# NEW GENERATION OF CIRCUIT-BREAKER SWITCHGEAR

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## ABSTRACT

*In every electrical network, the protection of assets is an important issue. These assets could be protected by fused-protection or circuit-breaker switchgears, depending on protection criteria or user's practises. When circuit-breaker switchgear is the chosen protection, several technologies are available, and they have to fulfil the main requirements such as dielectric tests, making and breaking short-circuit currents and others depending on application, such as capacitive currents and short-circuit making in earthing position. In addition, today there are new requirements with growing importance including full functionality in extreme conditions, such as low temperature or high corrosion environments, or smart grid readiness.*
*Which is the right technology for these protections and purposes? Are all these technologies prepared for these new requirements?*
*A 3-position circuit breaker in vacuum technology with isolating distance in $SF_6$ medium is available with the advantages of modern circuit-breaker technologies, answering actual requirements.*

## STATE OF THE ART OF CIRCUIT BREAKERS

There are many solutions of circuit-breaker switchgears in the present distribution network scene, but all can be placed into 2 big groups according to breaking technology used; vacuum circuit-breakers and $SF_6$ circuit-breakers, each with their advantages and disadvantages.

### Vacuum Technology

The latest circuit-breaker developments are based on vacuum technology due to its great possibilities, reaching levels of 145kV and 40kA of rated voltage and short-circuit current respectively in only one vacuum circuit breaker, as well as features such as:

- Low arc voltage and fast recovery voltage
- Short arc duration
- Ability to break high frequency currents and in stationary state
- Contacts have neither oxidation nor deterioration
- No decomposition products due to breaking in vacuum chamber

All these characteristics allow this technology to have these **main advantages**:

- **High Electrical Endurance**, as in number of short-circuit current breaking (up to E2 with fast reclosing –maximum category of electrical endurance according to IEC 62271-100), as in power breaking, being able to break, in secondary distribution, up to 40.5 kV and 25kA of rated voltage and short-circuit current.
- **High Mechanical Endurance**, achieving up to 10.000 operations (M2) that is the maximum category of mechanical endurance according to IEC 62271-100.

On the other hand, this technology has points to be improved and can be achieved, or at least minimized, with arc control, new contact materials or with the use of other devices. These **points to be improved** include:

- <u>Chop current</u>: When vacuum circuit-breakers have to break very low currents (less than 20 A or less than 5 A with advanced designs), the current does not wait for zero crossing to break, so the peak of the transient recovery voltage is higher, with its associated risk of reignition.
- <u>NSDDs, restrikes and voltage escalation in capacitive switching</u>: These effects could appear in capacitive breaking, some milliseconds after current breaking. If a restrike occurs, the current will re-establish and the capacitive polarity of the circuit will change, so the voltage in load side will escalate from 1pu o 2.5pu. The open gap will be more stressed, so the risk of occurrence of another restrike would be higher, with escalation from 2.5pu to 4pu. This effect could be repeated several times.
- <u>Voltage escalation by multiple reignitions in inductive switching</u>: This effect could appear in inductive breaking such as no load transformer, where the current to be broken is very low, very inductive and high frequency, so the circuit-breaker tries to break very soon, with minimum gap, so it is possible to have multiple reignitions with voltage escalation.
- <u>Necessity to have a disconnector in series with the circuit-breaker</u>: A vacuum circuit-breaker has neither isolating distance in open position nor insulation coordination by itself, linked to highly random dielectric behaviour compared with a gas-insulated disconnector. This means:
  - Necessity to have an operations sequence or interlocks to allow the circuit-breaker, disconnector and earthing switch operations in the right order, because usually, only the circuit-breaker has the short-circuit making and breaking duty.
  - Some circuit-breakers have the short-circuit making duties in service and earthing, so these cumulative short-circuit makings could severely erode the breaking contacts.

- Some switchgears have the short-circuit making duties in the disconnector and the earthing switch (to avoid the cumulative effect). This implies different operations sequences depending on equipment functionalities and manufacturers.

▪ Tendency to weld contacts in short-circuit makings: They have low probability to withstand several short-circuit makings of 200ms. This effect can be minimized with extra closing force, strengthening driving mechanisms and increasing maintenance to extend life expectancy. In any case, nowadays, short-circuit makings in circuit-breakers are tested according to IEC 62271-100, with immediate (e.g. 80ms) breaking.

▪ Capacitor bank switching: These circuits have a very high peak inrush current that can damage the vacuum circuit-breaker. Sometimes, this could be solved by adding a resistance to the installation to reduce this peak, or transferring the making duty to the disconnector placed in series, leaving the breaking duty in the circuit-breaker.

## $SF_6$ technology

There are also well-known technologies in the market, where the making and breaking of short-circuit currents are done in $SF_6$ medium. There are different technologies such as rotating arc, self-blast, blowing or combination of some of these technologies. The **advantages** of this technology are as follows:

▪ **Chop current, NSDD´s, restrikes and voltage escalation in capacitive and inductive switching**, mentioned in vacuum technology, are **less probable** due to break in $SF_6$ gas.

▪ **3-position circuit-breakers**: The isolating distance is reached in the same operation of breaking. As there is no disconnector to support, the operation sequence is unequivocal, and interlocks between circuit-breaker and disconnector are not necessary because they are the same device.

▪ **Better behaviour in short-circuit makings**: This technology has better ability in short-circuit makings, even 200ms duration, in service and earthing position. It also has the ability to make the peak inrush current peak of capacitor bank circuits.

This technology has some **disadvantages** to take into account:

▪ Limited breaking ability: Some circuit-breakers, used in Gas Insulated Switchgears, have limitations in broken power, in secondary distribution. In terms of rated voltage, the present limit of some technologies, such as rotating arc, is 24kV, and in terms of rated short-circuit current breaking, the current limit is 16kA or 20kA depending on rated voltage and technology.

▪ Low Electrical Endurance: Some of these technologies are used, usually for applications without fast-reclosing and without necessity of extended electrical endurance.

▪ Behaviour with low currents: Some of these technologies (such as rotating arc and self-blast) depends on current magnitude to cool the arc energy. In low current breakings, the cooling energy could be low or insufficient. In any case, these situations are checked in test duty T10 (Breaking of 10% short-circuit current) according to IEC 62271-100.

▪ Decomposition products: As breaking is done in the same medium responsible for both insulation and short-circuit breaking, this may imply high decomposition by-products, and as such the insulation could be degraded.

| ATTRIBUTES | TECHNOLOGY | |
|---|---|---|
| | Vacuum | SF6 |
| Decomposition Products in short-circuit breaking | NO | YES |
| High Electrical Endurance | YES | NO (for some designs) |
| Limitation of broken power in secondary distribution | NO | YES (for some designs) |
| Risk of effects as chop current, NSDDs … | Very low | Almost absent |
| Necessity of disconnector additional | YES | NO |
| Interlockings and diverse operation sequence | YES | NO |
| Behaviour in short-circuit makings | Good | Excellent |

Table 1 - Attributes summary by technology

## NEW GENERATION OF CIRCUIT-BREAKER SWITCHGEAR

ORMAZABAL has developed a 3-position circuit -breaker switchgear with breaking in vacuum technology and with isolating distance in $SF_6$ medium, so it has, as attributes, the advantages of both technologies.

This is achieved by the combination of vacuum circuit breaker and a 3 position load-break switch-disconnector (with built-in earthing switch) in $SF_6$ medium. Both devices are operated and mechanically synchronized by a single driving-mechanism as described:

▪ **Opening Operation**: First, the circuit–breaker will open, and a few milliseconds after the circuit breaker has completely opened, the load-break switch disconnector will start to open.

▪ **Closing Operation**: First, the circuit-breaker will close (in no-load condition) and then, the load-break switch will close establishing the current.

▪ **Earthing Operation**: The built-in earthing switch is placed downstream of the circuit-breaker, so the circuit-breaker has no duty in earthing operations.

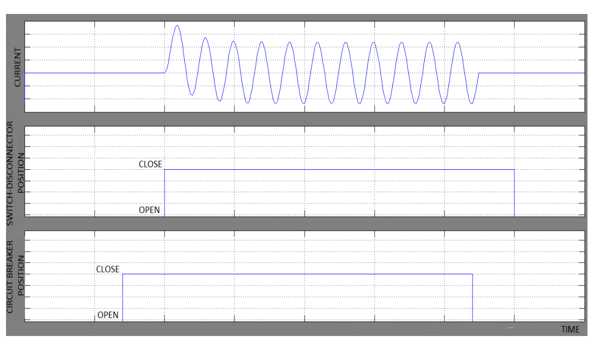


Figure 1 - Graphic of current, switch-disconnector position and circuit-breaker position

Due to this combination of both devices and operated by a single driving-mechanism, this switchgear has the following **advantages**:

▪ As the vacuum circuit-breaker only breaks the current and has no duty in making (in both service and earthing position), the **life expectancy** of circuit-breaker contacts is **longer**.
▪ As breaking is done in a vacuum chamber, there are **no decomposition products** due to breaking in $SF_6$ insulation medium.
▪ As the load-break switch has the making duty, the switchgear is able to **fulfill the short-circuit makings test, even 200ms duration in earthing position**, according to IEC 62271-200, and inrush current peak makings of capacitor bank circuits, because the vacuum circuit-breaker has only to withstand the current but not the arc.
▪ As the load-break switch disconnector opens a few milliseconds after the circuit-breaker, the **vacuum circuit-breaker** can be **optimized**, because the **open gap in $SF_6$** of the disconnector is withstanding dielectric requirements in open position.
▪ All effects such as **chop current, reignitions, NSDD´s, restrikes and voltage escalation** are solved, or at least **minimized**, because the only risk of these effects is during the few milliseconds between circuit-breaker opening and load-break switch-disconnector opening.
▪ On rare occasions, if these effects occur in these few milliseconds, the **load-break switch** will be able to **clear these effects**, because it has breaking ability for these low currents.

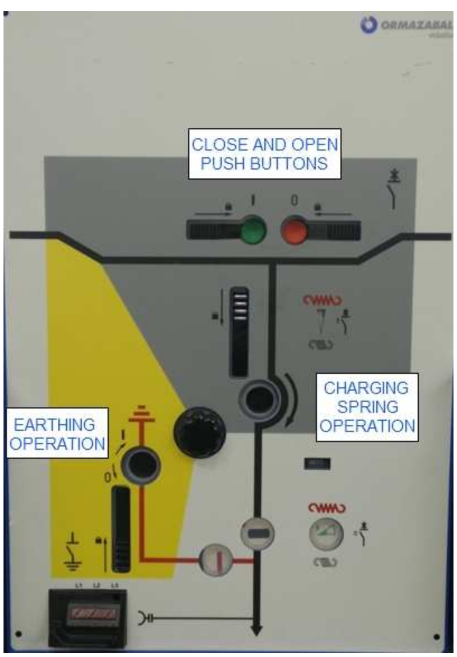


Figure 2 – Mimic diagram showing operation interface

▪ As both breakers are operated in a synchronized manner by only **one driving mechanism**, when users push the open button, the circuit-breaker switchgear will break the current and reach isolation distance in only one operation. Also, when users push the closing button, both circuit-breaker and load-break switch-disconnector will close in the same operation.
▪ The user will only see a charging operation point, a close push button, an open push button and a point to operate the earthing switch, so there is **an inherent interlocking between disconnector and circuit-breaker**, and the **operation sequence is unequivocal**.

In spite of other proposals implementing a load-break switch instead of a disconnector in a circuit-breaker switchgear, which would solve the effects described, it was necessary to measure and know in real-time the voltage and current to decide which breaker has the breaking duty.
With this ORMAZABAL proposal, a new circuit-breaker switchgear is available to break all kind of currents in different situations, because both breakers are synchronized and they are transparent to the user. Users only see a reliable 3-position circuit-breaker switchgear with advantages described in next table.

| ATTRIBUTES | TECHNOLOGY | | |
|---|---|---|---|
| | Vacuum | SF6 | ORMAZABAL Solution |
| Decomposition Products in short-circuit breaking | NO | YES | NO |
| High Electrical Endurance | YES | NO (for some designs) | YES |
| Limitation of broken power in secondary distribution | NO | YES (for some designs) | NO |
| Risk of effects as chop current, NSDDs … | Very low | Almost absent | Almost absent |
| Necessity of disconnector additional | YES | NO | NO |
| Interlockings and diverse operation sequence | YES | NO | NO |
| Behaviour in short-circuit makings | Good | Excellent | Excellent |

Table 2 - Attributes summary by technology with Ormazabal solution

## OTHER ATTRIBUTES FOR A NEW GENERATION OF CIRCUIT-BREAKER SWITCHGEARS

With all the main advantages of this new generation of circuit-breakers analysed from a medium voltage circuit point of view, it is necessary to highlight other attributes with added value greatly demanded in current times, and include:

▪ Possibility to **interchange the complete driving-mechanism** on-site and in service, removing and fixing only 4 screws.
▪ **Water-proof** option: The driving-mechanism, so the metal-enclosed circuit-breaker switchgear, can operate properly in unusual flooding condition.
▪ **Low Temperature** ambient conditions: The driving-mechanism and complete circuit-breaker switchgear, **can operate** properly in low temperature conditions, **down to -40ºC**, without necessity of heating resistance added.
▪ These attributes are achieved due to special own tight-housing driving mechanism design to avoid maintenance

work on-site and also to have a **very good behaviour in high corrosion environments**.

- **Possibility to motorize** the single driving mechanism of the combined function **circuit-breaker and disconnector**.

## TESTING OF THE NEW GENERATION OF CIRCUIT-BREAKER SWITCHGEARS

Validation of these attributes of new generation circuit-breaker switchgear has been achieved through testing procedures based on different standards. The main tests are described below.

### Making and Breaking of short-circuit current, Capacitive current and Mechanical Endurance of circuit-breaker

These tests have been performed according to IEC 62271-100 to cover a wide range of terminal faults, as symmetrical and asymmetrical conditions of 100% short-circuit current (T100s and T100a), as other short-circuit conditions tested by mandatory test duties T10, T30, T60, single-phase and double earth fault tests.
Also, cable-charging current tests according to circuit-breaker class C2 have been performed successfully. Other capacitive current tests could be done, according to different requirements, as line-charging current tests.
Additionally, the mechanical endurance has been tested for 2000 (M1) according to IEC 62271-100.

### Dielectric, temperature rise, short-time withstand current and mechanical operation tests of interlocks

These tests have been performed according to IEC 62271-200, IEC 62271-100 and IEC 62271-102 to check dielectric behaviour in closed, open and isolating distance position, temperature rise with normal current, short-time withstand current in closed and earthing position and mechanical operation tests of interlocks.

### Short-circuit makings in earthing position

These tests have been performed according to IEC 62271-102 and IEC 62271-200, being able to make the short-circuit current 5 times, withstanding 200ms short-circuit current each time, and opening the earthing switch in no-load conditions after each making.

### High corrosion and Low Temperature conditions

These tests have been performed in enclosures and driving mechanisms to check the full functionality of switchgear in these extreme conditions.
In case of high corrosion conditions, driving mechanisms are tested to salt fog conditions and to other atmospheric pollutants (depending on application) and the functionality of the mechanism has been checked during and after testing.
The same procedure is followed in the case of low temperature conditions according to IEC 62271-100 and IEC 62271-102.

## CONCLUSIONS

A 3-position circuit breaker in vacuum technology with isolating distance in $SF_6$ medium is available with the advantages of a 3-position switch such as simple and unequivocal operation sequence, making traditional interlocks between circuit-breaker and disconnector unnecessary, because there is one unique device from the point of view of operator.

The advantages of vacuum technology in breaking allow a Higher Electrical Endurance and Longer Life Expectancy. These features are also possible due to separation of duties; circuit-breaker has the breaking duty and synchronized load-break switch has the making duty. In this way, the contacts will be in better conditions and mechanical energy will be reduced due to transfer of the making duty to the synchronized load-break switch.

The synchronization of both devices operated by a single driving mechanism allows improvement of the breaking quality whilst making available a very compact, simple to operate and user-friendly circuit breaker switchgear.

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