BENEFITS OF WITHDRAWABLE SWITCHGEAR AND MOTOR CONTROL CENTRES

When are withdrawable switchgear and MCCs the best choice?

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Abstract – PR-42

Ever since electricity was first transmitted and distributed, there has been a need for switchgear. As distribution systems evolved, this switchgear became available in fixed and withdrawable forms. This evolution continues, and the emergence of new technologies and designs means that the “optimum” solution still changes over time.

This paper compares the benefits of fixed and withdrawable switchgear, taking into account the function that the switchgear has to perform. The topics covered include:

• Safety of personnel and processes,
• Total cost of ownership, including consideration of factors like reliability, availability, cabling, switch room size and process control connection,
• Operator friendliness: how easy is it to work with the switchgear, and the complexity of the switching protocols,
• The ease with which maintenance inspections and measurements can be performed,
• The need for switchgear to be fit for purpose and to be sufficiently robust to suit the application,
• Ease and speed of repair and ease of housekeeping for spare parts,
• The need for high time-to-failure and the consequences of failures.

The aim of this paper is to provide input for the panel discussion comparing withdrawable and fixed switchgear and MCCs, with the focus on usage of the switchgear and its function within the total process, also taking into account the newest technologies in switchgear and network architecture.

It is intended to provide answers to questions like:

• Should fixed or withdrawable or something in between be chosen?
• When is it best to choose fixed switchgear and when is withdrawable the better choice?
• Which applications require withdrawable switchgear?
• Which form of switchgear will be preferred in future?

Index Terms:
Fixed electrical switchgear or withdrawable electrical switchgear.

I. INTRODUCTION

Switchgear has been needed since the distribution and transmission of electricity began. In the pioneering days of electrical distribution, switching medium voltage (MV) supplies was a challenge. Since then there have been major changes to switchgear, and even now new technologies and insights mean that ideas about what is the “optimum” design continue to change.

Switchgear has evolved through many stages, from the open systems of the early days (see Figure 1) to state-of-the-art, modern enclosed systems.

Figure 1. Old style open MV switchgear.

After the first air-insulated systems, the development of switchgear moved on to oil-filled systems. The big advantage of oil-filled switchgear was that it required less space for installation. The oil also helped to insulate the electrically live parts of the equipment, which meant that no cage or barrier was needed.

Within the switchgear the oil distributes the heat generated by losses, which made it possible to further reduce the size of the switchgear. In the best designs, the oil also helped to extinguish the arc produced by the opening of the breaker. Alongside these advantages, however, oil-filled switchgear also have shortcomings. If they are pushed past their limits, the oil may ignite. To guard against this, frequent maintenance is recommended. (Typically check once a year, after 3 or 5 load breaking operations, or every 1,000 switching operations, and perform lifetime extending maintenance every 5 years, or after 5,000 switching operations). To make this frequent maintenance possible, withdrawable switchgear was developed. All parts that require maintenance are mounted on a carrier that can be easily and safely withdrawn from the switchgear, and then reinserted when maintenance is complete. This minimizes disturbance to the connected loads, because the rest of the switchgear can remain in service.

As a result of some unfortunate events, end users started demanding switchgear that was less combustible than the oil-filled equipment, but just as compact. Some
manufacturers addressed these requirements by using a gas (sulphur hexafluoride – SF₆) for insulation and for extinguishing the arc. Other manufacturers used cast resin insulation and vacuum bottles as switching devices. The maintenance requirements on these kind of switchgears are so low that manufactures often describe it as “maintenance-free”, recommending only a visual check once every 2 to 5 years. This newer switchgear is available in both fixed and withdrawable forms.

During the evolution of switchgear from open systems to enclosed, switchgear with withdrawable main parts emerged. The need for withdrawable main parts was and is dependent on multiple factors that are discussed in this paper in the light of current insight and requirements. This discussion is not related to any particular brand or type of switchgear. This paper focuses on indoor low- and medium-voltage switchgear.

II. SWITCHGEAR USERS

End users of switchgear have the most involvement with the equipment and, therefore, their needs are paramount. The purpose of electrical distribution is to transport energy from a source to a load, so it is reasonable to say that everything needs to be in line with the end user’s requirements for their particular loads. What is important for the load must be reflected in the design of all of the electrical distribution equipment.

Most switchgear users in the petrochemical industry indicate the following factors are important for their process equipment:
- Safety
- Overall cost of ownership
- Availability
- Ease of maintenance
- Operator interface friendliness
- Flexibility

A. Safety

In the early part of the 20th century, electrical switchgear used open-type construction, and was housed within wire cages. This type of switchgear used operator-dependent breakers. The inherent dangers of this design led to high risks of fatal accidents and required specially trained operators. Today, safety is the top priority when selecting new MV switchgear. Safety must be inherent in the design and switchgear should at least comply with these international standards:
- IEC 62271-1 Common specifications
- IEC 62271-100 Circuit-breakers
- IEC 62271-102 Disconnectors and earthing switches
- IEC 62271-200 Metal enclosed switchgear
- IEC 61439-1 & 2 Low voltage switchgear and controlgear assemblies.

Risk can never be reduced to zero, but managing safety means reducing risk to an acceptable level. Risk is influenced not only by the design of the switchgear but also by the way it is operated and used. A design, however, manages the risks associated with the switchgear throughout its whole operational life. Although IEC standards concern safety, these standards alone do not prevent all risks during the life of the switchgear. The IEC requirements ensure that safety is embodied in the design of the switchgear, but they don’t address risks relating to the use of the switchgear. Users need to take appropriate measures to reduce these risks to an acceptable level. By choosing the right type of equipment, setting specifications, performing maintenance correctly, giving proper training to operators and adopting proper working protocols – as illustrated in figure 2 – the risks in switchgears can be kept to a minimum. [5]

Figure 2. Risk reduction

So that risks can be reduced to an acceptable level, switchgear must be able to accommodate any application-specific safety requirements that may arise. One of these risk-reducing measures might be the requirement to be able to insert and withdraw a breaker, from the bus bar, with the door closed. This is a reasonable demand as accidents have occurred during the insertion of circuit breakers. Unfortunately the IEC standards mentioned above state only that the “transfer of withdrawable parts” should not reduce the protection level – a specific test for this situation is not required. An even more far-reaching solution is offered by electrical switchgear that allows the breaker to be maneuvered via a remote operating facility.

The options for reducing risks to an acceptable level need to be evaluated in line with the risk acceptance philosophy of the organization.

Some users, for example, require visual separation as a way of reducing risk of electrocution, since this allows mechanically skilled maintenance workers to minimize their exposure to risk when working on live circuits. At some sites it is mandatory to remove the breaker then close and lock the door before mechanical maintenance can be performed on downstream equipment. This is a main advantage of a withdrawable system – withdrawing the breaker gives clear visual separation. However, withdrawing a circuit breaker comes at a price. Moving the breaker in and out increases the risk of damaging the contacts and ultimately creating a fault. Special care is required in design, operation and maintenance to mitigate this risk. Clearly, this risk does not apply to equipment with fixed circuit breakers.

Reducing risks by using a withdrawable system for visual separation is, in fact, a paradox; It is visually clear that the downstream equipment is voltage free while the breaker is removed, hence risk for working in live load is reduced. But the act of making the visual separation, by withdrawing the breaker, and creating a visual separation, introduces a new risk.
The primary task of centralized process control is to control the process and it requires only basic information from the MV switchgear, such as on, off, isolated, earthed, test, withdrawn and fault status indications. Sometimes load measurements are also required. Withdrawable systems have more switching statuses that need to be communicated to the centralized process control system, and therefore a larger number of I/O points may be needed. This may not be a key consideration, but it is definitely a factor that can unexpectedly add to costs.

On the other hand, withdrawal switchgear provides a test position that allows the centralized process control system to operate the breaker independently of the switchgear, thereby offering the possibility of testing all signals without affecting the energy flow on the site. In most cases, however, this is only an advantage during the commissioning of a new system or after major overhaul.

Nowadays manufacturers and users are considering the environmental impact of equipment during manufacture and service, as well as at the end of its working life. In relation to the design of a MV switchgear, the concept of "the fewer components the better" applies, because every part must be manufactured and therefore has an impact on the environment. Furthermore the materials used need to be selected carefully; they need to be safe for personnel and the environment – not just during use, but also at the end of service life. Ideally, it should be possible to recycle them completely at the end of the life of the equipment.

Another smaller environmental aspect is energy losses within the switchgear itself. Losses caused by the conductors and by the connection points with in the switchgear, like the primary main contacts of the circuit breaker and the power connections between the fixed and withdrawable parts of the switchgear. A design that incorporates primary contacts with optimal surface contact, ensures safe interlocking and it reduces costs.

B. Overall cost of ownership

The cost of switchgear is not just the initial purchase price; the total cost of ownership includes much more. For example, the switchgear needs to be installed in a switchroom. Compared with fixed designs, withdrawable switchgear often has a bigger footprint and needs additional floor space to allow for convenient handling of the withdrawable parts. The switchgear also needs to be connected to the supply, the loads, and the process control system. Energy losses within the switchgear also contribute to total cost of ownership and the energy consumed in supplying these losses during the equipment's lifetime must be considered. Furthermore the operating staff needs to be trained, and procedures adjusted to suit the "new" switchgear. Finally, the switchgear will require maintenance throughout its life.

The total of all of these expenditures needs to be considered in initial cost evaluations, because they are different for each type of switchgear. Generally withdrawable systems also have, next to a bigger footprint, higher maintenance costs because of their additional moving parts. Many fixed circuit breaker switchgear designs adopt the sealed-for-life concept, resulting in very low maintenance costs. Total cost of ownership calculations for switchgear should include all the items in Table I.

### TABLE I

| Initial cost |
| Building cost |
| Cost for connection load and supply |
| Cost for maintenance during the lifetime |
| Energy cost losses |
| Expected lifetime and extended lifetime |
| Cost of disposal after end of life |

Plants in the petrochemical and chemical industries are operated by a centralized process control system that is connected to all devices within the process and also, in many cases, to the associated electrical switchgear. The cost of the centralized process control units is typically related to the number of I/O points since the number of I/O points determines the amount of required hardware as well as the programming time that will be needed. The primary task of centralized process control is to control the

On the other hand, the failure frequency of a system increases if it uses more parts. Conversely, removing parts and simplifying the system will improve its availability. Withdrawable switchgear consists of all the parts that are used in comparable fixed switchgear, plus the additional parts needed to make the switchgear withdrawable – that is, the parts needed to make possible
connection and disconnection. These parts include shutters, alignment gliders, signaling contacts, mechanical interlocks, primary disconnect main contacts, etc.

In both MV switchgear and LV motor control centers, the biggest threat to availability is arc flash. Switchgear must be designed to minimize the possibility of arc flash and to limit and contain the effects if an arc-flash event should occur.

Because withdrawable systems are always equipped with a door, slightly weakening the switchgear structure, manufacturers have to take special care designing a strong system capable of withstanding an internal arc. If designed well, fixed switchgear will inherently be more robust for internal arcing.

D. Maintenance friendliness

Circuit breakers are mechanical devices so ultimately they will wear out and fail. It is important to know when they will fail. Maintenance can reduce wear out and indicate the progress of the wear. To carry out maintenance, the breaker needs to be disconnected from the supply, but the increasing demand for continuity of supply makes it hard to arrange planned outages. With a withdrawable system, it is possible to perform maintenance on a breaker with a minimal effect on the rest of the switchgear. To maximize the advantages of this practice, all parts that need maintenance, including those that are likely to fail, must be mounted on the withdrawable section. In some designs, only the breaker itself is withdrawable—other parts, such as voltage transformers, current transformers, protection relays and earthing devices, are left behind. For maintenance on the fixed part of the main contacts, withdrawable electrical switchgear needs to be de-energized. This is similar to the situation when work is needed on a disconnecting switch in fixed MV switchgear.

If Life Cycle Maintenance (LCM) is implemented, the difference in failure rates will be minimized and the expected lifetime will be maximized by adopting an approach that provides the flexibility to structure a program that offers a way of meeting individual asset management needs. With an LCM program, a single, multiyear service agreement provides asset support for every covered product installed in a factory, plant or offshore complex until that product is modernized or retired after 3, 5 or even 10 years, in line with an operational, when new loads are being connected and the electrical energy supply system needs to be able to accommodate these changes. Switchgear can be designed to allow for the possibility of extension or even with spare equipment built in for later use. This demand for flexibility also extends to the execution of projects while the plant is operational, when new loads are being connected and when the installation of new switchgear is required.

Withdrawable switchgears have the advantage of time spread investments. Switchgear can be installed with a number of spare units, temporarily without the circuit breaker. In time, when required, the circuit breaker can be purchased and commissioned. The circuit breaker is most often the most expensive part of the installation and capital expenditure can be postponed to a later moment.

E. Operator interface friendliness

Electrical switchgear should have a user-friendly interface. It should be clear, easy, simple to use and pleasant to work with. Even though operators usually don’t directly mention this as an important factor, they most certainly evaluate it on a less conscious level. Most important is that the switchgear supports the switching protocol used on the site were it is installed. For example, some sites will only allow cable voltage testing on an installation with a closed door.

There is a culture change going on, with switchgear users moving away from employing dedicated switchgear operators to having all-round troubleshooters. Until 20 to 30 years ago, switchgear operators were trained specialists whose sole task was to perform the switching operations on “their” network. Many organizations are now requiring operators to carry out other tasks, and even non-specialists are asked to perform switchgear operating duties. The design of modern switchgear must, therefore, no longer be “operator sensitive”, and it must require less skill for safe operation. The increased likelihood of operation by less skilled operators means that ease of operation needs to be carefully evaluated, giving full consideration to the skills of the operating team.

Translating this issue to the discussion of using fixed or withdrawable designs, one should understand that moving the circuit breaker in and out of a switchgear is a sensitive task that requires some experience and care. Besides the system knowledge, fixed circuit breaker design typically only requires the push of a button, reducing the risk of improper operation.

F. Flexibility

Often a plant is not fixed in design and implementation. The process for which it was initially developed is likely to be upgraded and modified over time, and the electrical energy supply system needs to be able to accommodate these changes. Switchgear can be designed to allow for the possibility of extension or even with spare equipment built in for later use. This demand for flexibility also extends to the execution of projects while the plant is operational, when new loads are being connected and when the installation of new switchgear is required.

III. WITHDRAWABLE OR FIXED SWITCHGEAR

Electrical switchboards and motor control centers are available in two main types: fixed and withdrawable. Fixed switchgear comprises an enclosure that houses all the required devices and equipment to distribute and switch the electrical energy. In a withdrawable switchboard, some critical parts can be removed from the enclosure without disturbing function of the rest of the switchboard.
Figure 3 shows a simplified diagram of withdrawable and fixed electrical switchgear.

In the withdrawable version, the withdrawable part contains the breaker and the protection. Isolation of the outgoing cable is achieved by removing the breaker. In the fixed design a disconnecting switch is added to make isolation possible.

As will now be discussed, both types of switchgear have their own benefits and disadvantages.

A. Benefits of withdrawable switchgear

Withdrawable electrical switchgear has the following benefits relating to safety, overall cost of ownership, availability, maintenance friendliness, operator interface friendliness and flexibility.

Plant safety can be increased by using withdrawable switchgear if the plant procedures are based on visual separation achieved by removing the breaker. In addition, access to the terminals of the functional unit can only be gained if the functional unit is removed. This ensures that the terminals are always disconnected from the supply before work can be carried out on them, as shown in Figure 4.

Overall cost of ownership can be reduced because the withdrawable switchgear by spread investments.

Availability of withdrawable switchgear is increased because it is possible to rapidly replace defective equipment with an identical spare unit. Provided that the withdrawable units are standardized, time to repair is reduced and, therefore, higher availability is achieved. Access to parts is improved when they are removed from the switchboard enclosure, and testing equipment in the withdrawn position is easier because the parts are not connected to the "live" system. In addition, the testing can be carried out without affecting the rest of the switchgear.

Operator interface friendliness is increased because a test position is available, which means that the operation of equipment can be checked while it is disconnected from the mains. This allows total process control testing without disturbing other loads on the switchboard or even the load connected to the breaker.

Flexibility for further expansion is increased. In the most extreme case, only the switchboard enclosure needs be installed initially, with withdrawable units simply plugged in as they are needed to supply new loads.

Withdrawable switchgear allows for a unique application; For instance, switchgear with a double bus bar arrangement can use one breaker that can be inserted in two different locations to connect the load to either set of bus bars. To change from one set of bus bars to the other, the breaker is simply removed from one location and inserted in the other. This means that only one breaker is needed instead of two.

B. Disadvantages of withdrawable switchgear

Withdrawable electrical switchgear has the following disadvantages relating to safety, overall cost of ownership, availability, maintenance friendliness, operator interface friendliness and flexibility.

In relation to safety, accidents with electrical switchgear causing injuries and fatalities are thankfully rare. The few reports of such accidents that exist show that they are most often caused by interlocks that malfunctioned, either because they were faulty or because they had been tampered with. Interlocks are fitted to prevent dangerous actions, such as entering a cable connection room when the cables are live. A recurring cause of accidents is a foreign object that has been left on a withdrawable assembly after maintenance. If the withdrawable assembly is then re-inserted into the switchboard, the foreign object short circuits the primary parts and causes an arc flash. Accident records describe various foreign objects left behind after performing maintenance, including a tool, a phone, test wires and loose secondary wires [3] [4] [5]. Many accidents occur while the circuit breaker is being maneuvered in and out of the switchboard.

Overall cost of ownership increased because the withdrawable switchgear usually needs a bigger switchroom, as it has to allow space for the breakers to be maneuvered in front of the switchboard. Another factor that increases the total cost of ownership is the additional losses resulting from dissipation in the primary disconnect main contacts. And, most importantly, the increase in maintenance needed also adds to the total cost of ownership.

Availability and reliability of withdrawable switchgear is influenced by its increased potential for failure. The additional parts that are needed to make switchgear withdrawable all have their own failure rates which add to...
the overall potential for failure.

Generally speaking a withdrawable switchgear design will make use of more parts and more moving parts. For example shutters, align gliders, wrecking spindles, signaling contacts, mechanical interlocks, main contacts, etc., which increases the failure rate of the system; however due to its flexibility the failure duration will most likely be shorter in relation to a fixed circuit breaker design.

Maintenance friendliness is reduced because withdrawable switchgear has more parts that require maintenance. These include shutters, interlocks, primary contacts and secondary contacts.

Operator interface friendliness is reduced because maneuvering the breaker into and out of the switchboard requires a certain level of skill - operators need to know how to rack the breaker in and out. These are complex operations that need to be executed precisely, and they are also operations involving an elevated risk level. In the past, accidents have occurred during racking in and out of breakers and, since the IEC does not prescribe any tests for this operation, it is uncertain what the outcome will be if an arc-flash occurs. Hinged doors that need to be operated to rack out the breaker are often less robust. The operating staff who operate withdrawable switchgear need to be well educated and trained to be able to perform the racking operations safely, and additional procedures need to be in place for these operations (lock and sign).

In terms of flexibility and suitability for future expansion, withdrawable switchgear has no specific disadvantages.

C. Benefits of fixed switchgear

Fixed electrical switchgear has the following benefits relating to safety, overall cost of ownership, availability, maintenance friendliness, operator interface friendliness and flexibility.

The safety of a fixed electrical switchboard is high, because of its robust and simple design, and because it is easier to implement effective arc-flash containment.

Overall cost of ownership is lower because the compact construction of fixed switchgear means that the switchroom can be smaller.

Availability is increased by the simple fact that fewer parts mean fewer failures. Furthermore, limited mobility of the breaker means that handling is more controlled, and this ensures that the breaker end of life is more predictable than is the case with breakers that have been moved around.

Maintenance friendliness is enhanced because the need for maintenance is reduced. Fixed switchgear needs a minimum of moving parts, and has no shutters and no removable primary or secondary connections. In addition, the fixed construction allows the switchboard manufacturer to adopt a sealed-for-life approach, which further reduces maintenance requirements.

Operator interface friendliness is increased by the smaller range of options. Opening, closing and isolation are all achieved by operating fixed-mounted switches. There are no shutters that are locked and there is no alignment to watch. In addition, separation is achieved with and indicated by a switch tested to IEC standards that prescribe a defined operating life and predictable behavior in case of wrong operation.

In terms of flexibility and suitability for future expansion, fixed switchgear has no specific disadvantages.

D. Disadvantages of fixed switchgear

Fixed electrical switchgear has the following disadvantages relating to safety, overall cost of ownership, availability, maintenance friendliness, operator interface friendliness and flexibility.

In terms of safety, fixed switchgear has no specific disadvantages. Fixed breaker designs have limited possibilities to visually show the disconnector open position for all phases. Users with specific switching procedures with a visible open connection will have to take extra care in with these systems.

In relation to overall cost of ownership, if a component fails, the resulting downtime is likely to be greater than with withdrawable switchgear because of the increased time needed to carry out a repair.

Availability of the power distribution system overall may also be reduced because, if a breaker in fixed switchgear needs to be removed, the complete switchboard needs to be isolated, often for some considerable time affecting the all connected loads.

Maintenance friendliness is reduced because the breakers cannot be accessed easily and no complete spare units are available. If maintenance is required on a fixed circuit breaker system, then the whole bus bar must be de-energized with most likely a long planned outage required.

In terms of operator interface friendliness, fixed switchgear has no specific disadvantages.

Flexibility is not especially good. Extension of existing switchgear will involve considerable downtime. To make provision for expansion from the outset with new switchboards is costly because of the extra equipment that has to be installed.

E. Best of both worlds

Evaluating fixed and withdrawable switchgear reveals clear dilemmas between

- Fast repair ⇔ Fewer possibilities for failure
- Flexibility ⇔ Smaller footprint

The ideal would be a hybrid of fixed and withdrawable solutions that delivered the benefits shown in Table II.

<table>
<thead>
<tr>
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<th>The Ideal Solution</th>
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<tbody>
<tr>
<td>Safety</td>
<td>robust and simple</td>
</tr>
<tr>
<td>Overall cost of ownership</td>
<td>low</td>
</tr>
<tr>
<td>Availability</td>
<td>minimal failures and fast repair</td>
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<tr>
<td>Maintenance</td>
<td>low maintenance and easy access to all components</td>
</tr>
<tr>
<td>Operator friendliness</td>
<td>simple and intuitive</td>
</tr>
<tr>
<td>Flexibility</td>
<td>allows for future extensions without high initial cost</td>
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Focusing on availability, it is clear that there should be a good balance between failure frequency and ease of replacement. Only those parts that are likely to fail need to be easily replaceable. In modern switchgear, breakers seldom cause problems; failures are more often associated with CTs and VTs. Should we therefore have replaceable measuring devices on the primary parts? Furthermore making a part withdrawable should not increase the chance of failure.
IV. USAGE

The importance of the above mentioned points depends on how the switchgear is being used – for example, its position in the electrical grid and the function of the loads it supplies. If the switchgear is being used at a key position in the grid it is likely that there will be a need for future changes and extensions. It is also important to know how critical the connected loads are. If the consequential loss associated with downtime is comparable to the price of a breaker, it is recommended to have a spare breaker available. But if the consequential loss associated with a downtime is much greater, a better option would be to use a totally redundant system that is always on standby and can take over the supply immediately.

Furthermore it is useful to know how often the load will be switched on and off. If the breaker is connected to a distribution cable, it is likely that it will only be infrequently operated. But if the breaker is used to feed a motor, it is likely that it will be operated much more frequently. The number of expected switching cycles is important, because switchgear is available in versions intended for fewer or more operational cycles, depending mainly on the design of the breaker operating mechanism. In distribution applications, a life of 2,000 switching cycles could be sufficient (over 30 years, this equates to around 65 cycles per year), but for motor control, a life of 30,000 switching cycles could be too low.

The total cost of ownership of withdrawable switchgear is higher than that of fixed equipment, so a valid question to ask is which applications actually require withdrawable switchgear. It is clear that the key benefit of withdrawable switchgear is the possibility of executing fast repairs. In the event of a failure of the removable part, it is easy to replace it. Likewise, in case of a component failure it is easy to access the faulty component and replace it. But what are the situations where these benefits are important?

A typical petrochemical industry application is a process plant that operates continuously 24/7. Planned shutdowns for maintenance occur only once every five years and the costs associated with outages are very high, typically amounting to much more than the cost of the device that failed. Furthermore process plants have a low tolerance for equipment failures. Every plant, however, has its own specific requirements in relation to switchgear and the way it is used, and this makes it necessary to adopt a range of different operating philosophies as described below.

A. Fast repair

In a critical application where a philosophy of minimum down time essential, provision for fast repair is required. To minimize the risk of disruption to process continuity, it is possible to make all equipment fast to repair and/or replace. Implementing this philosophy, which accepts that short failures will occur and is focused on fast repair, requires the use withdrawable switchgear. With this, a device can fail with a minimum of influence on the process and, further, it is easy to make provision for performing maintenance. For this philosophy to work well spare-part housekeeping is essential, the right spare part needs to be available quickly or else delays occur and the benefits are lost. For maintenance, it is possible to remove a part and work under volt-free conditions; the maintenance can even be conducted in a different location, like a workshop. This fast repair philosophy is often practiced at the lower process levels, such as LV motor control centers.

B. N+x philosophy

To ensure process continuity, some plants use equipment that is designed with an N+1 philosophy that allows one device to become inoperative without affecting normal operation. This means that a device can fail, or be taken out of service to perform maintenance, without influencing the process. This philosophy is also implemented in the applied grid configuration to make sure that there always is an alternative route for electrical energy and, therefore, the N+1 philosophy is often available in the electrical switchboard. When using a N+1 philosophy the possibility of carrying out repairs without switching off the process is already built in, and a withdrawable system is not required if the N+1 philosophy is fully implemented and an alternative route is always available. This philosophy is often applied to distribution cables, with cables run in parallel. Sometimes even an N+2 philosophy is followed, which means that up to two devices can fail without loss of function.

C. 2N philosophy

An alternative approach to ensuring continuous process operation is to adopt an approach where all critical equipment is duplicated. This allows for one of the two sets of equipment to fail without interrupting the process. Plants with this philosophy are often fed with a dual grid system to make sure that there are always two routes for providing electrical energy. Typically, two separate switchboards will feed the process. Main substations are designed this way, having two main power transformers each capable, on its own, of fulfilling the required function. For example, LNG production facilities are often split into several trains. The trains are identical process units but operate completely independently. If one train fails, the other trains ensure continuity of process output.

For offshore equipment, like ships and production platforms, continuity is even more critical and equipment is often implemented in a 2N philosophy to attain the highest possible availability.

In petrochemical plants for continuous processes, the design for substations and switchgear is based on redundant duplicated switchboards (A and B) fed from transformers A and B. This maximizes reliability and availability.

D. Site culture

Each production plant and company has its own site culture based on knowledge, experience and best practice for relating to its own particular applications. Although this culture varies from site to site, there are some commonalities across petrochemical sites: LV motor control centers usually have withdrawable motor starters, for example, and HV installations are based on fixed breakers.

The rules are less clear cut for MV systems. Often sites are standardized on withdrawable installations, but if gas-filled switchgear is installed, the use of fixed mounted breakers is often accepted. Some sites, however, only
accept withdrawable breakers – a balance has to be struck between reliability and quick access for maintenance.

Site culture is also based on standardization, and it can be safer and more economical to choose one type of equipment on a site (fixed or withdrawable) rather than having a mixture, which would mean that staff have to be trained on both types of system, and that a greater variety of spares is needed.

V. FIXED OR WITHDRAWABLE?

To make the right choice between fixed or withdrawable equipment when selecting new switchgear the following evaluation procedure should be used. First, estimate the losses associated with a production outage, and then calculate what reduction of production losses can be achieved by using withdrawable equipment. Evaluate the financial implications and compare them to the additional total cost of a withdrawable system. If the reduction of production losses is small (financial value at minimum) the balance will tilt in favor of fixed equipment, but if a substantial reduction of production losses can be achieved, it could be that a withdrawable system is to be preferred – see Figure 5.

Figure 5.
Evaluation diagram for fixed versus withdrawable switchgear.

A. Not critical

In non-critical applications where downtime is not directly related to loss there is no requirement for fast repair. A withdrawable system is clearly unnecessary for availability purposes.

B. Withdrawable overkill?

If a plant is operated with the fast repair philosophy it is clear that as much of the equipment as possible should be amenable to fast repair. MV breakers that are easy to replace (withdrawable), and low voltage motor control systems using withdrawable drawers may be desirable in some cases, as they make replacement possible under live conditions without affecting the rest of the process. In other cases, however, fixed equipment would be sufficient. For example, if a 2N philosophy is implemented on a production site, withdrawable equipment for fast replacement may be overkill, especially for non-critical loads.

The benefits for withdrawable equipment are not needed, it is unnecessarily expensive, it places higher demands on operating personnel and it makes operating procedures more complicated. Here, fixed switchgear offers a more robust, less complicated, and more cost effective solution for power management, which has the additional benefit of requiring less space.

On top of this availability analysis one should also check what level of flexibility is required. A high level of flexibility tends for withdrawable switchgear systems and if flexibility is less important a fixed design will be more economically feasible.

VI. FINALLY

The question addressed in this paper is where the use of withdrawable switchgear is justified and advantageous, and the answer that has emerged is that, where a plant philosophy of fast repair is practiced, the need for withdrawable systems is clear both for MV switchgear and for LV motor control centers. However, in a plant where downtime is not especially critical, a fixed system is often the best and most economical option.

It is clear that there is a need for both fixed and withdrawable systems, as each system has its own merits and drawbacks. For this reason, all major switchgear manufacturers offer both types of equipment.

Within the petrochemical and chemical industries, there is a belief that withdrawable MV switchgear is easier to maintain and repair, and that this will result in reduced downtime. However, current MV breakers require much less maintenance than their predecessors and are much less likely to fail. Is it, therefore, really worth adding extra components to switchgear to make it withdrawable?

Many users of withdrawable switchgear claim that they do so for personnel safety reasons, as it provides clear visual confirmation of separation when carrying out maintenance on downstream equipment. But is a withdrawable breaker truck the best and safest way to provide visual confirmation of separation?

For maintenance activities on downstream equipment, fixed electrical switchgear provides safe isolation with a disconnecting switch that has reliable indication of status.

During the research that was conducted prior to writing this paper, an accident report on a withdrawable MCC surfaced. The accident report indicated that an arc flash was initiated by a part needed to make the breaker withdrawable. The part worked loose and, as a result, caused the arc flash. The benefits of having a fast repair time were totally negated by the arc flash that put the whole MCC out of service for days.

With reference to this arc flash incident in 2011 in withdrawable switchgear, the following questions seem appropriate:

Should there be a specific requirement in the electrical codes of the Netherlands concerning arc flash containment, periodic hazard identification and risk assessment in electrical apparatus like switchgear?

Should the industry recognize normal switching of 400 VAC switchgear as a hazard?
Every effort has been made to use consistent terminology in this paper, but it is possible that some terms may be different from those used elsewhere. To avoid possible confusion, therefore, this glossary provides brief definitions of the principal terms used in the paper.

<table>
<thead>
<tr>
<th>Term</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>Medium voltage (MV)</td>
<td>1 kV ac up to 52 kV ac</td>
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<tr>
<td>Switchgear</td>
<td>Electrical switchgear is a device that directs electricity from one source to another.</td>
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<tr>
<td>Fixed switchgear</td>
<td>Electrical switchgear with fixed mounted breakers.</td>
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<tr>
<td>Withdrawable switchgear</td>
<td>Electrical switchgear with breakers that are mounted on trucks that can be withdrawn from the switchgear.</td>
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<tr>
<td>Availability</td>
<td>The time for which a switchgear is fulfilling its function</td>
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<td>Failure frequency</td>
<td>Frequency of failures (failures/yr)</td>
</tr>
<tr>
<td>Failure rate</td>
<td>The rate of the failures (e.g. one failure every 6 months)</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Manufacturer of MV switchgear</td>
</tr>
<tr>
<td>Switchroom</td>
<td>A room specially designed to house MV switchgear</td>
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<tr>
<td>Primary main contacts</td>
<td>The connectors that provide the power connections between the fixed and withdrawable parts of the switchgear – usually sprung flexible connectors</td>
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<tr>
<td>Breaker</td>
<td>Circuit breaker</td>
</tr>
<tr>
<td>Truck</td>
<td>Structure to make the breaker maneuverable, also called a wagon</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Moving the breaker to or from the connected position, also called racking in and racking out.</td>
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