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Moving from withdrawable to fixed circuit breaker switchgear in ANSI medium-voltage applications

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Executive summary

In the United States, medium-voltage (MV) power distribution typically uses withdrawable circuit breaker switchgear (WCBS). Withdrawable breakers allow for regular maintenance and provide an easily visible confirmation of circuit isolation but at a cost — having removable parts and the act of inserting and withdrawing breakers could result in the possibility of arc flash incidents. Modern fixed circuit breaker switchgear (FCBS), which uses highly reliable and virtually maintenance-free vacuum and gas breakers, eliminates this concern and introduces other potential advantages.

This paper contrasts the features of MV FCBS and existing WCBS designs. Modern FCBS design elements that are discussed include an internal disconnect for isolation and grounding of circuits and interlocked operation among disconnect, breaker, and grounding switch for improved safety. Furthermore, features such as lower maintenance, smaller footprint, and reduced life cycle costs that result from its simpler design will be explored. By comparing the traditional ANSI WCBS technology to that of the FCBS, this paper will demonstrate that the fixed design, which has gained widespread acceptance in global markets outside the United States, is a viable alternative to the withdrawable designs.

Index terms — Fixed circuit breaker switchgear, withdrawable circuit breaker switchgear, ANSI medium voltage, switchgear design, reliability, safety, footprint.

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Introduction

Switchgear with circuit breakers that can easily be drawn out for maintenance and repair are called withdrawable circuit breaker switchgear (WCBS). WCBS make up a majority of the switchgear deployed in the ANSI medium-voltage (MV) market. Figure 1 shows a typical WCBS with a breaker racked out. Modern switchgear designs that employ breakers that are not withdrawable are called fixed circuit breaker switchgear (FCBS). Figure 2 shows an example of a fixed breaker unit in a FCBS.

The first circuit breakers developed had limited endurance and required regular maintenance every few switching operations.[1] This necessitated switchgear designs that allowed the breakers to be easily withdrawable. However, in the late 1970s, vacuum circuit breakers were developed that no longer required frequent inspection or rigorous maintenance routines to achieve their service life expectancy. In almost all cases, routine inspection once every two to five years suffices[2] and, hence, can be performed during scheduled plant shutdowns. For this reason, the need for withdrawable circuit breakers is diminishing while the benefits of fixed devices are being recognized. The next section of this paper expands on the history and the evolution of the FCBS.

The third section of this paper compares and contrasts the basic design principles of FCBS and WCBS. One of the main features of an FCBS is the dedicated disconnect that is provided on the line side of the circuit breaker for de-energizing and grounding the portion of the circuit that requires maintenance or testing. The rest of this section is dedicated to contrasting the two technologies in terms of their safety, reliability, and cost effectiveness.

The past few decades have slowly but surely seen an increasing trend where utility companies in certain markets outside the U.S. are moving toward more frequent use of FCBS.[3] In the last section of the paper, applications where the FCBS designs can be used in the ANSI markets are highlighted.

In this paper, the authors aim to demonstrate that the ANSI MV FCBS is a safe, reliable, and viable alternative to the current withdrawable designs.

Figure 1

Withdrawable Circuit Breaker Switchgear with a breaker racked out

Figure 2

Fixed circuit breaker unit in an FCBS

Evolution of MV breakers

The first circuit breakers used air as the medium to extinguish the arc that is formed while interrupting a circuit. Since these breakers worked by increasing the resistance between the contacts and expanding the arc in order to extinguish it, air circuit breakers needed to be large and were typically loud. In an effort to reduce the footprint, oil soon became the common medium for extinguishing the arc. However, oil breakers were large and heavy since the oil tank needed to be strong enough to withstand the pressure generated by the arc. Oil breakers also needed frequent maintenance, along with thorough checks and inspection performed at least once a year, to maintain their electrical performance. For instance, GE recommends that the oil be tested at a three month interval.[4] Such a rigorous inspection schedule needed to be instituted due to the rapid and heavy carbonization of the oil used and the significant fire risk posed by the highly combustible oil medium. This meant regularly accessing the oil tank and other parts of the breaker, which naturally led to the development of the draw out feature of circuit breakers in switchgear. In such WCBS, all parts that required maintenance were placed on a rolling tray that could be easily withdrawn from the switchgear and then reconnected after maintenance was complete. This ability to draw out the breaker also meant that there was always a clear visual confirmation of the break in the circuit. It was also easy to replace a faulty circuit breaker with a healthy one if necessary.

Despite regular maintenance, accidents involving oil circuit breakers related to the flammability of oil resulted in an increasing demand for safer and more reliable MV switchgear. This led to the development of switchgear designs that used gas (SF6) and vacuum (VCB) interrupting elements in the circuit breakers.[2] These breakers had a higher electrical endurance and could withstand a much higher number of fault and load interruptions. Both VCB and SF6 breaker technologies had the advantage of being compact, significantly safer, and more reliable. The maintenance requirements for these switchgear types were so low (i.e., typically a visual check once every two to five years) that manufactures started dubbing them “maintenance free.”[2] This made the breakers highly attractive to customers and switchgear manufacturers who began redesigning their equipment offerings to capitalize on these advantages.[5] This resulted in the MV market that is seen today — comprised almost entirely of VCBs.

The withdrawability of circuit breakers from switchgear was developed due to the frequent maintenance and testing requirements arising from using oil as the interrupting medium. Consequently, most of the maintenance and safety procedures were written around this drawout feature.[6] As the more expensive VCBs were developed, there needed to be cost savings elsewhere in the design to make them commercially viable.[7] Since VCBs were capable of many fault interruptions without maintenance, the need to have withdrawable breakers was obviated, giving rise to fixed switchgear designs using VCBs. The FCBS designs eliminate equipment needed to withdraw breakers, and the need to clean and lubricate periodically, resulting in lowered costs.

However, utility companies were reluctant to adopt early FCBS designs that would have required them to rewrite their operational procedures and retrain their staff. Also, a fixed design would have to be highly reliable since maintenance or repair may require more extensive shutdowns. This, along with concerns regarding reliable earthing and testing arrangements, and the fact that the disconnection was not immediately visible, resulted in the initial reluctance toward adopting FCBS.[7] However, in the current global MV markets outside the U.S., these issues have been addressed resulting in the co-existence of FCBS and WCBS.[6]

Comparison of FCBS and WCBS

A. Design and operability

The key design elements of FCBS and WCBS are compared in Figure 3 below. In the withdrawable design, isolation of the load is achieved when the breaker is physically drawn out. However, since this is no longer the case in the fixed design, there is a dedicated isolating disconnect switch that is in series with the circuit breaker to make isolation of the load possible. This is one of the main distinguishing features between the two designs.

An appropriately designed disconnect switch can also be used for grounding the line or load side of the switch, depending on how the switch is configured, prior to performing work. So, in FCBS designs, the core functions of breaking, disconnection, and earthing can be embedded in a single unit with the switches interlocked between these operations to achieve a high level of safety.

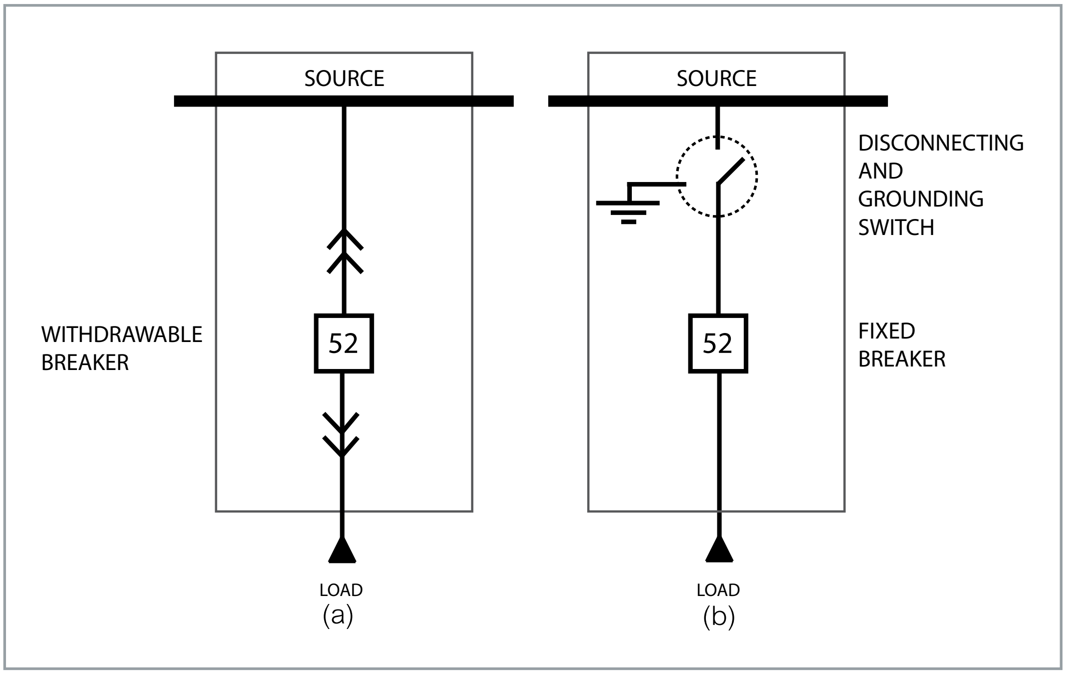

Figure 3

Key design features of WCBS and FCBS. (a) WCBS showing a withdrawable breaker. (b) FCBS showing a fixed breaker with a disconnecting and full short circuit rated grounding switch on the source side of the breaker

The compact nature of some modern FCBS designs allow them to be front accessible so that all maintenance can be performed from the front when needed. All the components that require maintenance are located near the front. Certain designs allow for periodic inspection and lubrication to be performed on the breaker without having to remove it.

The front accessibility architecture eliminates the need to meet the NEC rear aisle space requirement. This saves space by allowing installation of the switchgear very close to a wall and typically results in an even smaller footprint. For instance, consider a switchgear that is 2.1 m (7 ft) deep. If this switchgear requires a minimum working space of, say, 1.2 m (4 ft) at the rear and the front (cf. NEC Table 110.34(A)), it can easily be seen that its footprint would be at least 25% smaller if the rear aisle space requirement is eliminated.

Some new FCBS designs have solid and shielded insulation systems, made possible by improved materials and processes used in the most recent switchgear designs. That is, the entire main circuit will have solid insulation that will be at earth potential at every point on its surface. This provides improved safety and reliability compared to open bus construction. Data from the IEEE Gold Book® indicates that uninsulated bus has twice the failure rate of insulated bus. The bus insulation, coupled with the reduction in size of the switching devices, has allowed further reduction in overall switchgear size.

In most cases, the FCBS designs in North America conform to ANSI requirements and are available with ratings up to 15 kV, 1200 A continuous, and 25 kA interrupting. These designs are intended to replace traditional metal-enclosed gear with something that is physically smaller and that has more features. They are not intended to replace metal-clad gear, which typically has higher maximum ratings (available up to 4000 A continuous, 63 kA interrupting at 15 kV) and more options. However, the trade-offs of FCBS allow for smaller size and costs savings of 10 to 20% over metal-clad gear.

B. Safety

FCBS provides interlocked operation between the breaker, disconnect switch, and grounding switch (cf. Figure 3(b)) before allowing access to the load side in order to ensure that the circuit is in a de-energized and grounded state. For instance, suppose that the current state of the switchgear is such that the breaker and disconnect are closed and the switchgear is energized. Then, in order to access the circuit breaker compartment, the following sequence of operations is performed:

- Open breaker
- Open disconnect
- Ground disconnect
- Close breaker (to earth conductors)

This ensures that the entire circuit breaker compartment is de-energized by the disconnect, resulting in a high level of safety. This is not the case in WCBS, where line-side connections are still energized even after the breaker is drawn out, thus requiring the use of shutters to isolate electrically live parts for safety, and fully rated voltage and arc flash PPE. Current transformers (CTs) and voltage transformers (VTs), when present in an FCBS unit, may also be located on the load side of the grounding switch.

Most modern FCBS designs also have increased safety levels with internal arc-rated designs and compartmentalization to prevent unintended access to energized parts of the switchgear. However, adoption of these new MV switchgear will need certain operating procedures to be rewritten and personnel to be trained to correctly operate the new switchgear for continued safe operation.

WCBS traditionally have no grounding switches and therefore a common method used to ground the switchgear is by the manual use of a hot stick with ground cable assembly. This practice exposes the worker to a potential hazard. Some users recognize this risk and use devices known as ground and test devices (G&T). These devices, when electrically operated, act similarly to grounding switches but expose the worker to the potential hazard of first racking out a breaker and then racking in the G&T before it can be used.

C. Reliability

Reliability data is difficult to compile. It is commonly believed that manufacturers collect this data. However, they generally only have data related to warranty issues, which may be more indicative of a manufacturer's quality control processes than true long-term reliability of equipment. MV switchgear can remain in service for decades. Compiling such data requires substantial effort and resources.

One of the best sources of reliability data is the IEEE Gold Book (IEEE Standard 493).[8] For MV breakers, its database is from the mid-1980s and includes only air-magnetic breakers. The sample of vacuum breakers was too small to be included. Unfortunately, even the air-magnetic breaker failure sample is quite small. However, the data that was available does show an interesting trend. For 75% of the failures, the breakers were repaired in place (no details were provided). The fact that they are removable did not provide any advantage. (This percentage is even higher for low-voltage (LV) breakers). This implies that the complexity and cost of withdrawable breakers may not confer much improvement in repair time.

Charles Heising compared reliability for vacuum breakers from different sources in the article "Reliability of medium-voltage vacuum power circuit-breakers."[9] It was concluded that vacuum breaker failure rate was four times less than the industry average (which at that time included a large portion of non-vacuum breakers). With the lower failure rate for vacuum breakers, there is even less of a benefit to have withdrawable breakers.

The interrupting components of the vacuum breaker are far more durable than the air-magnetic or oil breakers. Vacuum is a remarkable dielectric. The contact gap is only about 10 mm compared to 5 to 10 cm in the older types. Less stored mechanical energy is needed for operation, simplifying the operating mechanism. Since there is no gas or liquid insulating medium, contact erosion and pitting are reduced. There is no arc chute or oil to become contaminated. Vacuum breakers have been in widespread use for several decades and users may no longer be aware of the remarkable improvements in performance over older technologies.

Racking problems are not listed in any reliability database. It is not considered a failure since the breaker is already out of service. However, Annex C of IEEE 1584 lists anecdotes of arc flash incidents based on data collected over the years. Several of those incidents are related to breaker racking or otherwise inserting or removing withdrawable components. We should note:

1. Racking is a known cause of electrical arc flash events and is cited multiple times in IEEE 1584 Annex C.
2. NFPA 70E PPE tables require higher levels of PPE for racking operations.[10]
3. FCBS eliminates racking and therefore eliminates one potential risk.

Generally, racking problems are uncommon. When they do occur, they are often due to improper breaker reinstallation. They can increase in frequency with lack of maintenance and age of the equipment.

D. Cost

The economic evaluation of any equipment depends on its complete life cycle cost — which includes capital costs, operational and maintenance costs, and the cost of demolishing and recycling it at the end of its lifetime.

Some of the newer FCBS designs have an optimized architecture yielding smaller dimensions. The front accessibility feature, as discussed previously, allows for installation close to the wall resulting in even further reduced footprint and, thus, reduced installation costs. FCBS provide further space savings because it does not need the additional floor space in front to accommodate the removable part as in WCBS.

Due to improvements in construction features and components, FBCS equipment has a five- to 10-year recommended maintenance period. However, many large facilities are locked into a three-year maintenance cycle for many reasons. They may not be able to realize maintenance cost savings immediately but could potentially benefit in the future from the reduced maintenance requirements of the FCBS.

Compared to an air-insulated fused disconnect switch, FCBS provides a smaller footprint and many more options and features than the switch at a slightly higher price. Compared to WCBS, FCBS provides slightly reduced electrical ratings but with many of the features of metal clad at a lower price.

FCBS applications

This section provides some examples of possible applications for FCBS.

1. MV/LV transformer primary — FCBS can offer more automation and protection functions than a typical fused switch without requiring the full size and cost of a WCBS cubicle.
2. Mains and feeders — FCBS can be used instead of WCBS as an upstream protective device for lineups of fused switches, or other FCBS with added protective functions including differential protection.
3. Ring-main networks — FCBS can provide the automation that is traditionally provided by WCBS while holding down the cost of these expensive networks.

While FCBS has distinct advantages over WCBS in some circumstances, it is not intended to replace it for all applications. Systems with very high ratings or maintenance requirements, due to harsh environments or very frequent operation, are some examples where FCBS may not be ideal (e.g., arc furnace breakers). The efficient use of space within the switchgear also leaves less room for complicated bus architectures and other special customizations.

FCBS has been successfully implemented in certain global markets outside the U.S.

Conclusion

The ANSI MV market provides an array of applications for both WCBS and the FCBS technologies. One is not intended to replace the other, but the vision is to have both technologies co-exist in the ANSI market in the near future. Through the discussion of modern FCBS designs, this paper shows that they are safe and cost effective, and provide a viable alternative for many applications.

Table 1

Typical attributes of FCBS and WCBS

Attribute	Fixed circuit breaker switchgear	Withdrawable circuit breaker switchgear
Design and operability	• Isolation via disconnect • Compact design with front access	• Isolation via breaker withdrawal from cubicle • Larger design requiring rear access
Safety	• Has grounding switch • Interlocked to prevent entry until system is grounded • Has some level of arc resistance • Removes risks associated with removing withdrawable components	• Requires manual grounding via hot stick and cable assemblies • Allows access while switchgear is energized • Arc resistance construction is a unique design • Retains the risk associated with racking operations
Reliability	• Intuitive interlocked operation • Has no complex racking mechanism or shutter assemblies	• User-dependent manual steps to withdraw the breaker to isolate circuit • Requires use of racking mechanisms and shutter assemblies
Cost	• Lower in both capital and operational expenses	• Higher in both capital and operational expenses

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