WHAT YOU NEED TO KNOW ABOUT

Switchgear retrofitting and upgrades

Why engineering & testing matters

Retrofitting and upgrading older switchgear assemblies can be a cost-effective method to extend the life of your electrical distribution capital and reduce maintenance costs while improving reliability and safety. Failure to invest in quality retrofit solutions can have the opposite effect.

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What you need to know

A quality retrofit solution rests on three fundamental pillars: expertise, testing and implementation. Expertise takes the form of both knowledge and experience. Testing confirms that the expertise was properly transferred to the retrofit design, but it is not a substitute for a fundamentally good design. The design must then be implemented by building the retrofit circuit breakers through a quality process that covers everything from installation to follow-up support, drawing on the resources of a global leader in electrical distribution equipment. This paper will explore how ABB provides high quality retrofit products that are a cost-effective life extension solution by building on its strong foundations of expertise, testing and implementation.

The history of switchgear retrofitting
The invention of compact modular vacuum circuit breakers in the 1980s was a revolutionary event in switchgear design. At the same time, the bulk of the electrical distribution system of many countries, built in the 1940s and 1950s, was reaching its end of life. While the switchgear itself was still serviceable, circuit breaker maintenance was becoming increasingly difficult. The most troublesome parts were the arc-chutes, main contact assemblies, and the operating mechanisms — all of which were now available in a single modular compact vacuum circuit breaker.

Service shops begin the retrofitting revolution
Many service organizations began the process of retrofitting circuit breakers once considered unrepairable and returning them to service. Initially, retrofitting an air-magnetic circuit breaker with a complete vacuum circuit breaker module was considered a “repair” technique not a new design. The old circuit breaker was stripped, and a vacuum circuit breaker installed. Although experienced in maintenance and repair these service shops lacked design expertise.

Hard learned lessons in design & application
This “retrofit as repair” concept, left in the hands of maintenance technicians, has led to several serious accidents. Failures in interlocking designs in which inadequate consideration of possible failure modes have resulted in fatal accidents in some cases and in product recalls. A more subtle, but similarly disastrous failure results from failing to account for the electro-dynamic force under short-circuit conditions. What may appear to the technician to be “strong enough”, without actual full-power type testing, it is impossible to know. This failure mode is particularly difficult to manage with “rules of thumb”. The electro-dynamic forces are complex to calculate even for experienced electrical engineers. The dynamic strength of both the relatively soft copper conductors (often formed in complex shapes) and the adequacy of the restraints which rigidly secure the circuit breaker (with a different mass and center of gravity) in the switchgear under a high impulse force, present the kind of problems that occupy the nightmares of mechanical engineers. This type of failure may only manifest itself when a system fault occurs, but instead of the retrofit breaker interrupting the downstream fault, it often manifests itself as an internal arcing fault within the switchgear panel, greatly increasing the hazard to personnel and multiplying

the severity and recovery effort required. Other design failures resulting in dielectric breakdown and over-heating exist, but because these types of failures occur in all aging switchgear it is more difficult to assign the root cause of the problem to the design and testing – often because these deficiencies take years to manifest themselves. Poor choices in selection of dielectric materials, or installation of fasteners with surface treatments, which by themselves may be corrosion resistant but conversely, may interact with adjacent materials to cause corrosion. This has been observed in early retrofit solutions and sadly persists to this day.

Not all retrofitting problems arise from the design of the circuit breaker. Proper application is also important. It may be as simple as properly interpreting old circuit breaker nameplate information to select the proper replacement rated under current standards or may require a deeper understanding of the system. Misapplication of retrofit circuit breakers has contributed to fatal accidents. Replacing old circuit breakers with obsolete interrupting technologies which have vacuum circuit breakers, may even require new or different ratings, such as capacitive switching or generator duty circuit breakers.

Retrofitting standards

IEEE Standard C37.59™-1991 “Standard Requirements for Conversion of Power Switchgear” was created in response to the deficiencies in design and testing. It has been extensively revised four times as experience has dictated additional testing and verification processes are needed. It now includes low voltage circuit breaker conversions and switchgear modifications and upgrades. IEC 62271-307 provides extensive guidance for applying type tests from one circuit breaker or switchgear design to another. These documents are essential references for experienced designers to use in designing their type test plans but are often misunderstood to be a ‘cookbook’ for the newcomer to the business.

Type testing

In a similar manner, while type testing is essential, it is not a substitute for good design. Type testing, particularly on retrofit projects, is performed on a single circuit breaker sample in a single specimen panel. Type testing is the final quality check which confirms the calculations, simulations, design reviews and engineering expertise which support the design. To compensate for the inherent uncertainties of performing a limited set of type tests on a single sample, an organizational structure that combines the experience (and previous testing) of many designs with a documented history of successful (and the occasional, unsuccessful) retrofit projects in disparate applications supporting the expertise necessary to justify confidence that the mandatory type testing is sufficient. As an analogy, no respected university would allow a stranger who walks in off the street having attended none of the lectures nor completing any of the requisite coursework to even sit for the final examination, much less grant a degree should they achieve a passing mark on the examination if given. ABB's internal “Retrofit Design Policy” adopts the requirements of IEEE C37.59 plus specific checklists, reviews, and oversight to ensure that the knowledge and experience of the entire organization is disseminated to every project team and applied to each new design. ABB’s Customer Care Response Process (CCRP) documents all issues experienced during the life of all products – including retrofits – and includes long-term improvement tools which feed back into our processes so that the lessons learned are not lost.

Type testing applicability and extension

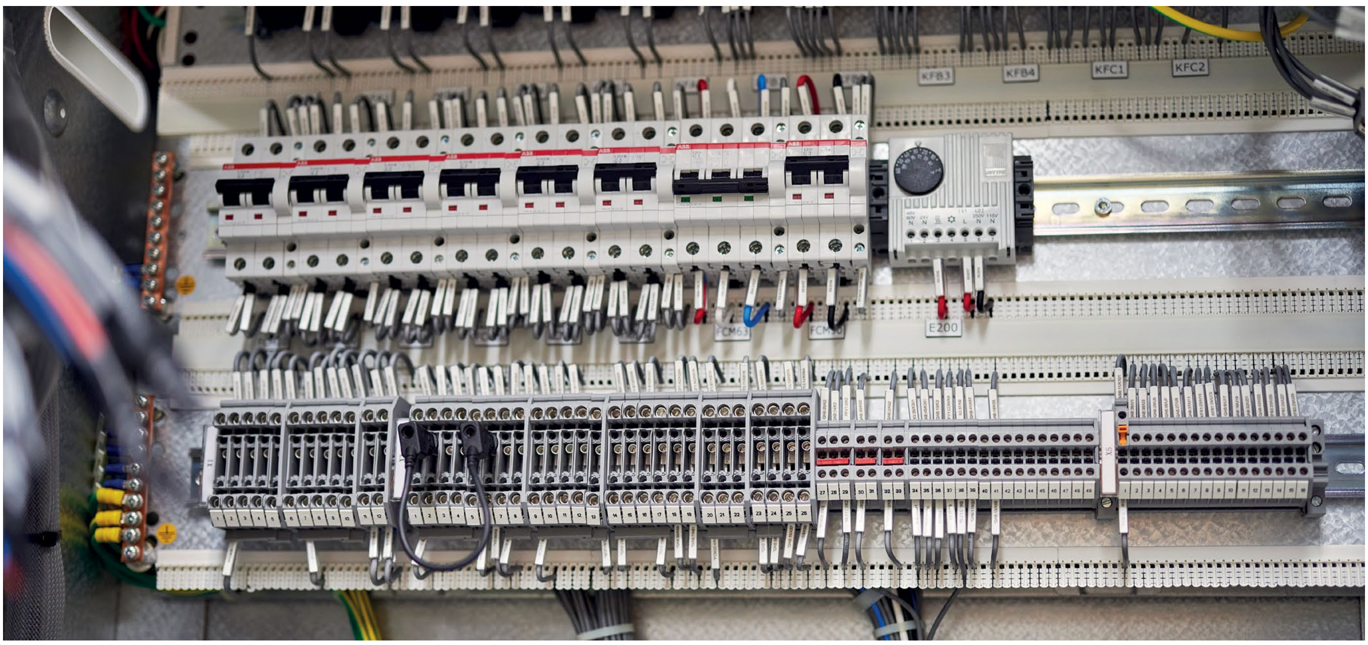
In both low-voltage and medium-voltage equipment, the circuit breakers work as a system and were designed and tested as such. The applicable IEEE standards for circuit breakers C37.04 & C37.09 work with the switchgear standards C37.20.2 and C37.20.3 to ensure safe and effective medium voltage systems. The IEC companion documents are 62271-100 and 62271-200. For low voltage installations, IEEE C37.13, C37.17 & NEMA C37.50 along with IEEE C37.20.1 are used in the ANSI market; while IEC 60947-2 and IEC 61439-1 &

-2 apply to IEC. Each of these standards recognize that the type testing which applies to the circuit breaker is a prerequisite to and supports the type testing of the full switchgear assembly, but that not every combination of circuit breakers and switchgear can be fully type tested. This problem is particularly acute in low voltage installations where an almost limitless range of combinations of variously rated circuit breakers are arranged in multitiered stacks of mixed ratings. These rules apply to retrofitting as well. Although the rules are well known to original equipment manufacturers like ABB, they are less familiar to organizations with only work within the retrofitting market. IEEE standard C37.59 was created to provide detailed requirements to ensure that the proper set of combined circuit breaker and switchgear type tests are performed and that extensions of existing type tests represent sound engineering principles. IEC 62271-307, while not created for retrofitting also applies. In some cases, certain localities require, or certain users may desire, further assurance. Some third party certifiers, such as Underwrites Laboratories (UL) have recognized that retrofitting new circuit breakers into existing panels is a valid method of not just extending the life of, but improving the reliability and safety of these old switchgear assemblies and offer review and certification of retrofit designs, in some cases field [re] labeling of installed switchgear assemblies.

Application considerations

The most common instruction received from a customer when considering a retrofit solution is “Give me exactly what I have now.” While a replacement with similar capabilities is often possible, changes in the standards usually make an exact match impossible – nor may it be the best choice.

- **Changing standards**
  From the early 1960’s until now, the basis of ratings and the ratings engraved on their name-plates have changed dramatically. Early circuit breakers were rated on a ‘total current’ basis without a specified degree of asymmetry meas-ured in ‘MVA’ at nominal system voltage which was proven by interrupting different magnitudes of symmetrical and asymmetrical currents at different voltages; later the basis of rating changed to symmetrical current at maximum rated voltage, but still varied according to system voltage. The testing methodology has also evolved over the years to better reflect the requirements of real world systems. Early standards, and thus early breakers, were often subjected to only maximum capability tests under whatever system conditions could be obtained at the test laboratory in terms of asymmetry, power factor and transient recover voltage. Later, defined degrees of asymmetry which were to be demonstrated based on circuit breaker opening time were added. Additional tests to demonstrate circuit breaker performance across a wide range of applications were also added. The preferred values of interrupting current were chosen to approximate to previous MVA levels and still varied according to the test voltage. Later still, the basis of rating remained as it was, but remained constant within a voltage class. The preferred ratings changed to values selected from the Renard ‘R10’ series of values in ISO Std. 3. If the above seems confusing, it is. The result of all these changes is that a circuit breaker built in the 1980’s and 90’s to replace an older ‘5 kV/250 MVA’ breaker would have a nameplate interrupting of 29 kA at 4.76 kV but with an actual capability of up to 36 kA at 3.85 kV and 33 kA at ‘nominal’ system voltage of 4.16 kV. The closest equivalent circuit breaker according to current standards would have a rated interrupting capability of 31.5 kA at any voltage up to 4.76 kV, but in fact would be about 5 % underrated at a nominal system of 4.16 kV compared to its ’29 kA’ equivalent. 5 % is not something to ignore, but for many years ’29 kA’ was the lowest preferred rating in the ANSI tables, so in fact 31.5 kA might be much more than needed and perhaps a 25 kA, or even a 20 kA breaker would be a more economical choice. This is another example where simply matching the existing nameplate, or matching it as closely as possible, may be a poor choice



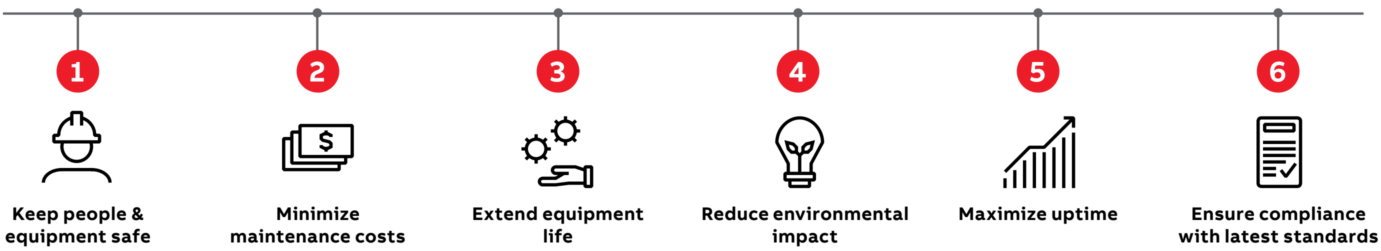
- **New ratings and standards**
Over the years, new standards and ratings have been developed. Oftentimes these are the result of increased awareness of system characteristics which result in failures. Within the past 20 years alone, major enhancements have been made to properly defining the transient recovery voltage (TRV) characteristics of systems and commensu-rate improvements in demonstrating the TRV capabilities of circuit breakers have been added. Similarly capacitive switching ratings (and type testing) have been added to the standards. These enhanced TRV and Capacitive current switching capabilities may not be among the default offerings of a small retrofitting organization because such details are beyond their expertise. With the proliferation of small co-generation capabilities in many facilities, the need for applica-tion specific generator circuit breakers even on smaller systems is possible. Generator circuit breakers are governed by a completely different standard that did not even exist when many of the circuit breakers being considered for retrofit were installed. Adding co-generation to a facility may require upgrading one or more circuit breakers to the new standard (or not) Older 'general purpose' circuit breakers on existing generator busses which have given many years of satisfactory service may in fact need to be replaced with specially rated generator circuit breakers. It takes considerable expertise, which ABB can offer, to be sure.

- **System changes**
Electrical systems grow and adapt over the years to meet the changing requirements of their owners. Some changes are obvious, such as the addition of co-generation discussed above. Other changes are more subtle such as the upgrading of motors to higher efficiency specifications, adding tie breakers to improve reliability or even changes by the utility to the service which alters the available fault current. It is not uncommon that the system fault current study predates the circuit breakers which are long past their useful life. Perhaps also the system study?

- **The retrofit specification**
For the above reasons, and many others, it is important to work with a capable partner from the beginning of a contemplated retrofit project. ABB has a broad network of technical experts available for consultation; these include dedicated field application engineers with many years of experi-ence across a broad range of industries. Also, highly trained specialists are employed to per-form detailed studies if need be – for example to evaluate the need for generator circuit breakers according to IEC/IEEE 62271-37-013. Product specialists who are familiar with the most recent developments in the industry can help choose new products better suited to the application where obsolete technologies limited choices. These engineers can assist in determining the precisely what ratings and types of circuit breakers are needed as well as other necessary switchgear upgrades. A knowledgeable and reliable partner can help the user develop a competitive retrofit specification to ensure the investment in circuit breaker retrofitting returns the required value over the long run.

The value of ABB experience
ABB's engineers understand the special challenges associated with retrofitting. We recognize that even small retrofit projects are new designs and require the same tools and expertise which are used for products planned for thousands of production units. ABB has a global network of experts that give us a 'deep bench' of talent plus the procedural, computational and infrastructure resources to ensure more than compliance, but excellence in developing switchgear life extension solutions.

Early retrofitting solutions
Early retrofit solutions took existing circuit breakers which were judged not repairable — often already cannibalized hulks — and stripped them of all the parts which were functionally replaced by the vacuum circuit breaker, leaving a bare frame, the racking and a portion of the interlock system, the high voltage bushings and the low voltage secondary disconnect. It was often literally the case that the



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The benefits of retrofitting obsolete circuit breakers with ABB's Modernization Retrofits

'design' of the retrofit happened on the shop floor. New primary circuit copper conductors were bent to fit and connect the vacuum circuit breaker terminals to the remaining portions of the primary bushings. Available steel bars and sheet metal was cut and formed on the shop's iron worker to replicate the interlocking systems and front cover. Insulating heat shrinkable tubing was fitted over the copper, and additional sheets were cut on a table saw to create insulation systems according to 'rules of thumb' passed down from old hands and jotted down in notebooks. Design testing consisted of an AC power withstand test (sometimes only a 1500 V insulation resistance reading), a low resistance measurement, and some functional testing of the interlocks without benefit of the matching switchgear panel. The new parts and the truck modifications were sketched on graph paper and then the assembly process was documented with photos. The documentation was placed in a threering binder and the "new" retrofit shipped to the customer. The repeatability of these retrofit designs suffered from poor documentation, the physical limitations of trying to modify the large circuit breaker trucks and the difficulties of dealing with subtle – and not so subtle – changes in the original circuit breaker obtained for conversion which could require drastic 'on-the-fly' changes in the retrofitting process.

Roll-in-replacement breakers
The difficult logistics of retrofitting actual old air-magnetic circuit breakers was the genesis of the "Roll-in-Replacement" or "RIR" breaker in the early 1990's. A facsimile of the modified original breaker frame would be newly manufactured, not adapted from a scrapped circuit breaker of the proper design. No longer would old components of questionable integrity be reused, but instead the 'retrofit' – now 'replacement' – was 100% new parts. This solved one set of problems, but it introduced others: the expertise and ingenuity of original designers and their knowledge of properly fitting into the switchgear that was embodied in original product went on the scrap heap with the original circuit breaker trucks.

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Figure 1 Vacuum Retrofit for Minimum Oil CB

- **Racking and interlock systems**
  Ostensibly simple, the racking and interlock systems of the original breakers were thoroughly engineered to be reliable and tolerant of the full range of variations in manufacturing and installation of the switchgear. The original systems were much more sophisticated than they appeared. Universally, interlocking systems had to prevent closing a circuit breaker unless it was in a safe position within the enclosure to do so; also to prevent moving a closed circuit breaker. Often these interlocks were both strong enough to effectively make mis-operation impossible and incorporated backup features which would open the circuit breaker if the prevention function somehow failed. Early retrofit designers often substituted simple lever systems which had to be individually adjusted and failed to build backup 'fail-safe' tripping into their replacement breakers. Systems which need to be adjusted into operation can be easily mis-adjusted into mis-operation, with perhaps deadly consequences. In the IEC market it is common for switchgear to incorporate an earthing (grounding) switch in the panel. Additional interlocks are required to interact with the circuit breaker to also prevent insertion of the circuit breaker in the cell if the earthing switch is closed, and to prevent closing the earthing switch if the circuit breaker is racked in. These earthing switch interlocks add yet another level of complexity to the replacement breaker design. The material strength, hardening and finishing of the original racking mechanisms were abandoned in favor of the characteristics of similarly sized commercially available components many times not adequate for the task.

- **Replacement breaker tolerance challenges**
  The tolerances of the original components which worked with the switchgear and were critical to proper performance were lost. The conventional wisdom of service organizations was that medium voltage switchgear is "eighth-inch" equipment – meaning that 1/8" tolerances were generally used in switchgear construction. Knowledge of original circuit breaker design documentation – not available to these 3rd party service organiza-tions – shows some key interface dimensions, such as shutter rollers and critical locating features have tolerances measured in 32nd inch increments. While ABB designers do not have the applicable drawings for competitor equipment, their familiarity with the broad scope of ABB legacy equipment, which originated from the many companies which have become part of ABB over the years informs them of the usual practices in older switchgear design and construction. This experience is typically not present in small service organizations and the need unrecognized.

- **Mechanism operated cell switches (MOCs)**
  Although atypical in many modern designs, older air-magnetic circuit breakers had few connections available through their secondary disconnects and relied upon auxiliary switches mounted in the switchgear and operated by levers on the removable circuit breaker to convey breaker open-closed status to the plant controls. The mechanisms of the old breakers were designed to travel longer distances with more force than required by vacuum circuit breakers. The ability to properly operate the switchgear MOC switches became a notable issue with vacuum retrofit and replacement breakers. In some instances, the MOC force was sufficient to prevent the vacuum circuit breaker from closing; more seriously in some cases the design of the vacuum circuit breaker was such that it would then slowly close over the next few seconds as the spring charging motor recharged the closing springs. This slow closing onto an energized bus is both harmful to the circuit breaker and dangerous to the con-nected electrical system. Although ABB vacuum circuit breakers are not susceptible to this failure mode, sufficient energy to operate MOC switches is an issue. Our broad experience and market knowledge ensure adequate design and subsequent type testing is performed to guard against this failure. ABB holds a patent on one such method to prevent even completely failed switchgear MOC components in switchgear cannot interfere with proper circuit breaker operation.

- **Engineers and technicians as a design team**
  Early retrofit designs were being created by indi-viduals who were not engineers. While there is much to be said for the value of experience, it cannot fully replace the learned skills followed by additional years of actual experience supervised by senior engineers. Conversely, well trained en-gineers often lack the practical experience gained by getting one's hands dirty. A balanced team which embodies both theoretical and practical knowledge is essential to producing a retrofit solution that is both effective and durable.

- **Global resources**
  Sometimes even an experienced and well-balanced team of engineers and designs needs a little help. As already mentioned, ABB's internal design review and quality processes support all aspects of the design, testing and subsequent manufacture of our retrofit circuit breakers.

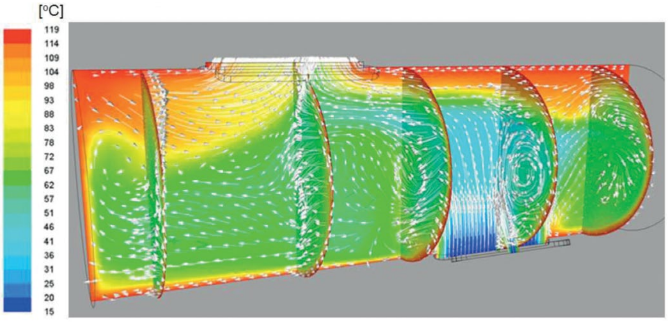

Figure 2 Thermal Simulation of 3000A Contact Arm

ABB's internal policies and procedures embody our culture of excellence as a choice, not an acci-dent. They include mandatory process steps and many pages of guidance and checklists to memo-rialize the global experience and lessons learned that create a permanent institutional memory. Many of our service centers are co-located with our manufacturing facilities to draw not only on their knowledge and experience, but also access to sophisticated measurement and analysis tools and extensive internal test laboratories up to and including short-circuit test facilities. All the tools and resources employed in our large product de-velopment efforts are also available as needed for out retrofit projects.

Application issues of retrofitting

Among the most common issues is that the basis of rating for circuit breakers has changed since the original breakers were created, sometimes more than once. The details of those changes are beyond our scope here, but a breaker with a nameplate interrupting current of 29 kA is not fully covered by a circuit breaker with a name-plate of 31.5 kA. (31.5 kA is most likely adequate for the purpose, but it is important to have a partner who understands and can explain the differences). Another issue arises when older air-magnetic circuit breakers which protect small- and mid-size generators are being considered for replacement. The IEEE Generator Breaker standard (originally IEEE C37.013™, now IEEE/IEC 62271-37-013) did not even exist until 1989, well after the breakers being replaced were installed. Both the process on the customer side of evaluating systems to determine the necessity of generator rated breakers and the difficulty on the manufacturer side to meet the design and testing requirements of the Generator Breaker standard are significant and require the resources of a major manufacturer to complete successfully.

Application issues are not limited to only the characteristics of the high-voltage (primary) circuit. The control (secondary) circuit is also essential, but often overlooked. A circuit breaker that cannot work with the electrical controls is useless. Common issues that can arise are existing wiring schemes within the panel that incorporate logic which is incompatible with the replacement circuit breaker; power systems which are under-powered for the new circuit breaker; or which subject the new circuit breaker to voltage transi-ents which are either damaging or cause mis-operation of the circuit breaker. Where the operational logic of the switchgear is incompatible and modifications to the panel are required, particular care must be exercised to ensure that replacing the new breaker with an original will not cause mis-operation or a rejection scheme must be devised and installed to prevent this situation. In other cases, secondary power filtering or other signal conditioning is necessary to ensure reliable reliable replacement breaker operation.

Special application requirements

Occasionally, the customer application is highly specialized and demands additional qualifications which, depending on the age of the equipment, may not have been standardized at the time of the original installation. As noted above, generator circuit breakers applications are one of these special applications; others include seismic qualification, nuclear 1E certification, shipboard or mobile platforms, etc. Retrofit circuit breakers afford the opportunity to test these new circuit breakers according to these standards.

Accidents and retrofitting failures
This “retrofit as repair” concept, left in the hands of maintenance technicians, has led to several serious accidents:

– In 1993 at Sabine Power Plant near Beaumont, TX where a retrofitted breaker from 1987 had an inadequate interlock design which resulted in two fatalities. The retrofitter incorrectly adapted the original circuit breaker’s safety interlocking features for use with the Toshiba vacuum breaker used in the project. Although years passed from the original retrofitting, when those interlocks were needed, they failed to protect the operators.
– In 1994 at the J.M Stuart Power Station near Aberdeen, OH a failure to consider the control power requirements in the conversion of circuit breakers to fused contactors resulted in an arc flash accident which killed two men and severely injured two others. Although it was determined that the design itself was not faulty, the accident was partially attributable to an inadequate understanding of power re-quirements of the replacement circuit breakers.
– Even into the 2000s manufacturers were discovering problems which some early retrofitting organizations had built into their products because of a lack of experience in designing with all possible failure modes in mind. Westinghouse discovered a flaw in a design which aged in a manner that could cause an internal arcing fault during withdrawal. Siemens discovered with their vacuum replacements for their own type ‘MA’ breakers the ability of users to force the breaker past the interlock point without a fail-safe action. Both manufacturers issued safety bulletins and no serious injuries are known to have occurred.

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Figure 3 Interlocking Failure Consequence

Low voltage circuit breaker trip unit retrofitting
Low voltage circuit breaker modifications started with the replacement of old direct acting trip mechanisms with self-contained electronic trip units. Originally, these trip units were offered by the circuit breaker manufacturers as options on new models of existing low voltage product lines. As such, they were fully type tested in accordance with ANSI and IEC standards. The superior performance of the electronic trip units and breadth of additional features drove a strong demand for retrofitting other types of low voltage circuit breakers. Vast numbers of retrofit kits were de-veloped, mostly in local service shops like the orig-inal medium voltage vacuum retrofits— also with no type testing. The retrofitted low voltage circuit breakers with new electronic trip devices plus the required current transformers and tripping systems which had never before been fitted to these circuit breakers were typically only subjected to primary injection calibration checks using the shop’s multimeters. Nominally this seems sensible; but there were documented failures to trip because at very high currents (beyond those needed to check the ‘Instantaneous’ trip point) the current transformers could saturate and not provide sufficient energy to operate the tripping mechanism of the circuit breaker. ANSI C37.50-1989, which provides the test procedures for Low Voltage breakers, requires additional maximum short circuit current interrupting tests for every frame size utilizing a solid-state trip device even if the interrupting performance has already been demonstrated with a direct acting trip system or another type of solid-state trip device. Despite this, few trip-unit retrofit ‘kits’ were tested as required by the standard.

Other low voltage retrofitting solutions
The innovative technology incorporated in compact modular vacuum circuit breakers paved the way for the first wave of medium voltage circuit breaker retrofits. Similarly, the invention of solid-state trip devices for low voltage breakers triggered low voltage circuit breaker retrofitting. These programs whet the users’ appetites for additional and more aggressive offerings to extend the life of their switchgear through retrofitting. Although low voltage interrupting technology did not undergo the sea-change ushered in with medium voltage vacuum technology, years of incremental improvements shrunk low voltage circuit breaker sizes and increased performance. A variety of retrofitting solutions for low voltage circuit breakers were introduced.

- **Low voltage switchgear construction fundamentals**
  Industry practice is to have both the OEM and 3rd party manufacturers produce low voltage switchgear utilizing a standardized low voltage breaker and a matching ‘cradle’ assembly. Each of these cradles is surrounded by a sheet metal box of a certain minimum size (“minimum enclosure”) which varies according to the ratings of the circuit breaker. These are arranged into multiple vertical structures and connected with bus bars to the main power bus to form the switchgear assembly. Each minimum enclosure resembles a “matryoshka nesting doll”: a trip unit, inside a low-voltage circuit breaker, inside a cradle, inside the minimum enclosure, which fits

inside the supporting structure that also contains the main bus and outgoing cables. This system of gradually larger assemblies offered service organizations many options in retrofitting the switchgear.

- **Bolt-in cradle replacement low voltage retrofits**
  Here, the existing cradle of the low voltage panel is replaced with the cradle for a new LV circuit breaker. The cradle would be bolted in place and new bus fabricated and bolted to the main conductors; secondary (control wiring) from the connectors replaced prior control components. The new low voltage circuit breaker remains in its original unmodified form. Although this involves the most on-site labor, if the dimensions of the old enclosure into which the cradle is fitted comply with the new manufacturer's requirements, this is nearly foolproof. There are some cases where the dimensions of the original enclosure and those of the desired replacement are incom-patible, but this is rare. The most significant drawback of this solution is the outage time and on-site labor required to implement the solution.

- **Direct replacement low voltage circuit breakers**
  All the interlocks and racking systems of the new breaker are modified, and new primary disconnect assemblies ('finger clusters') and secondary disconnects to mate with the original cradles are added. This mimics the medium voltage vacuum retrofit concept. From the customer perspective may be the most appealing: it can be undertaken incrementally and executed with no more difficulty than exchanging original breakers for routine maintenance. However, it is the most difficult for the manufacturer to execute: all the challenges of recreating a reliable racking and interlocking system still exist, but because the space is smaller and the difficulties larger. Small, project based retrofit shops cannot invest the time and talent necessary to do these well. Furthermore, the adaptations necessary for a direct replacement often reduce the clearances from the arc chutes to the grounded steel enclosure or the energized terminals. This can cause ionized arc exhaust gases to hit these pieces with potentially catastrophic results. Guarding against this danger requires more extensive type testing than other types of retrofits. Direct replacement low voltage retrofits offer many benefits to the user and where possible are perhaps the most effective and economical solution. But as noted above the challenges they present to the design organization are considerable and are best suited to orig-inal equipment manufacturers supporting their own switchgear. In some cases the physical limi-tations are such that even the original manufac-turers must look for alternative solutions.

- **Rack-in cradle replacement low voltage retrofits**
  The cradle assembly for the new LV circuit breaker is fitted with bus adapter pieces and primary disconnect assemblies to fit the bus stabs of the existing cradle and sufficient racking and interlocking features are added to the new cradle to mimic the original circuit breaker for a 'one-time' racking operation into the existing cradle. Because the new racking ad interlock systems are only used rarely, or only once, they can be much simpler than those of the original breaker. From the perspective of the old cradle, the new cradle now looks like an original circuit breaker. Now, the unmodified low voltage circuit breaker is used with its usual cradle, albeit one which was externally modified to match the existing cradle. The new low voltage circuit breaker remains in its original unmodified form. One drawback of this system is that each phase of the circuit now has a total of four primary disconnects, instead of two.

- **Hybrid cradle replacement low voltage retrofits**
  A 'hybrid' cradle retrofit uses both a modified new low voltage circuit breaker for the primary power circuit and a modified new cradle for racking and interlock purposes. The rear portion of the cradle is removed and the primary conductors on the circuit breaker are modified and fitted with finger clusters to mate up with the original low voltage cradle stabs. This is like the rack-in cradle retrofit but eliminates the issues related to putting two sets of finger clusters in series but at the expense of modifying the low voltage circuit breaker.

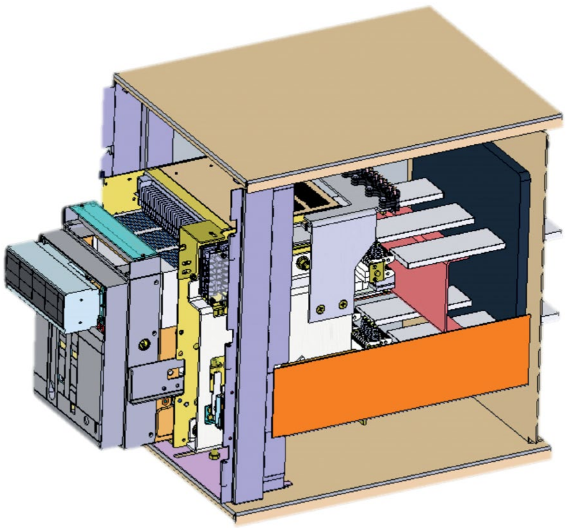

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Figure 4 LV Rack-In Cradle Retrofit

- **Summary of low voltage replacement methods**
  All these approaches present their own advantages for the user and challenges to the manufacturer. The direct replacement solution is perhaps the most appealing for the user when it can be employed, particularly for incremental upgrades to a large and homogenous population of old panels. The bolt-in cradle retrofit is simplest from the design portion, but most difficult to execute in the field. Both rack-in cradle and hybrid cradle replacement solutions leave the most critical functions to the unmodified portions of the circuit breaker and cradle and so are highly reliable. While they use the racking features of the original cradle to secure the assembly in the switchgear, the feature set is limited. Interlocking is also limited to ensure that the cradle cannot be removed from the minimum enclosure while carrying current. The author was a pioneer of both these types of cradle replacement methods and holds a patent on such an interlock system.

The choice of which retrofitting approach depends on several factors, in some cases circumstances may eliminate one option or another from consideration. The size of the minimum enclosure may make any rack-in – or even bolt-in – solution infeasible. Outage time may argue against a bolt-in cradle solution, but the complexity of the racking and interlocking may make a direct replacement impossible. A direct replacement solution clearly requires a complete and very rigorous type test program; a bolt in replacement solution can safely be undertaken with a less stringent series of type tests. Both types of cradle modification solutions will require customized test plans. An often overlooked advantage of the cradle-based retrofitting solutions is the opportunity to standardize what were formerly disparate breakers from a variety of manufacturers to a single type with the resulting savings in training, logistics, service, and support from a world-class manufacturer.

Alternative medium voltage retrofitting solutions

- **Hard-bus retrofills**
  The innovative solutions necessitated by low voltage retrofitting constraints have inspired similar approaches in retrofitting medium volt-age switchgear. Equivalent to the low voltage 'bolt-in' cradle replacement is the "Hard-Bus Ret-ro-fill". The existing circuit breaker compartment is modified or removed and a new medium-voltage minimum enclosure from current switchgear offerings is installed. Although the expense is higher, and the outage time is longer the customer benefits from a completely standard modern design everywhere it matters. Reasons to consider a hard-bus retrofill include lack of a roll-in-replacement design (for many reasons); the original panel has been damaged or is worn out; real or perceived defects in the original design; or as is sometimes the case a facility may have four or more substations, all utilizing different circuit breakers and there is a strong economic incentive for a common circuit breaker for training and logistics reasons.

- **OneFit**
  Another low-voltage inspired solution is embodied in the ABB "OneFit" solution. It is like the Rack-in Cradle solution in that it inserts into the existing circuit breaker minimum enclosure a standard ABB minimum enclosure and that enclosure includes separable disconnects to make up the primary power connections. Unlike the low-voltage 'rack-in' cradle solution, the OneFit is bolted into place in the existing switchgear. Importantly, although the new circuit breaker compartment includes separable disconnects, the design of these disconnects are such that they are manually clamped onto the existing fixed terminals in the switchgear with a high-pressure connection that presents minimal thermal losses and has been tested many times to ensure its ability to withstand the electromagnetic forces and thermal stresses of a short-circuit fault. This solution still requires a complete outage for installation, but the time and labor involved are reduced compared to a hard-bus retro-fill and the customer still gains the benefits of a completely standard, unmodified, modern circuit breaker with all the durability and reliability which is inherent in such a product.

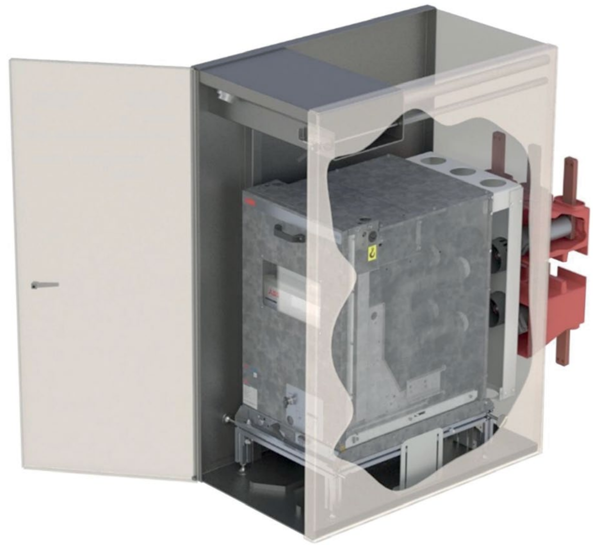

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Figure 5 OneFit Solution

- **Internal arcing fault and arc-resistance upgrades**
  Protecting operators from the effects of internal arcing faults is of growing importance. Although structural changes to achieve limited traditional arc-resistance ratings in accordance with IEEE C37.20.7 and IEC 62271-200 or IEC TR61641 it is likely not practical. However, similar results may be achieved by installing active arc-quenching systems that act in milliseconds to prevent damage to the equipment and injury to personnel. These types of systems are acceptable according to standards but require extensive testing.

'Top 10' retrofit misconceptions

There are often misconceptions around retrofitting equipment. Below are the top 10 common misconceptions encountered by ABB.

1. Type tests guarantee a quality design
Actually, it is the other way around, a quality design will yield satisfactory type tests. Type testing is the final check that the design was done correctly. But type testing does not, and cannot, check every aspect of the design nor can it speak to the long term performance of the design.

2. Type tests are not needed if not requested
False, type tests are never optional.

3. Duplicating a part substitutes for type testing
Duplicating a part, or more accurately attempting to duplicate a part, is not a substitute for type testing. First, part design extends well beyond what can be measured with a micrometer; also, how the part interacts with the rest of the system is as important as the design of the part itself and type testing is often the only way to verify this.

4. An old working retrofit must be a good design
Unfortunately, some of the most serious accidents which have occurred with retrofit designs have root causes stemming from infrequent operations. Only in extreme circumstances — when it matters most —are the limitations of a poor design exposed.

5. The original fault current study is sufficient
Electrical systems grow and evolve over time, changes in the system may necessitate different types or ratings of circuit breakers. Even if the underlying fault current has not changed, advances in our understanding of circuit breaker application may guide the user to better replacement selections.

6. Matching the old nameplate is always best
Original nameplates values may not convey the same capabilities as are reflected by current standards. Also, even on an apples-to-apples basis, the original ratings may not be a good fit for the current system.

7. A proper retrofit will always fit flawlessly
This often happens, and is more likely with mature retrofit designs, recognize that the panel into which the retrofit circuit breaker is being installed is just as old as the no-longer-fit-for-service circuit breaker — and has likely been serviced less. Service should always accompany a new retrofit installation, and subsequent installa-tions in different locations.

8. Using a quality vacuum module is all that matters
A chain is only as strong as its weakest link. While using quality vacuum circuit breakers is essential, they are high quality because they are produced in large quantities by top tier manufacturers. Top tier manufacturers employ diverse teams of experienced engineers and designers with access to sophisticated tools and techniques to ensure that quality extends to the entire retrofit project.

9. A local supplier is always best
While having someone close by is comforting if things go wrong, local suppliers may not have the resources or expertise to avoid the problems in the first place.

10. A supplier asking many questions is a "Red Flag"
It's the quality of questions, not the number that matters. Asking detailed questions is how we ensure that our solutions fulfill customer needs and provide long-term value.

Conclusion

The apparent modularity of the components which may be assembled to form a retrofit solution hide the difficulties of providing a durable, reliable solution. Current standards such as IEEE C37.59, and IEC 62271-307 are valuable references for experienced designers to use in designing their type test plans, but these standards are often misunderstood to be a 'cookbook' for the newcomer to the business. This is not true; reading the rules of baseball does not qualify one to coach any major league team.

Medium-voltage and low-voltage circuit breaker retrofits and replacements are a mature technology. Major manufacturers like ABB have refined their Roll-in-Retrofit designs into robust and reliable products with service and support backing these products.

About the author

John Webb is a principal engineer for ABB Electrification Service in North America concentrating in circuit breaker testing and application, and global standards. He has spent much of his 30+ year career in the retrofit field with the service groups of ABB, Westinghouse Electric, Siemens and Pacific Breaker Systems. He was among the pioneers of medium voltage roll-in-replacement breakers. His experience includes developing and delivering hundreds of designs and ratings of medium-voltage and low-voltage retrofit solutions of the types described in this paper. He holds several patents in the retrofitting field.

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ABB Limited
Electrification Service Division
Email: global-elsemarketing@abb.com
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