Advent of fixed type Disconnecting Circuit Breakers in Medium Voltage secondary switchgear: a new arrangement of main circuit functions

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Abstract
The purpose of this paper is to challenge some well-known arrangements of devices like racking trucks, disconnectors, circuit breakers and earthing switches. A new single line diagram will be proposed, more in accordance with needs and expectations of users and future trends in breaking and disconnection techniques. It will be taken in account elements as necessity to implement alternative solutions to SF6 gas, generalization of fixed type switchgear for Medium Voltage secondary applications, usage of disconnecting load-break switches or disconnecting circuit-breakers, and the never-ending quest of improving users safety and network efficiency.

Keywords:
Disconnection, circuit-breakers, load-break switches, SF6, single line diagram, earthing, cable test
The past decades have seen the trend of fixed devices replacing slowly but surely the drawout ones. Techniques like Gas Insulation in sealed-for-life tanks or vacuum interrupters no longer require heavy inspection or maintenance routines to ensure their ability to achieve their service life expectancy. That’s why the necessity of specifying drawout circuit breakers is disappearing while the benefits of fixed devices are more and more recognized and appreciated due to smaller dimensions, cost effectiveness, better reliability because of less components involved, maintenance-free and harsh environment withstand due to no more sliding contacts in free air etc…

One effect of the replacement of drawout devices by fixed ones is that the disconnection can no longer be naturally provided by racking out the device, and consequently fixed dedicated disconnectors have to be installed in the primary circuit in order to isolate a part of the network prior to earthing it for maintenance purposes such as inspection, testing or cable injection. The pros and cons regarding arrangements between the disconnector, the breaking device and the earthing device is still a passionate subject of discussions between manufacturers, end users and specifiers.

The next step of integration in order to save space and increase safety and reliability is to embed together in a single device disconnection and breaking properties. This has been achieved for years within load-break switches of Medium Voltage secondary switchgear such as SF6 modular equipment or compact Ring Main Units and is also appearing in the new generation of circuit breakers called Disconnecting Circuit Breakers, thanks to the unique properties of SF6 gas providing excellent behaviour for both breaking and insulation. With one single contact, providing disconnection and breaking means one single operation. The benefits for end users is maximum simplicity, no further need for interlocking between different operations, so maximum safety is also achieved. Other benefits for network operators are the ability for normally-open loops to be remotely opened and isolated in one single operation. A single contact provides less power-loss also, offering energy savings and greater environmental friendliness.

The core purpose of this paper is to evaluate how the advent of Disconnecting Circuit Breakers could show new possibilities of arrangements between earthing, disconnecting and circuit breaker functions. Various single-line diagrams will be analysed, the pros and cons will be evaluated according to needs and constraints during some critical phases of the life cycle of MV switchgear like operation, maintenance and cable high voltage testing in order to satisfy the needs of users in terms of safety, reliability and ergonomics in a simpler way than traditional solutions.

Assessment of various arrangements
1.1 “Drawout air insulated switchgear” typical arrangement:
This reference in terms of single line diagram is the oldest, but is still widely used in primary switchgears using drawout circuit-breaker:

![Figure 1](image.png)

In such a case, disconnection is made by racking out the movable part of the drawout circuit breaker, thereby providing clear and obvious visibility of the disconnection.
Therefore, disconnection can be made only locally, as remote operation is only possible on the circuit breaker mechanism and not on the mechanism of the racking cradle. In the same way, earthing the cables for safe intervention in any case requires a separate device either an earthing truck which needs to be racked or a fixed downstream earthing switch. We note that the earthing truck is often heavy and can be difficult to handle. Using a downstream fixed earthing switch is easier, but raises a point concerning user safety: The interlocking between the earthing switch and the draw-out position of the circuit breaker may be difficult to achieve in a positive way on some devices. Regarding high voltage testing of the cables, the test equipment is generally connected directly to the cable end, as this type of switchgear often uses bare conductors in free air for the cable connections.

1.2 “Fixed Gas Insulated Switchgear” typical arrangement:
As mentioned in the introduction, drawout switchgear may not be necessary anymore, as compulsory inspection or maintenance is drastically reduced. Thanks to vacuum or SF6 switching techniques maturity and the associated mastery of the industrial processes, electrical performances and quality level are reaching extremely high values, bringing the MTTF level of modern CBs to tens of thousands of years, far greater than the user expectations for normal applications in MV distribution as tertiary or in non the electro-intensive industry. Fixed type switchgears also provides protection to the live parts in a sealed-for-life tank which is connected to the cable with screened and insulated connections, making the entire primary circuit totally protected against harsh environment such as dust, condensation, pollution etc., thereby drastically increasing its reliability and life expectancy.

Fixed type switchgear allows the disconnection to be carried out in a separate device, according to the typical single-line diagram shown below.

![Figure 2](image)

The MV circuit breaker is combined with a separated upstream 3 positions disconnector, providing four different operating positions – (1) closed on line, (2) open, (3) disconnected, and (4) cables earthed - achieved by only two separate devices. Cable earthing is made by reclosing the main CB once the upstream device is in the earth position. In terms of user friendliness, we have to point out that operators have to interpret a combination of 6 positions – 2 for the CB and 3 for the upstream disconnector – resulting in the operation being not so intuitive. We note in the same way that the operational safety interlocks have to be achieved by external devices, and in opposite ways. The main CB must be locked in the open position prior to opening the disconnector, but it must be allowed to close again for earthing the cables when the upstream device is in the earth position. Positive earth position indication can be achieved either through transparent windows or positively driven indication on the upstream device, but it must be associated anyway with the position of the CB, which needs be closed to provide the earth. As the cables are earthed through the closed CB, the safety of personnel working on the cables is entirely dependant on the CB staying closed in all circumstances. That is why some specifications require that the tripping circuit or protection should be disabled when the disconnector is in the earth position.
Testing the cables is generally carried out by voltage injection directly through the cable connections. Testing the circuit breaker with primary current injection can be done with the upstream device in the disconnected position and the cable connection removed.

1.3 “Fixed Gas Insulated Switchgear” “reverse” arrangement:
The following single line diagram described below is similar to the previous one, but with the 3 positions disconnecting device placed on cable side, allowing the earthing of the cables to be done directly regardless the position of the CB. The downstream earthing switch must have the full making capacity as the CB is not used for this purpose. But the safety of people working on the earthed cable is no longer dependant on the position of the upstream device. The interlocks are simplified and the position of earthing switch is sufficient to indicate the safe earthed position.

![Figure 3](image)

The above single line diagram also illustrates a specific device dedicated to cable testing, by opening the earth circuit via a removable link and applying the test voltage to the cables without accessing the cable ends or opening the earthing switch. Such a device is appreciated because it keeps the cable testing as a very specific operation with a dedicated procedure. This is particularly useful when cable connections are made with fully insulated terminations. Temporary dismantling of cable terminations can be tricky if the installation is old or if the working conditions are poor.

1.4 “Upstream two positions selector” arrangement
This type of arrangement, used in recently introduced switchgear, is a variation and a simplification of the one described earlier in paragraph 1.2. It is still an association of two separate devices, an upstream two position selector and a downstream circuit breaker. The CB is used to break load and fault currents when the selector is in the ‘line’ position and to earth the cables when the selector is in the ‘earth’ position.

![Figure 4](image)

This diagram is simpler, as the total number of operational combinations is reduced to four, two for the selector plus two for the CB. But the major drawback is still not resolved.
The main device, here the circuit breaker, has to be reclosed to earth the cables. The operation and the interpretation of four different positions on the front facia mimic diagram may not be so intuitive. Therefore the compulsory interlocks are still to be achieved in two opposite ways. First ensuring the CB is open prior to disconnection via the upstream selector, and ensuring the CB remains in the closed position and is unable to trip during the cable earthing phase, in order to ensure total safety of users working on the earthed cable. Furthermore, the positive earthing position indication is dependant on the status of two different devices: the upstream selector – line open and earth on - and the main CB – closed.

1.5 “All in one Ring Main Unit” arrangement:
One of the major properties of SF6 gas is its ability to provide insulation, disconnection and breaking performances within a single sealed-for-life tank. This advantage has led to another famous single-line diagram being used for decades in SF6 Ring Main Units, which is so much appreciated because it is so simple:

Figure 5

Main technical point of interest is that breaking and disconnection are made together in a single operation. Disconnecting Load Break Switches and Disconnecting Circuit Breakers were introduced, using only one single device providing both properties and were type tested in accordance with both relevant standards for breaking and disconnection. Key benefit for end-users is the friendliness and the simplicity of operation for both local and remote operation as breaking and disconnection can be achieved in a single manoeuvre. The total number of positions of the system is reduced to only three: closed, open-disconnected and earthed. Additionally, the operation and the interpretation of the switchgear status through the front face mimic diagram are very easy and intuitive. Safety interlocking between the three positions is inherent to the principle itself as there is only one contact moving from one position to the other and its position is undoubtedly defined.
Remote operation of the main switch or circuit-breaker for remote switching and disconnection is carried out in a single operation.
And lastly, the cables are directly earthed in a single operation, which may include a dedicated cable testing device, providing the entire system the well-known reliability resulting from using the simplest of solutions.

New arrangement proposal:
The never-ending search for innovative solutions may challenge the previous arrangement. Future possible alternative solutions without SF6 gas may not be able to present the same perfect multiple property of breaking, disconnecting and earthing in the same single device. As most natural prospective solutions to replace SF6 gas usage are vacuum or air technologies, or a mix between both of them, the question of mixing disconnection, breaking and earthing devices will rise again. Furthermore, the key question could be how to achieve the best compromise between friendliness of operation, reliability and safety of people when using new technologies?
This is the main reason of the following proposal:
This arrangement is aimed at providing the best combination between the different devices, (a) upstream Disconnecting Circuit-Breaker or (b) Disconnecting Load Break Switch, combined with a downstream Earthing “change-over” Switch. Furthermore, the downstream earthing switch has been placed in series with the main device, in order to provide double gap isolation between the busbars and the cables. This redundancy of isolation provides additional safety in case of failure of any one of the two involved devices in order to provide maximum safety for end users working on earthed cables.

Regarding network management and switchgear operation, this proposed single line diagram presents the same well-known benefits as shown in the “all in one Ring Main Unit arrangement” in paragraph 1.5. Breaking and disconnection are made in one single and simple operation. Remote disconnection can be achieved by just opening the load-break switch or the circuit-breaker through remote control. And the system provides only three different operating positions: closed, open/disconnected and earthed (as shown in the next illustration). The front face mimic diagram is one of the simplest possible, making the interpretation by the end-user extremely intuitive.

In the same way, safety interlocks between the two devices can be easily achieved in a positively driven way and are therefore safer.

“Cable earthed” situation can be checked easily and confirmed by looking at the contacts or at the positively driven indicator, because it only depends on the position of the earthing switch and no longer on the combination of two different devices. Thereby earthing is made directly on the cables side without any other device in series between earth and cable.

High voltage cable testing can be achieved by accessing the cable terminals in a traditional way as shown earlier, but will be far safer and more efficient when using the dedicated device designed for the earth conductor as shown in (c).
By the way, the main earthing switch will remain in the earthed position. Connecting the cable test equipment can be done easily and safely by dedicated earthed rods without entering the cable box or interfering with the cable terminations. Removing the earth link can be carried out as the last operation before carrying out the cable test by opening a dedicated and fully interlocked earth switch.

Aiming to find the best combination between disconnectors, circuit breakers, load break switches and earthing devices in order to achieve the safest and the most advanced solution in terms of compactness and efficiency is a never-ending quest. Starting from the air-insulated traditional solutions employing drawout switchgear, then using fixed devices in a simpler arrangement, this quest looked to find a state-of-the-art outcome using SF6 gas in the “three in one” Ring Main Unit. The necessity of imagining new technologies to challenge the use of SF6 may lead to challenge as well the single line diagram arrangements of secondary switchgears, trying to find the most efficient use of vacuum and air breaking technologies. As people safety is the value which should never be compromised, we tried to propose one of the simplest solutions achievable, plainly because the simplest solutions always provide the safest solutions.

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