Advantages of Fixed Circuit Breaker Switchgear

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Introduction

The purpose of this paper is to review the advantages of fixed circuit breaker designs compared to withdrawable types regarding the architecture of medium voltage metal-enclosed switchgear.

Until the 1990’s the majority of metal-enclosed medium voltage circuit-breakers in the UK and Europe both on public distribution and industry networks were the withdrawable type where the circuit breaker can be physically disconnected from the busbars and circuit connections. Since the 1990’s there has been a significant increase in the use of fixed circuit breaker designs.

This paper reviews the reasons for this change and discusses the different features of the fixed type of circuit breaker.

Why were withdrawable circuit-breakers popular?

In the UK in the 1950’s and 1960’s, when the electricity distribution network was developing, the common technology for arc interruption was oil. In general the arc was interrupted by simply drawing a long arc or arcs under oil to produce what is now known as a plain break circuit-breaker. These circuit-breakers required generous clearances in the tank containing the oil and a strong tank in order to withstand the pressures which were generated by the arcing in the oil.

Consequently, plain break circuit-breakers were both large and heavy. Arcing times were long by present day standards and this meant that contact erosion when interrupting faults was significant, and the oil quickly became heavily carbonised. It was therefore necessary to maintain circuit-breakers frequently, which meant gaining access to the tank in order to change the oil and maintain the contacts. Later designs employed improved arc control devices that improved the performance, but they still required regular maintenance.

For indoor substations good design meant making the equipment as compact as possible, to minimise building costs and the best solution was to make the circuit-breaker withdrawable, either by rolling it horizontally, or by lowering it vertically. The horizontally isolated system often required a maintenance trolley to gain access to the arcing contact system whereas the vertical isolation design allowed the circuit-breaker to be withdrawn from the busbars and the arcing contacts could be easily removed from the tank.

In both cases, providing the LV auxiliary contact arrangements were compatible, it was possible to interchange circuit-breakers of the same rating. This was an important facility when only a few short-circuit clearances were possible on a circuit-breaker before maintenance.

As arc control devices developed and performance improved, the withdrawable oil circuit-breaker continued to dominate the design of switchgear for indoor use.

During the 1960’s the UK the supply network was growing rapidly. This meant that many switching operations were necessary to provide access to circuits that were being developed and led to a demand for improved operational facilities. It became necessary that applying earths to an outgoing circuit should be an easy operation, provide visible disconnection and that the earthing circuit should reliably carry the fault current, without danger to the operator, if a live circuit was accidentally earthed. The reliable and easy application of the earth was also needed for reconfiguration of the network during fault location and maintenance work.

The vertically isolated design was easy to adapt to this requirement, by providing earthing contacts within the switchgear cubicle and moving the switchgear horizontally so that one side of the circuit-breaker connected to the circuit and the other side connected to the earthing contacts. Earthing was then through the circuit-breaker which had a proven fault making ability.

The disadvantage of using this approach was an increase in the front to back dimensions of the switchgear to allow for the horizontal movement of the circuit-breaker.

Summarising with oil as the interrupting medium withdrawable circuit-breakers became popular because:-

a) They needed frequent maintenance and the withdrawable feature meant that this was reasonably easy to carry out.
b) Having withdrawable circuit-breakers meant that it was possible to provide interlocked earthing and testing facilities that were effective and easy to understand.

c) It was easy to replace a faulty circuit-breaker with a healthy one.

The last point is often mentioned in discussing this topic, but in the UK experience, it is very rarely necessary.

**Developments in MV switchgear for secondary MV/LV substations in the UK**

In Primary Substations where power is being transformed down to 11kV, the switchboards generally consist of circuit-breakers. This was also true for secondary substations in the early days of ring cable systems, but engineers soon realised that unless unit protection was being used, three withdrawable circuit-breakers were an unnecessary expense and so designs developed to the present typical arrangement where a circuit-breaker and two switches are incorporated in one enclosure that is frequently filled with SF₆.

Subsequently, non withdrawable switchgear, with all the switching devices making up a ring main unit integrated in one compartment is now the universally accepted approach in the UK and many other countries around the world for this type of substation.

**The introduction of fixed circuit-breakers**

Whilst the distribution circuit-breaker employed oil as the circuit interrupting medium, there was no incentive to move away from the well developed vertical isolation withdrawable circuit-breaker design. In the early 1960’s viable vacuum interrupters became available at 12kV in America and by 1970 one UK electricity company was encouraging British Switchgear manufacturers to develop vacuum circuit-breaker designs that made use of the vacuum interrupters which were soon being manufactured in the UK by Vacuum Interrupters Ltd. (VIL).

Three vacuum interrupters are more expensive than the active components of an oil circuit-breaker. If vacuum circuit-breakers were to be commercially viable there needed to be cost savings elsewhere in the design to balance the increased cost of the vacuum interrupters.

The vacuum interrupter is sealed for life and non-maintainable. The only maintenance possible on a vacuum circuit-breaker is lubrication and operational checks on the mechanism, insulation cleaning and in the early days, an occasional high voltage test to prove that the level of vacuum was satisfactory. Vacuum interrupters are capable of many fault interruptions without maintenance before replacement and it is very unlikely they will ever need replacing when used on a distribution network.

It was therefore quickly realised that providing care was taken in providing earthing and testing facilities, a fixed circuit-breaker design needed no maintenance and this would lead to savings; the design could be simplified because there would be no lifting carriage, no shutters and the isolating bushings could be replaced by one set of fixed bushings. There would also be the advantage of a reduced component count that would improve quality and reliability. It was important that the new fixed designs were reliable because maintenance or repair would require more extensive shutdowns.

Manufacturers soon produced fixed circuit-breaker designs at 12 kV using vacuum interrupters and a few were available in the early 1970’s. Single line diagrams showing the two arrangements used are shown in Fig. 1.

![Fig. 1: Single line diagram of early fixed pattern vacuum switchgear](image-url)
The three position disconnector is interlocked with the vacuum circuit-breaker so that it can only be operated with the circuit-breaker open.

During early discussions between manufacturer and users the disconnector started as a 2 position device, but was changed to 3 position following concerns by some users regarding the use of the new vacuum interrupter circuit breaker as a disconnector.

Using a two position device during cable testing the open vacuum interrupter would be acting as a disconnector, if the 2 position device was left in the ON position, with the AC busbar voltage on one side, and DC cable test voltage on the other. At that time the vacuum interrupter was not designed to meet the enhanced insulation performances required for a disconnector. Using a 3 position device or disconnector, it could be moved to the OFF position providing isolation from the busbar and not be connected to earth. In addition the 3 position disconnector allows circuit-breaker operation for mechanical testing without energising or de-energising the connected circuit.

These early fixed circuit-breaker designs did not have mimic diagrams, therefore it was decided to call the disconnector a “Selector” and great care was necessary in labelling its 3 positions. The description for the 3 positions was standardised and can be found in the UK Utility user specification.

The arrangements shown in Fig. 1 met the essential operating requirements of being able to safely energise, de-energise and earth the incoming and outgoing circuit and they also provided a convenient test point where connection could be made directly to the cable. This was necessary to enable system phasing to be checked and also for cable testing before commissioning and after repair. This was another area of controversy when these designs were introduced.

The vertical isolated oil circuit-breakers provided circuit access via the open shutters which covered the live conductors when the circuit-breaker was withdrawn. This withdrawal clearly identified the unit on which it was intended to work. With a fixed circuit-breaker this simple identification was no longer available, but it was possible for these designs to offer access to conductors behind carefully labelled and bolted covers.

The layout shown in Fig. 1a has an advantage in that it is easy to design equipment with the test point located at the front. The test point shown in Fig. 1b gives a more direct connection to the cable, and makes it easier to carry out primary injection testing on the current transformers.

With either of these arrangements work on the vacuum interrupters requires earthing down the remote end of the cable circuit, and putting the selector in the select circuit earth position. This was not acceptable to some potential users, so the alternative design of Fig. 2 was introduced with a second selector. This allowed easy earthing of the vacuum interrupters and busbar earthing, but created extra complication and cost in the equipment and extra difficulties providing clear operational instructions.

Fig. 2: Single line diagram of 2 selector version

Another manufacturer produced a compromise design in which the circuit-breaker could be isolated, but it was normally operated as a fixed circuit-breaker. This was a fore runner of the recent “Cassette” designs. It provided full operational facilities, but was more complicated and expensive.
These 4 designs were the standard for 11kV Primary Substation switchgear in the UK during the 1970’s up to the mid 1980’s.

A few of the UK Utilities made widespread use of these designs, but others insisted on retaining withdrawable circuit-breakers. This split in the market demand was a major influence that forced manufacturers to drop these early fixed designs and produce new ranges which included withdrawal of the circuit-breaker.

This split in Utility preference caused a decline in the availability of the early fixed designs until the late 1990’s when new lower cost designs were developed.

There were four reasons for this reluctance to adopt fixed circuit-breakers:-

1. A distrust of early designs of vacuum interrupters. This was based on the fact that there is no easy way of continuously monitoring the high levels of vacuum that are necessary in a vacuum interrupter, together with the small gaps that exist in open vacuum interrupters. In the early days there was also disbelief that the manufacturer’s life claims were accurate.

2. Dissatisfaction with the arrangements for testing and phasing out on the non withdrawable designs.

3. Concerns regarding reliable understanding of the earthing arrangement. This was due to the practice being different on this equipment to the conventional withdrawable equipment and was made worse by the lack of an active mimic diagram which would have allowed the operator to clearly understand what he was doing.

4. Reluctance by the Utilities to teach operational staff about the new designs of equipment and rewrite the operational procedures.

The Utilities that installed these early fixed designs have had good experience operating them and they have been essentially trouble free. There was a quality batch issue with some early vacuum interrupters which meant that it was necessary to make the circuit-breaking compartment dead so that the interrupters could be inspected. This was unexpected, but found to be quite practical. There were also a few design issues with interlocking and insulation that needed to be improved.

**SF₆ versus vacuum for fixed circuit-breakers**

The first designs of fixed circuit breakers used vacuum because that was the first viable available technology. SF₆ was being widely used for transmission circuit-breakers in 1973, but initially it did not appear to be a likely competitor to vacuum at 12kV. This changed in the UK when one manufacturer introduced the new rotating arc SF₆ technology. This shares with vacuum the advantages of high electrical performance and low operating energy, but has other advantages and disadvantages. These are summarised in Table 1.

There is little to choose between the two technologies for distribution applications. What matters now is how well a manufacturer has exploited the possibilities inherent in the technology, which he has chosen to use.

<table>
<thead>
<tr>
<th>Property</th>
<th>SF₆</th>
<th>Vacuum</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interrupter Assembly</td>
<td>3 Phase</td>
<td>Single Phase</td>
<td>With SF₆ (a) Insulation design is simpler (b) Combined switching devices are possible</td>
</tr>
<tr>
<td>Open Gap dimensions</td>
<td>cm</td>
<td>mm</td>
<td>A vacuum circuit breaker to meet the disconnector performance would be an advantage</td>
</tr>
<tr>
<td>Pressure Monitoring</td>
<td>Possible</td>
<td>Not Possible</td>
<td>Both need careful assembly</td>
</tr>
<tr>
<td>Operating Seal</td>
<td>Rotating</td>
<td>Bellows</td>
<td>SF₆ is a greenhouse gas which should not be released to atmosphere. Arcing by-products require careful handling</td>
</tr>
<tr>
<td>Environmental aspects</td>
<td>SF₆</td>
<td>No specific concerns</td>
<td>Both need careful assembly</td>
</tr>
<tr>
<td>Contact Life</td>
<td>Long</td>
<td>Longer</td>
<td>Replace the complete vacuum interrupter</td>
</tr>
<tr>
<td>Repairable</td>
<td>Possibly</td>
<td>No</td>
<td>Replace the complete vacuum interrupter</td>
</tr>
</tbody>
</table>

**Table 1: Comparison of SF₆ and vacuum interrupters**

There are growing concerns in the World for the global environment and SF₆ is a greenhouse gas. New European Regulations that came into force in 2009 require stricter management for the movement of gas and the end of life of the switchgear.

The UK market trend from the early 2000’s has been towards vacuum technology for Primary Substation applications because it meets the operational requirements and is available at a competitive price.
If vacuum technology is to be used on secondary distribution applications it will be necessary for it to be available at a competitive cost and provide the necessary operational features. This will be a challenge, for example, a ring main unit would require a minimum of 9 vacuum interrupters.

The New Fixed Designs

By the mid 1990’s after a gap of almost twenty years, manufacturers again produced economically attractive fixed 12kV circuit-breaker designs. It is useful to review these new designs against the experience of operating the earlier designs. The main changes from earlier designs were the requirement to provide internal arc performance and more reliable MV insulation systems.

One UK manufacturer exploited the use of SF$_6$ and rotating arc technology to produce a three position switching device in which the contact when moving from the open position to one set of contacts is a fully rated circuit-breaker and disconnector and to the other set of contacts is a fault making earthing switch. Fig. 3 illustrates the concept.

![Fig. 3: One example of fixed CB using rotating arc in SF$_6$](image)

All the requirements for a non withdrawable circuit-breaker have been implemented with a single moving blade. This avoids the complexities involved in the early designs where separate devices are used to provide isolation and circuit interruption.

Cable testing facilities were provided via an integral mechanically interlocked test access point with the fault making earthing switch. The removable link of the test access point can only be removed when the circuit has been earthed and must be replaced before it can be returned to the service position.

Any maintenance work on the switching unit or the busbars requires earthing of the complete switchboard, but this should be a very rare requirement. If a bus section is used then the busbars on either side of the bus section circuit breaker can be earthed through the bus section circuit breaker which has a 3 position disconnector on both sides of the circuit breaker.

The other operational requirement to prove phasing can be covered with this fixed design arrangement in three possible ways:–

1. The use of voltage transformers.
2. The use of capacitance driven indicators providing these are acceptable to the user.
3. The use of test devices on the cable connectors providing a moulded type termination is being used.

Another manufacturer offers a non withdrawable vacuum circuit-breaker design with the layout shown in Fig. 4. It is a close descendant of the Fig. 1a design, but with the vacuum circuit-breaker and the 3 position disconnector in one compartment filled with SF$_6$. Cable connection is by screened mouldings which allow cable testing. Removal of the cable box cover is interlocked with the earth switch.
Another manufacturer has introduced a non withdrawable vacuum circuit-breaker design with the layout shown in Fig. 5. In this design all the active components are placed inside one SF₆ filled compartment, but it only uses a two position selector. It incorporates the latest protection techniques and transducers the mimic is part of the “cubicle control and protection unit”.

As described earlier, the two position selector raises operational questions with regard to cable testing, and circuit-breaker testing. In this arrangement the vacuum interrupter needs to provide a disconnector performance.

There is no defined test point to allow the application of a test voltage to the cables. The cables are intended to be unplugged for testing and care must be applied to safely re-connecting them.

One manufacturer uses an innovative idea where the circuit breaker sub assembly rotates to provide an isolating distance in air. An interlocked earth switch and cable access cover provide facilities for applying the cable test to the cable terminations. This is illustrated in Fig. 6.
Another example of a manufacturer where the vacuum interrupters and the 3 position disconnector are included inside an SF6 chamber to reduce the size and cost of the cubicle is illustrated in Fig. 7.

Since the late 1990’s the trend has been for manufacturers to offer vacuum technology with a 3 position disconnection function that may also include SF6 used only for insulation. Cable testing may either be applied to the cable terminations or through an interlocked cable test facility.

One manufacturer offers a non withdrawable vacuum circuit-breaker design with the layout shown in Fig. 8. This design is similar to that in Fig. 4 except the vacuum circuit breaker is air insulated and the 3 position disconnector is contained inside a sealed cast resin earth screened enclosure. Cable testing is by a mechanically interlocked cable test access cover.

An example of this design of product is shown in Fig. 9.
Fixed switchgear designs, most using vacuum technology are being installed by all the Utilities in the UK for primary applications on the 11kV and 33kV networks. The quantity of Fixed Circuit Breakers installed since 2000 by one of the leading Utilities in the UK is shown on Fig. 10.

Fixed SF₆ designs e.g. ring main units and single function circuit breakers and load break switches, have been successfully used for more than 20 years in the 11kV secondary distribution network.
The UK market trend from the early 2000’s has been towards vacuum technology for Primary substation applications because it meets the operational requirements and is available at a competitive price. If vacuum technology is to be used on secondary distribution applications it will be necessary for it to be available at a competitive cost and provide the necessary operational features. This will be a challenge, for example, a ring main unit would require a minimum of 9 vacuum interrupters.

**Switchgear Reliability**

It is very difficult to obtain meaningful statistics for switchgear reliability, because most switchgear is in fact very reliable and this means that very large populations of switchgear are required to obtain statistically meaningful results.

In the UK a consistent system of fault reporting has existed for many years. Whenever a customer loses supply due to a fault on the medium or high voltage system a fault report is completed, which explains how many customers were affected and what the failure was on the system that led to the loss of supply.

The reporting system gives total fault frequency figures and typically in faults reported per 1000 devices installed per year these are:-

a) Circuit-breakers with auto-reclosing 10
b) Other ground mounted circuit breakers and ring main units 2

Analysing the statistics a different way, of all faults involving customers losing supply only 3% to 4% involve problems with switchgear.

These figures include cable box failures and it is widely accepted that the majority of faults occur on the cable termination system which indicates that switchgear is very reliable.

The circuit breaker isolating contacts are one of the most common locations for faults on withdrawable equipment which is not present on fixed equipment. From a safety point of view carrying out cable tests via an interlocked test access is inherently safer than inserting loose devices through shutters and phasing out can be easily carried out using a VPIS or VDS device.

These statistics demonstrate that due to the low number of normal operations and the very low number of faults per device there is a worthwhile increase in reliability changing to fixed design switchgear. Following 30 years of experience with vacuum interrupters it is generally not considered necessary to carry out routine checks on the integrity of the vacuum interrupters.

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Conclusions

It is not necessary for circuit breakers to be withdrawable when the circuit-breakers use modern technology, either SF$_6$ or vacuum, which requires little or no maintenance to the main or arcing contact system and such designs have demonstrated they can provide satisfactory service and an economic advantages.

Modern fixed designs will offer reliable service providing the life of the switching devices meets the service application and the manufacturer has considered the important operational requirements which are:-

a) Safe working procedures for cable jointing  
b) Cable fault location and testing procedures  
c) System phasing out procedures  
d) Protection testing procedures  
e) Working procedures for switchboard extension  
f) In the case of SF$_6$ based equipment a policy on handling SF$_6$

Many of the UK Utilities have followed a programme of staff education on the philosophy and operation of the new fixed equipment. This has smoothed the changeover and avoided switching errors. Whether or not this is still necessary for a Utility introducing fixed switchgear in 2009 would depend on the range of existing switchgear designs being operated on their system.

References