SYNCHRONOUS MEDIUM VOLTAGE CIRCUIT BREAKERS: ABB SOLUTION BASED ON MAGNETIC DRIVE AND ELECTRONIC CONTROL

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ABSTRACT

The present paper describes the principles and the customer-value of synchronous medium-voltage circuit-breakers, available with SF6 and vacuum interrupters. These circuit-breakers have three individually driven poles enabling complex synchronous switching strategies that can be adapted to various loads and network configurations. The use of magnetic actuators for the drives takes advantage of the mechanical simplicity and the opportunity of controlling the motion by changing the current in the coils during the operation. This leads to a very high reliability. Considerable cost reduction in the network can be achieved thanks to the reduction of switching transients.

Acronyms

CB: Circuit Breaker
CE: Control Electronic
SCB: Synchronous CB
MA: Magnetic Actuator

INTRODUCTION

Since 1997, ABB has introduced in the market a new series of medium voltage CBs having a magnetic drive instead of a spring based mechanism [1]. This solution immediately proved much more reliable than the spring based one. Following this successful development, ABB is now developing a new controlled switching technology which will enable the user to carry out closing and opening operations synchronised with the power network.

Synchronous or “point on the wave” switching is a well-known concept [2]. In particular, it has been used in HV applications to avoid or reduce switching transients and associated disturbances on the power network.

Compared with conventional switching equipment, the SCB will:

- reduce transient stresses on network components
- improve the network power quality.
- enhance the electrical life & performance of the CB
- enable to simplify the design of the network and to reduce the costs of the overall system.

ELECTROMECHANICAL SYSTEM

To obtain a SCB with a spring based mechanism, the manufacturer has to rely on the predictable behaviour of the opening/closing operation. This requires a mechanism with a high excess energy, having low dependence on wear and friction. It is critical to keep the environmental influences under control. This demands extensive laboratory tests, leading finally to algorithms which have to be implemented in an electronic control.

This alone does not assure a reliable behaviour, because the motion of the spring based mechanism cannot be influenced after being released. The magnetic actuator, however, provides the opportunity to implement the adaptive algorithm into a closed-loop control. This enables the control of the motion to compensate for disturbing influences coming from temperature, ageing, etc., which guarantees the long term stability of the operation time.

Medium voltage CBs nowadays consist usually of three poles, that are mechanically connected, and one drive. The drive can be of mechanical spring type or an electromagnetic actuator. For a really controlled switching, that is not limited to certain applications, an individual drive for each pole is required. With a magnetic actuator, this is much easier to achieve than with a mechanical drive.

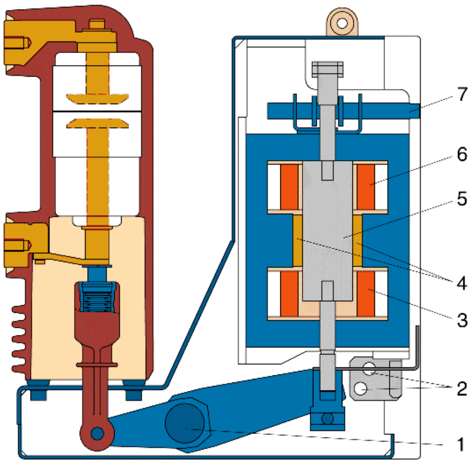


Figure 1: Section of the operating mechanism and pole part of the vacuum circuit-breaker

1	Lever shaft	5	Plunger
2	Proximity sensors	6	Opening coil
3	Closing coil	7	Emergency manual opening
4	Permanent magnets		

Furthermore, the repeatability of a magnetic drive is much better due to the lower number of mechanical parts being involved.

Figure 1 shows the simple mechanical structure of the vacuum CB: the pole is connected with the actuator via a lever shaft. The SF6 CB (figure 2) has a similar mechanical structure: the actuator turns a shaft that leads into the SF6 compartment of the pole. Inside the pole, this rotational movement is transformed into a linear movement and drives the moving contact. These principles are proven for non-synchronised breakers , where one actuator drives all three poles in parallel.

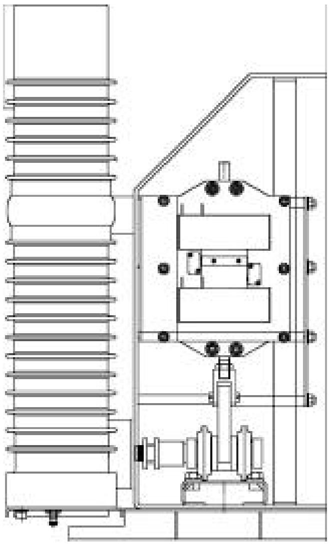


Figure 2: Section of the operating mechanism of the SF6 CB

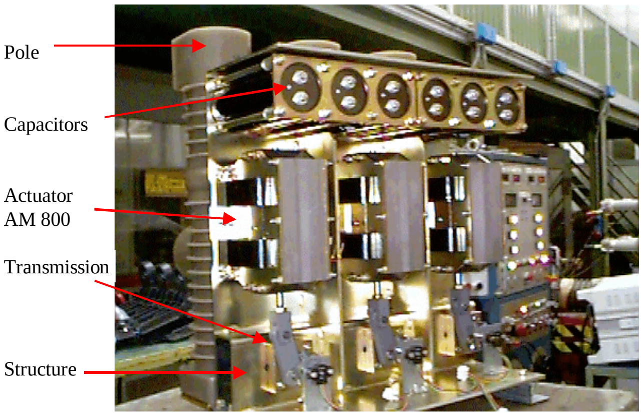


Figure 3: Arrangement of actuators and poles of the SF6 SCB

The arrangement of individually driven poles is shown in figure 3 for the SF6 CB and in figure 4 for the vacuum CB. In comparison to a mechanical drive, this can be done with magnetic actuators in a rather simple way, leading to a compact design. The SF6 CB is based on H Brea King poles manufactured by ABB SACE TMS, while the vacuum CB is based on VM1 poles, where the vacuum interrupters are cast in epoxy-resin, manufactured by ABB Calor Emag Mittelspannung GmbH.

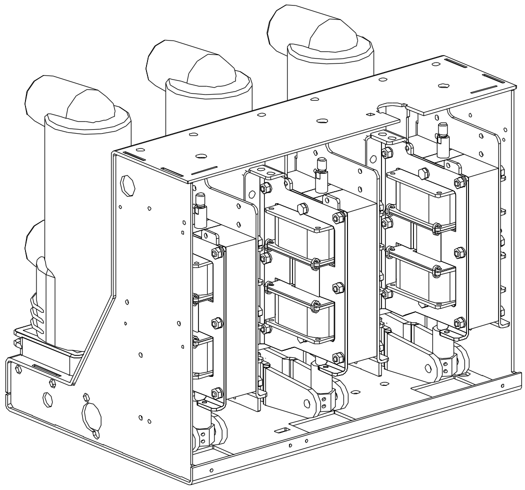


Figure 4: Arrangement of actuators and poles of the vacuum SCB

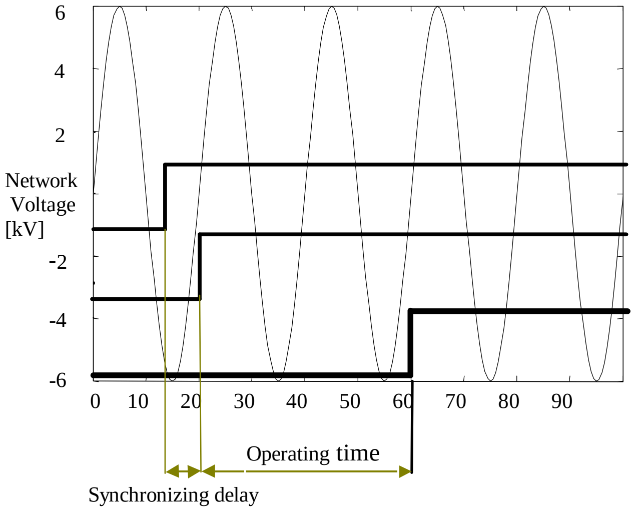
Network synchronism

A SCB is a CB that is able to carry out operations that are synchronous with the network signals, voltage or current, disregarding when the starting signal is given, either manually or by a remote control.

Figure 5: Example of synchronous operation

Figure 5 shows how a SCB should behave during a closing operation:

- The solid line indicates the asynchronous closing signal given to the CB by the user or the control-protection systems.
- The dashed line shows the closing signal given by the CE to the actuator, synchronised with the voltage signal or current signal.
- The dotted line shows the closing instant at zero voltage of the SCB.



The CE has the task to keep the operation time as much as possible constant. To do this it must have both an auto adaptation mechanism and a real time close loop control.

In this way it is able to keep the specified tolerances, even at different environmental temperature, capacitor charge and all the other relevant parameters. The CE is able to compensate automatically for the contact wear so as to always keep the right closing or opening instant.

Switching CB time tolerance

The basic property of the SCB is to carry out operations in a highly reliable, pre-defined time, to guarantee during its service life the expected transient reduction.
The switching time tolerance of the described CB has the following maximum values:

± 1 ms for the closing operation,
± 2 ms for the opening operation.

While the second value is mainly important (but not only) for the CB producer, the first one involves the tolerance in the closing operation which, according to the literature, is defined as the minimum value required for an equal or better behaviour in terms of closing transient, with the standard means (see table 2) to reduce them [3].

To be able to guarantee these values for the complete life span of the CB, the on factory tests have a reduced tolerance range of:

± 0.2 ms for the closing operation,
± 1 ms for the opening operation.

DESIGN OF SCB

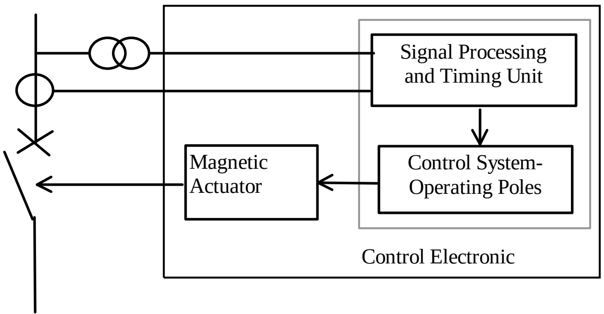


Figure 6: Simple block diagram of the SCB

Figure 6 shows how the SCB CE is arranged *The Signal Processing and Timing Unit* is the part of the SCB that deals with the voltage and current signals, it receives the command to make the close/open operation and decides when to give the signal to open or close to the following unit. The *Control System - Operating Poles* takes care that the operation is carried out within the tolerance time range defined.

Control Electronic hardware architecture

Figure 7 gives more details on the architecture of the CE. The *Signal processor & Timing Controller* checks the power network currents and voltages, and manages the *Operation Command.* The *Control Unit* is interfaced with the *Magnetic Actuators* by means of the *Switching Unit* and the coil current sensors, while it takes the CB poles under control by the position sensor *X*.

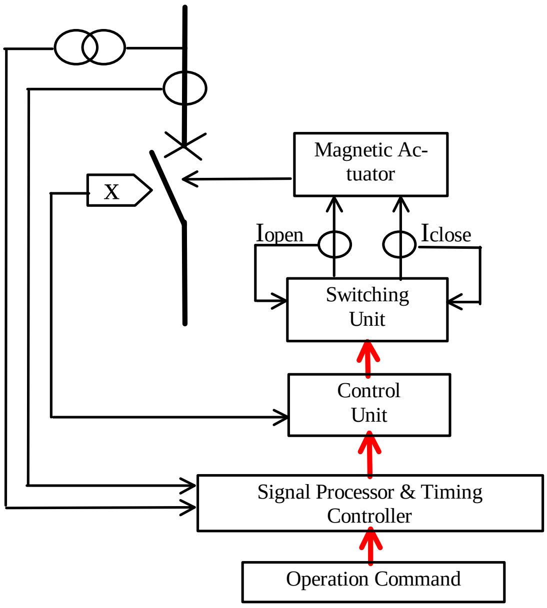


Figure 7: Block diagram of the SCB

Control Electronic Software architecture

The CE software can be divided into two main parts:

1. The system software, that controls the interface with the hardware resources (DSP core, on-chip and external peripherals) and the time scheduling for the application software.
2. The application software, that is responsible for the CB position control, network quantities, zero-crossing calculation and man-machine interface.

Control Unit: Application software

The heart of the electronic system lies in the control unit functionality. The main task of the control unit is to assure that the operation occurs in the pre-assigned time.

An operation is composed of two parts:

1. The current is flowing inside the coil, charging the magnetic actuator, but the CB pole does not move yet. This part can not be controlled directly by the software.
2. The pole starts moving and it is ‘guided’ to make the operation in the correct time. This part can be adapted within a certain range.

Reaching the desired closing or opening instant is the real target of the controller.

VALUE OF SCB FOR CUSTOMERS

Advantages of transient reduction

Switching transients originate a variety of disturbances on distribution power systems, ranging from poor power quality to protection untimely tripping, to unacceptable overvoltages leading to severe damage and premature failure. While current transients are localised to the switch location, transient overvoltages travel to remote locations, sometimes affecting several other users and propagating to different voltage levels.

The use of a SCB greatly reduces the stresses, in terms of both overcurrent and overvoltages, experienced by the components of the network at closing and opening operation on the loads, thus leading to significant advantages in terms of higher power quality and increased system reliability.

Network components stress reduction

The effect of this reduction is evaluated for capacitor banks. Similar conclusions can be extended to other components from the insulation ageing point of view (cables, transformers, etc.).

Capacitors are designed and manufactured in order to withstand the service rated conditions with a high reliability. This capability is tested through type test, following the requirements of IEC871-2. According to this standard, switching overvoltage stresses have the highest influence on the capacitor dielectric ageing and the component failure modes. Figure 8 shows the possible stresses on capacitors as a consequence of closing operations with a standard CB or a SCB. It can be seen, that the standard CB generates overvoltages above the partial discharge inception voltage (PDIV), while the SCB limits the overvoltages below this level.

The occurrence of voltage magnification phenomena or restrikes (see one paragraph below) is accounted for the area above 2.6 p.u stress level, that can greatly overcome the values used for endurance tests.

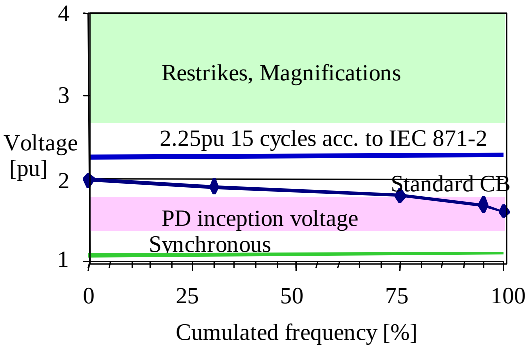


Figure 8: PDIV vs. synchronous and standard CB overvoltage cumulated frequency.

It is clear that the limitation of closing transients far below the PDIV, for all the expected operating temperatures, and the reduction of the restrike probability to virtually zero, will have a beneficial effect on the insulation service life, totally removing partial discharge failure mechanism and greatly reducing electrical ageing processes during transients.

Voltage magnification

Transients generated by switching loads can cause resonances leading to worse transients, or voltage magnification, in other sections of the network. This particularly occurs with capacitor bank switching transients, that propagate to other voltage levels (MV or LV), when the natural frequencies of two coupled parts of the network are equal or similar, causing overvoltages up to 4 p.u. at the remote bank location (figures 9 and 10).

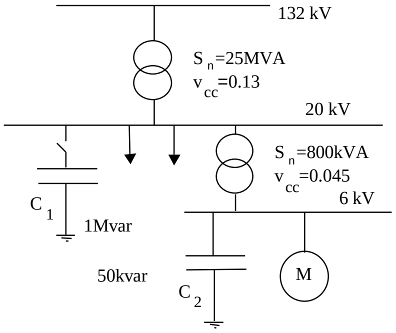


Figure 9 –Voltage magnification circuit diagram

Using a SCB, the overvoltages due to switching loads (especially capacitor banks) can be drastically reduced with huge advantages, not only in MV but in LV too, where those overvoltages can easily lead to dielectric faults.

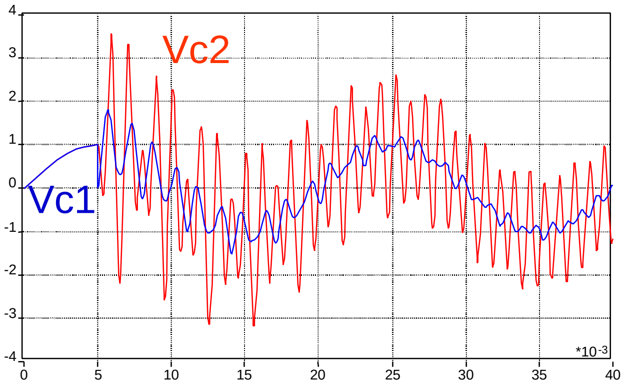


Figure 10 – Switching of bank C_1 at 20KV causes at C_1 a typical overvoltage of 1.8 p.u., while at C_2 over 3.5 p.u. , due to magnification

CB electrical life enhancement

The electrical life of a circuit-breaker mainly depends on the arcing energy which the circuit-breaker is subjected to, the electrical stress being relevant to the arcing energy withstood (contacts wear; dielectric stress; overtemperature and overpressure; gas wear). Thus, the reduction of the arcing energy, by operating each phase independently and reducing the arcing time, means a reduction of the above mentioned stresses. This can extend the CB expected service life by increasing its electrical life, minimising the thermal requirements of the interrupting chamber and the mechanical requirements for the driving actuator. Furthermore, the synchronous opening of fault currents can possibly increase the CB interrupting capacity.

Taking the electrical endurance test according to IEC 56 as a reference, the SCB allows in the worst situation, even assuming precautionary hypothesis, an electrical stress reduction of at least 50% for both vacuum and SF6 interrupting technologies.

Considerable economic advantages can be derived from CB wear reduction and therefore increased life-span, particularly in applications with high frequency switching of rated current, where reconditioning or replacement of CB poles is foreseen on yearly basis.

Restrike performances - Improvements in technology of traditional CB have surely reduced the probability of restrikes. However, as switching frequency in industrial networks can be high, the probability of overvoltages cannot be neglected.

However restrikes sometimes occur in service, despite the use of switching devices, which are ”restrike free” in accordance with the current specifications. To this purpose, IEC 56 draft, currently under revision, introduces a new concept: ”*As all CBs have a certain restrike probability in service, it is not possible to define a restrike free CB. It appears to be more logical to introduce the notion of a restrike performance in service*”.

The basic nature of a restrike transient is identical to that of inrush transients, but, due to the increased magnitude, may be damaging to power system equipment and imposes a challenging demand on the switching device.

Synchronisation enhances the “restrike free” capabilities of CB, because poles are independently opened long before the current natural zero occurrences. Thus, while minimizing the total arcing time and energy, the needed arcing time is provided to ensure contact separation and the needed dielectric strength at the time of maximum TRV, essentially eliminating reignitions and restrikes and the associated dangerous overvoltages.

Reliability - The reduced stress of the CB during switching operations leads to a higher reliability. Although breaker failures play a minor role in the frequency of network failures, they typically lead to severe consequences because of loss of selectivity.

The improved restrike performance ensures again lower CB stress and lower risk of damage to the switching equipment and to other network components.

Therefore, the SCB has an additional beneficial impact on network and supply reliability and power quality.

Power quality

In an ever increasing competitive energy market, power quality is becoming a performance indicator. Transients, once considered as acceptable minor variations, may give rise, in particular because of an increasing use of power electronic, to unexpected failure modes, leading to process standstill and significant production losses.

Adjustable speed drives (ASD) tripping - ASDs are more and more applied to improve the efficiency and flexibility of motor applications.

The tripping of ASDs overvoltage protection is often referred to as “nuisance tripping” because the situation can occur day after day, often at the same time. Due to the fact that capacitors at MV busbar are operated at least daily, nuisance tripping can potentially cause frequent standstills.

Combined with the fact that ASDs are often applied in critical process control environment, nuisance tripping can be very disruptive with potentially high downtime cost implications.

Even when very conservative failure rates are assumed, total tripping costs can easily be several times the installation cost of a SCB.

Transformer inrush current reduction - The use of a SCB can greatly reduce the inrush at transformer energisation, avoiding the statistical occurrence of problems like tripping of protections and those related to the heavy harmonic content of inrush currents.

The optimal closing strategies have been evaluated depending on the residual flux to be considered when energising the transformer.

It is, however, required that the residual flux can be recorded without doubt. A closing strategy neglecting the transformer residual flux leads to conditions which are not optimal. However, even in this case, the worst conditions which can occur using conventional circuit-breakers can be avoided by the use of a SCB

Inrush currents, in the worst case, are of the order of 8-15 times the transformer full-load current rating [2]. Table 1 shows, from modelling of a specific transformer behaviour, the inrush reduction when controlled closing is adopted. A comparable current reduction is expected for different winding configurations and ratings.

Table 1: Reduction of transformer inrush currents (peak value) in p.u. by use of a SCB

Case	Switching device	Inrush [p.u.]
Residual flux present, worst case	CB	Up to 7.5
Residual flux present, closing strategy neglecting it used	SCB	Up to 3.0
Residual flux present, optimal closing strategy used	SCB	0.05

Better protection and selectivity - The reduction of transformer inrush currents to negligible values allows wider margins to select the curves of protection relays and avoids inopportune trips. Furthermore, the drastic transformer inrush current reduction allows the concurrent energisation of more transformers, also with small power generators, and eliminates a typical cause of fuse ageing, improving definitely the power availability.

In a typical time-current diagram of protections coordination (figure 11), selectivity is obtained if the curves of the equipment on the load side are located under those of the equipment on the supply side. Limits are given by, in the upper part, the tripping curve of the equipment of the network on the load side of the plant; in the lower part, by the inrush curve of the transformers.

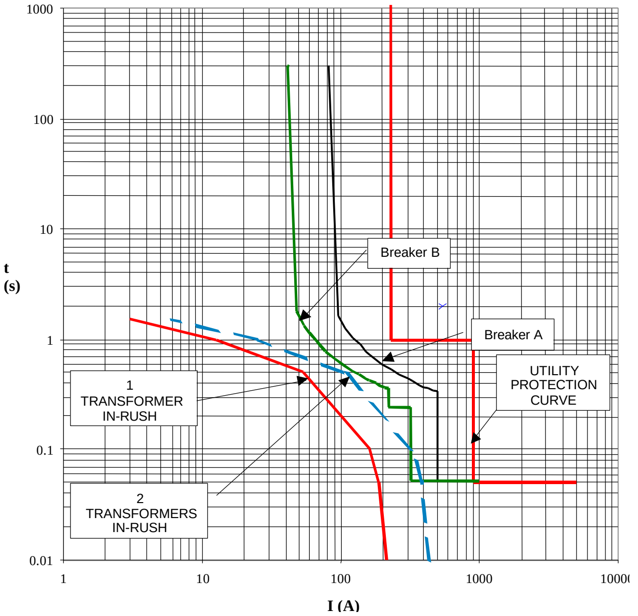


Figure 11 – Time-current protection diagram, two transformer inrush curves intersect with breaker curve

These often stringent limits make the tripping curves of the protections “crush” upon each other, preventing the application of suitable tolerances on the thresholds with the risk of possible untimely trippings. This often prevents the concurrent energisation of several transformers in parallel.

Fiumicino (Rome) Airport, an example - In the case of Fiumicino airport, under emergency condition, only one transformer at a time can be switched on, leaving a suitable time interval between the following transformer energisation, to avoid protection tripping of the generator. This causes a long and complex procedure for energisation of the emergency loads after losing the network supply. The use of SCBs shifts the inrush to the left in the time-current protection diagram. It allows easier and more reliable protection co-ordination as well as the concurrent energisation of all the emergency loads with a significant reduction of the outage duration.

Methods to reduce switching transients

The most effective solution to reduce switching overvoltages is the use of suitable switching equipment. The protection of sensible equipment by means of surge arresters, chokes or higher insulating levels is expensive and not always effective. Alternative methods to avoid switching transients are traditionally employed and compared in table 2.

When compared with other means to reduce the system transients, like fixed or pre-insertion inductors and pre-insertion resistors, the SCB offers a simpler, cost effective solution as well as comparable or better results.

The SCB allows reducing effectively both current and voltage transients. It can manage both opening and closing synchronous operation, by software configuration of the control to fit the CB installation and it is much more flexible with different load operation.

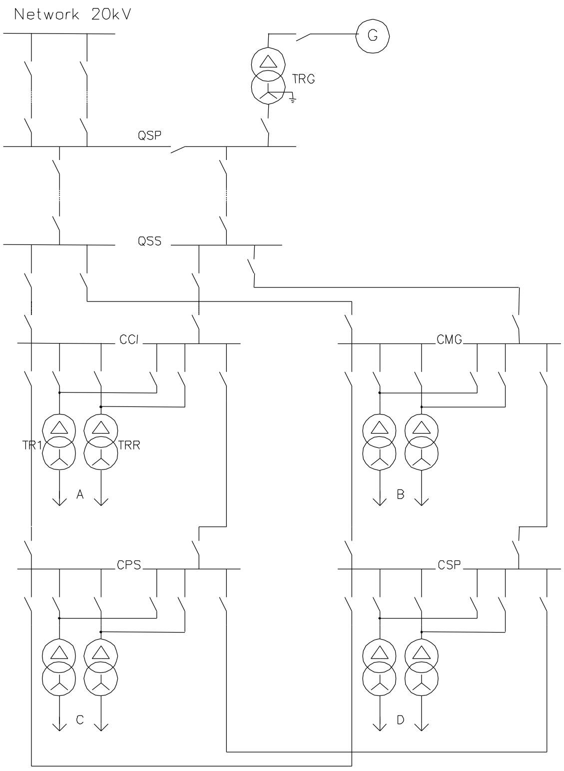


Figure 12 – Fiumicino airport simplified circuit schematic

Table 2: Comparison of different means for the reduction of transients

Transient control means	Advantages	Disadvantages
Fixed inductor	Easy Effective on current	Losses & noise Life cost
Pre-insertion R	Only at switching No losses	Complicated, low reliability
Pre-insertion L	Only at switching No losses More effective than fixed L	Complicated, low reliability
SCB	Effective on both I &V, opening and closing operation Reduced CB wear	Reliability & consistency in traditional solution; problems overcome by presented SCB

CONCLUSIONS

The SCBs shown in this paper are turnkey devices, fully integrated in the MV switchgear, to provide the synchronous functionality at distribution level. The ratings that will be available in the first step are shown in table 3.

Table 3: Available ratings in the first step

SCB	Rated voltage	Rated current	Breaking current
SF6	12 kV	630 / 1250 A	20 - 25 - 31.5 kA
	17.5 kV	630 / 1250 A	16 - 20 - 25 kA
	24 kV	630 / 1250 A	16 - 20 - 25 kA
Vac-uum	12 kV	630 / 1250 A	20 - 25 - 31.5 kA
	17.5 kV	630 / 1250 A	16 - 20 - 25 kA
	24 kV	630 / 1250 A	16 - 20 - 25 kA

ABB SCBs have been developed as multi-purpose, flexible devices, fully software configurable, extending the synchronous operation features from the switching of capacitor banks to all the distribution CB applications, including the synchronous opening of short circuit currents.

Furthermore, they can manage all types of networks such as isolated network, compensated network by means of the extinguishing arc coil, neutral connected to the ground by means of a resistor and neutral strongly grounded, therefore providing a very flexible solution.

The SCB solution achieves a higher degree of product quality and reliability, over the full expected service life, reduces maintenance requirements and allows higher availability and service continuity.

Furthermore, it can save costs in the increasing applications where power quality is important.

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