cubicle. In many cases it is not possible to obtain a cubicle of the relevant design – and even if one is available there are often subtle and not so subtle variations, within a single switchgear range. Then, even if the equipment is available, the costs of such an exercise would be colossal and, therefore, prohibitively expensive.

So, what is a realistic, experience and engineering judgment led approach for retrofit circuit breakers? What and how much type testing is required to demonstrate an acceptable level of confidence of satisfactory future performance?

Circuit breaker type testing

The series of type testing required for general purpose medium voltage indoor circuit breakers is prescribed in IEC/BSEN 62271-100. The following tests would normally be expected to be performed on a breaker in its cubicle for a new development,

Dielectric testing – i.e.
Short duration power frequency withstand voltage tests
Impulse tests
Temperature rise tests
Short-time withstand current and peak withstand current tests

Making and breaking tests, i.e. Test Duties T10, T30, T60, T100s, T100a. Single phase, while normally performed on a breaker in a cubicle for convenience, are not really affected by the presence of the cubicle and could be performed outside it.

Other making and breaking tests may be required if ratings are claimed or assigned. Again, these relate to the performance of the breaker and not the interface with the cubicle. These include:
Out of phase making and breaking tests
Capacitive current switching tests:
Line-charging and cable-charging current switching tests
Capacitor bank switching tests

Mechanical endurance tests are usually performed on the circuit breaker without the cubicle.

P&B Retrofit or Replacement Breaker Designs

P&B Switchgear has developed over 30 designs and variants of retrofit circuit breaker, investing heavily in type testing these designs and has around 100 type test reports and certificates. The majority are short circuit tests but include temperature rise, dielectric and mechanical endurance testing too. Almost all tests were performed with the circuit breaker in its housing. Most developments were performed as we came across new development requirements for customers and utilised the ABB VD4 range of vacuum breaker. This was either in the refurbished original truck for air break retrofits, or, in the case of bulk oil replacements, completely new breakers.

As the number of bulk oil breaker retrofits increased an approach was made more recently by P&B Switchgear to introduce as far as possible a standard circuit breaker module design, which we could adapt into a series of trucks designed specifically to replicate externally the original breaker and fit into the various manufacturers’ switchgear cubicles. The aim was to reduce the repeated design work, reduce the type testing requirement as the range grew and to increase standardisation in manufacture.

P&B Switchgear now offers two types of design to replace bulk oil circuit breakers. One design utilises a complete ABB VD4 VMax motor wound spring type vacuum breaker in a P&B Switchgear designed module, which is then fitted into a vertical isolation truck designed to fit directly into the switchgear housing of the original manufacturer. This is the P&B Switchgear VOR-S range.

For customers who prefer a magnetic actuator drive rather than a spring mechanism, P&B Switchgear has developed the VOR-M range of replacement circuit breakers. This breaker range uses cast resin embedded vacuum interrupter poles from the ABB VD4 breaker range driven by a MagLatch magnetic actuator. Again, the breaker module is identical for any VOR-M breaker of a given rating and, like the VOR-S, is assembled into a truck designed to fit directly into the original switchgear housing.

The same vertical racking system, the same cast resin bushings and the same isolating contacts are used on either type of breaker.
Type testing the VOR-M range of circuit breakers

P&B Switchgear developed the VOR-M breaker in 2010. This range uses cast resin embedded vacuum interrupter poles manufactured by ABB in Germany and used in ABB breakers internationally across their MV switchgear range. These devices have been subjected to numerous series of type tests in various ABB switchgear ranges covering all of the IEC / BSEN tests described earlier. This includes the VM1 circuit breaker range, which is the VD4 breaker with the EL spring mechanism replaced by a magnetic actuator.

The P&B VOR-M uses a MagLatch actuator supplied by EPS in Nottingham. The same design of actuator is used by ABB in their VM1 range.

P&B have performed extensive type tests to the latest IEC standards on the VOR-M circuit breaker in representative switchgear housings. These include short circuit, dielectric, temperature rise and extended mechanical endurance tests.

Again, by employing widely used ABB vacuum interrupters and the well proven MagLatch actuator, we can offer high confidence of excellent service performance and reliability.

Service experience and practical considerations

It is important that any new circuit breakers being offered as retrofit solutions can be shown, by performance of relevant type testing, to be capable of the ratings claimed. It is important that this includes testing of the interface between the new breaker and the old cubicle. At P&B we have performed a huge range of type tests on air and oil breaker designs in original cubicles to demonstrate this.

We have discussed earlier the practical difficulties of testing every arrangement, for a vast array of different, usually obsolete, older switchgear designs. However, we have tested both VOR ranges of breakers in a range of representative switchgear units which demonstrate that the circuit breaker designs are suitable for even wider use.

During type testing in some LV breaker designs we found the condition of original isolating contacts had deteriorated with age and led to complete failure at currents below the original short circuit ratings. For this reason we have introduced a new fully tested, isolating contact design for our VOR range of breakers and we supply new or refurbished contacts with all other retrofit breakers.
Previous designs of older circuit breaker required a high degree of maintenance to ensure reliable operation. Apart from regular contact and oil changes in bulk oil breakers, mechanisms have not always been reliable and required regular servicing. Newer designs of breaker have lower operating forces and thus lower loaded and simpler mechanisms were introduced. Mechanical endurance testing on modern breakers can require the number of operations to be increased by a factor of 10 compared to the older designs. New magnetic actuators are capable of a further factor of ten operations more than even modern, lightly loaded spring mechanisms. Modern vacuum interrupters have shown they perform excellently in all system switching conditions, their life span is into thousands of load operations, they last 30 years and beyond and the number which fail in service can be counted, virtually, on your fingers.

There is little doubt that the latest generation of circuit breakers are designed and tested to higher standards than those of the products they are replacing. Control of manufacturing processes and quality systems are also of a different order to those in place in most factories 3 or 4 decades ago.

Rather than just concentrating on type testing, more problematic and probably of more concern to the user, is whether the new generation of retrofit breakers will overcome some of the other design weaknesses of the original switchgear which have shown up in service life.

Some switchgear designs have seen failures in service caused by various mechanical problems, but some have been caused by gradual increase in partial discharge, leading to dielectric failure and major flashover. Standards require routine factory partial discharge measurement of some components such as bushings. Some customer specifications, such as ENATS request partial discharge factory testing of complete switchgear but PD testing of breakers, or complete switchgear units, is not widely performed and is not a required routine test in IEC/BSEN standards. In reality, it is very doubtful if it is realistic to perform meaningful measurements of partial discharge on completed switchgear units and, other than a major assembly error, find latent problems. Switchgear experts point out difficulties in interpreting PD results and relating these to life expectancy. It is doubtful if such measurements would identify on new equipment, the likelihood of experiencing problems seen on some existing designs in their later years of service.

Partial discharge checks in the factory can be useful in finding some flaws in the final assembly and at P&B Switchgear we have introduced PD testing as part of our routine test procedure on our VOR retrofit circuit breakers. PD checks are, however, invaluable as an ongoing check of the switchgear condition in service. That said, satisfactory long term dielectric performance is better ensured by taking into account the experience gained to date, at the design stage. This is achieved in the design, for example, by avoiding high stress forming shapes, ensuring adequate clearances, eliminating small gaps at different potential etc. All these could gradually cause ionisation under prolonged stress at normal voltage.

However, another major factor in the service performance of indoor switchgear is related to the environmental condition in which the equipment is to operate.

Normal conditions for indoor switchgear are defined in the previously mentioned standards and switchgear is designed to operate in these conditions. This assumes ambient air is not significantly polluted by dust, smoke, corrosive and / or flammable gases, vapours or salt. Conditions for humidity are specified, which should result in no more than occasional condensation.

High levels of humidity and condensation are to be avoided to prevent onset of partial discharge, potentially leading to breakdown of solid insulation. If conditions of high humidity and condensation are likely, they can be prevented by suitable substation ventilation and heating of the equipment. Measures such as these should be adopted by the user to ensure long term reliable service performance.