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Integrated disconnector on Generator Circuit Breakers for environmental and footprint optimization

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SUMMARY

By considering the evolution of technologies and re-visiting lucidly preconceived design habits, some architectures have appeared in the last decade that lead to an interesting imbrication of the functions while maintaining first-rate operational qualities in terms of installation, testing, powerplant operation as well as maintenance needs.

This paper aims to enlighten the pros and cons of Generator Circuit-breaker (GCB) system architectures and how they fulfil the user needs, which have evolved along the years with the growing environmental people awareness as well as with the evolution of the technologies.

The examination of the architectures from different angles such as the degree of integration of the functions, the way they are integrated, or the used technologies, will lead to show their impact on environment, shake up some preconceived ideas about the possible layouts and the way to specify the requirements. GCB system's architectures also have consequences on maintenance programs or powerplant commissioning procedures. By considering the ultimate purpose of the maintenance or commissioning tests, this article intends to show how the most integrated architectures can be implemented with total respect of the legitimate safety needs of the users.

There is no doubt that in the near future, environmental concerns will gradually lead engineers to modify the way they specify the equipment present in power plants, and to choose architectures that are more respectful of the environment.

KEYWORDS

Generator Circuit Breakers, GCB, architectures, environmental impact

1 Generator Circuit-Breaker specificities

Generator Circuit-Breakers [GCBs] have been installed for decades in power plants to improve their overall life cycle cost by efficiently contributing to the protection system and ensuring the safety of the synchronization to the grid. They are commonly associated with other switching equipment such as disconnectors, earthing switches, application dedicated starting switches, as well as to instrument transformers, to provide all the switching and measurement functions that are needed in a powertrain. All these functions are grouped under the name of GCB system, the definition being that the system comprises at least one generator circuit-breaker plus other equipment submitted to similar electrical constraints, and which operations depend on each other's status.

GCB systems present decisive advantages for coupling powerplant generators to the HV grid, via a step-up transformer. The most important point is that GCB systems are specifically designed for that purpose, by considering all the peculiar duties that are to be encountered in a powerplant environment. On top of general purpose MV circuit breakers performances; a GCB system have to deal on a daily basis with very high nominal current, out-of-phase voltages during several minutes before synchronization to the grid. In case of fault, GCB systems have also to deal with strong short circuit currents, high values of Transient Recovery Voltage, high current asymmetries, out of phase fault currents (50% of the rated fault current), very high arc energy when AC current decay is faster than DC component decay, creating relatively long period without current zeros, disabling therefore the capability of current interrupting for technologies with low arc resistance.

These specificities have led IEEE to issue a dedicated standard for Generator Circuit Breakers, IEEE Std C37.013, in 1997 and 2007 [1][2]. This standard has recently evolved to a Generator Circuit Breaker Systems dual logo standard IEC/IEEE 62271-37-013 [3][4] to cover the circuit-breaker ratings as well as all the associated switches submitted to the same constraints.

2 Introduction to environmental impacts

GCB systems, as part of the powertrains, are built according multiple layouts that have evolved over the years, from completely separated functions, each in individual enclosures, to fully integrated solutions in a reduced number of enclosures. These solutions are all fulfilling the customer needs but are not equal in term of environmental footprint.

As an example, the complexity of the installation, the number of stand-alone functions, may have a direct impact on the amount of raw material needed to build the supporting structures.Another example is given by the way functions may be integrated, which directly drives the compactness of the equipment, hence the amount of insulation/arc interrupting gases needed to fulfil the design requirements, as well as the overall heat losses. The latter being of the essence on the long run for the functions that carry continuously huge amount of current, such as circuit-breaker or main disconnector functions. Each current carrying function connected in series is source of heat losses. When such functions can be merged by smart integration of the equipment, then the losses are immediately divided by two.

Design choices have various effects, sometimes opposite, on the different criteria that form an equipment environmental footprint. Despite all the designer good will, it is not possible to reduce all the impacts in every possible domain. Some choices tend to optimize the environmental footprint during the construction phase of the product, while other choices will privilege the impacts during the operating life.

The Joules losses management is a good example to illustrate this point. Some manufacturers may choose to optimize the construction phase by using as less material as possible for the product basic skeleton, with the subsequent consequence that the current flow in the product will create a huge amount of heat by Joules effect during the 40 years of the operating life, which will have an negative impact on the global warming criteria. Figure 1 presents the Life Cycle Assessment of a typical GCB system where it is clearly visible that the operational phase (referred to as the "Use" phase) is the most impacting phase in term of environment, Joules losses representing the vast majority of the impacts.

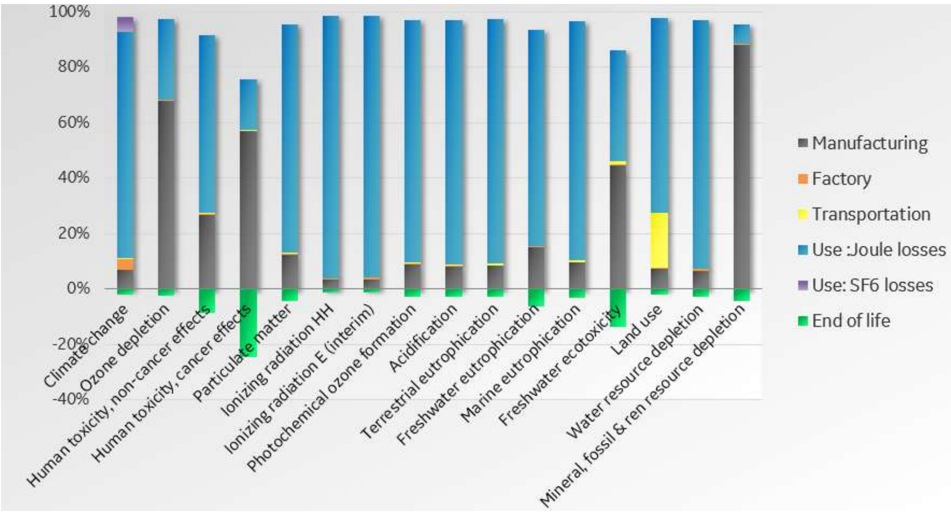


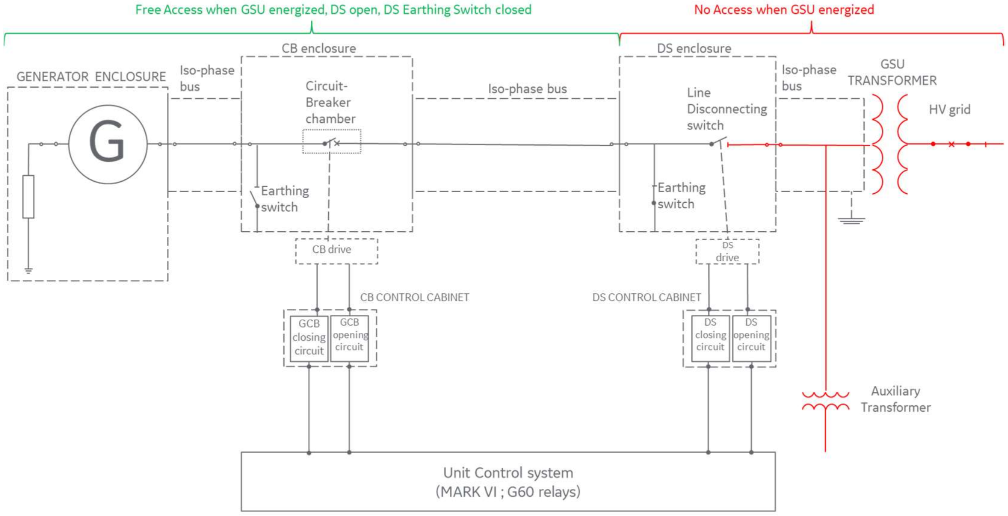
Figure 1 - GCB system typical Life Cycle Assessment

For some products of the high hand range, the necessity to use a cooling system to evacuate the created heat will have an additional negative impact on the construction phase also, by using additional material. Another design option is to optimize the operational phase, which is much longer than the construction phase. They will create devices suited to carry current without overheating, at the cost of a slightly greater use of material resources, but with no need of cooling system at the end.

The beneficial integration of these environmental criteria in the construction of GCBs will not go without calling into question the automatisms of the profession. For designers, the integration of other modes of thinking is necessarily added to the usual technical and cost criteria. On the user side, it is worth to rethink some inherited ideas that have not been questioned for a long time, while not losing sight of the basic needs of power unit operation, as well as maintenance necessities.

3 History of Powerplant layouts and GCB integration versus technology

3.1 Stand-alone equipment



Power unit equipped with stand-alone equipment

Figure 2

Arising from the electrical equipment market available devices, the first architectures (Fig. 2) on the market were naturally built around stand-alone equipment, connected to each other by portions of busbars. This architecture had the direct advantage, given that the circuit breaker at that time required a lot of maintenance, to allow access to the circuit breaker poles without deenergizing the transformer: Secured by the opening of the main disconnector and the closing of an earthing switch between the circuit breaker and the disconnector, the maintenance teams could easily inspect the poles and measure their operating times.

This layout is best suited for circuit-breakers in need of frequent inspection, or for situation where access to the circuit-breaker chambers is really needed while main transformer energized. For example, when many generators are feeding one transformer, and in case auxiliary transformer feeding is not redundant, it is generally not accepted to shut down the whole unit when one circuit-breaker is out of order. The access to the circuit-breaker poles enclosures shall then be insured while transformer energized, which can only be insured if the disconnector is in a separate enclosure and equipped with the appropriate earthing switch to provide the requested safety.

Please note that, in that case, the place of the disconnector must be between the circuit breaker and the transformer.

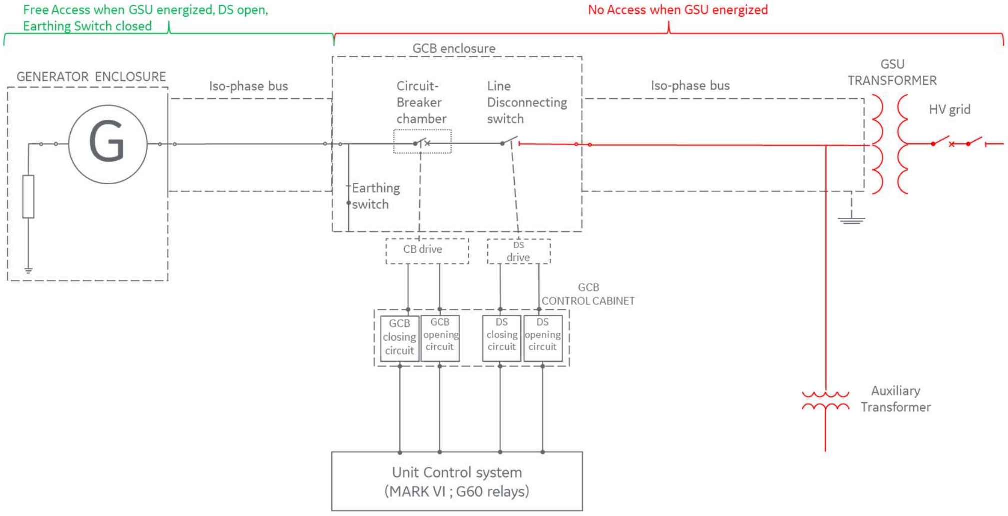
This universal architecture is adapted for all powerplant layouts. It gives the breaker maintenance flexibility that was needed with circuit-breakers of older technologies.

The counterpart is that it is the most expensive solution, and the less effective from an environmental point of view. The lack of function integration leads to the need of several support structure as well as the most complex busbar made of several segments. The use of raw material is therefore at its maximum to build all the elements of the powertrain.

The presence of a circuit-breaker and a disconnector in line with the current path creates inevitably two permanent heat loss sources for the whole lifetime of the system. Considering the GCB being closed most of the time, the impact of this feature on the environmental footprint is quite important.

3.2 Integrated GCB systems

A first step of integration has been implemented some decades ago, mainly to reduce the cost of a GCB system, by locating the circuit-breaker, the main disconnector, and some other switches in the same enclosures (Fig. 3).



Power unit equipped with Generator Circuit-Breaker and Disconnector in line

Figure 3

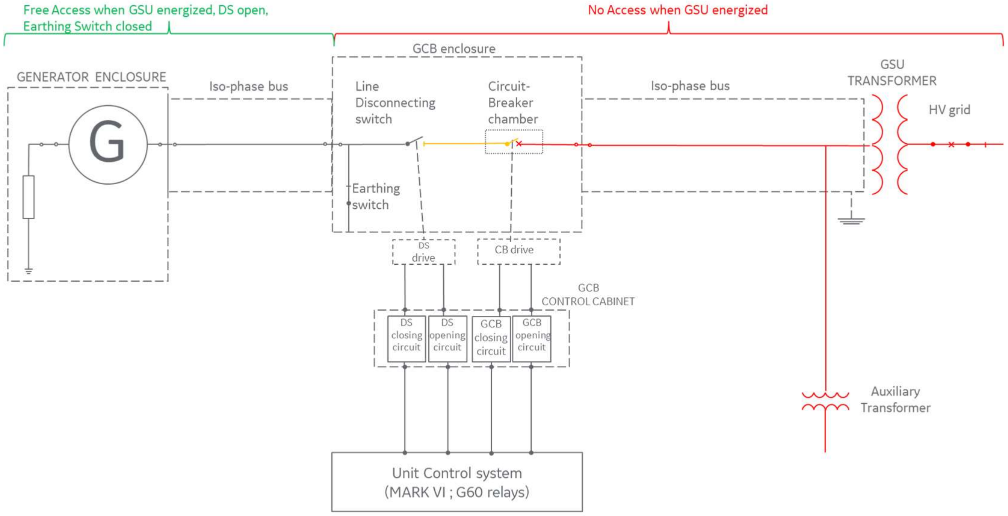
This architecture provides an identical electrical behaviour of most power plant during unit operation as with stand-alone equipment.

The difference here is that the intimacy of the circuit-breaker and the disconnector excludes the access to the common compartment when the busbar is energized, which is the case on transformer side in case

the auxiliaries are fed by the grid. It reduces then the possible maintenance operations of the breaker to the operations which are located outside the equipment phase enclosures.
It is for example possible to replace parts of the breaker drive, while disconnector is open. But when busbar is energized it will not be possible to open the pole enclosures to install operating time or electrical resistance measurement cables. For these operations it would be mandatory to shut down the unit.
With this solution of compact Generator Circuit Breaker, the maintenance area while the busbar is back-fed by the grid has been reduced to the generator and its terminals, and the external parts of the circuit-breaker.

This compact architecture, now worldwide well accepted, has been made possible by the significant progress of circuit breakers reliability and their reduced need for pole maintenance. Modern SF6 circuit-breakers doesn't therefore request frequent access to the pole enclosures.

Another consequence of this GCB system architecture, to drop an idea coming from the previous architecture, is that the position of the disconnector is no longer necessarily on the transformer side: If access to the active parts can only be allowed when unit is shut down, the position of the disconnector is then irrelevant. When the disconnector is open, it is indeed theoretically possible to operate the breaker, even while its active parts are energized, as long as there is no current flowing through it, thanks to the open disconnector, whatever the side it is installed (Fig. 4).
The position of the disconnector would not change the maintenance activities that are allowed when busbar is energized on transformer side.



Power unit equipped with Generator Circuit-Breaker and Disconnector in line – alternative layout

Figure 4

This architecture, well suited for powerplant with classical layout (one generator feeding one transformer), is also necessary for GCBs with circuit-breaker drives which requires breaker operation after drive maintenance.
For example, when circuit-breaker drive motion is transmitted to the active parts through a hydraulic circuit, it is indeed necessary to operate the breaker to "bleed" the hydraulic circuit (evacuation of air bubbles trapped in the circuit) each time it has been opened for maintenance, for example to change one of the multiple seals present in this type of circuit.
The presence of a disconnector in line with the breaker (whatever its location) is therefore mandatory to shield the breaker during this operation when the transformer busbar is left energized.

This need doesn't really exist for breakers with spring mechanism, whose reliability has been more than demonstrated on the countless fleet of spring-operated HV circuit breakers all over the world (refer to [5], [6]). With these pure mechanical drives, the breaker doesn't technically need to be operated after a mechanism common maintenance operation that can be done without access to the breaker active parts.
Of course, even with spring mechanism operated breakers, it is easy to take advantage of the

disconnector in line with the breaker to discharge the spring drives by operating the breaker, but it is not a technical obligation. Another way to perform the maintenance operation in safe conditions would be for example by locking safely the breaker in open position during the breaker drive maintenance.

From an environmental perspective, this solution is more compact, needs less support structures, hence less raw material than the previous solution made of stand-alone switches. It also presents a simpler busbar architecture, only made of two busbar segments. The environmental footprint is therefore reduced by these features.
On the other hand, the presence of a circuit-breaker and a disconnector in line with the current path still creates inevitably two permanent heat loss sources for the whole lifetime of the system.

3.3 GCBs with integrated air disconnector

The previous evolution, which can be described as the simple concatenation of circuit-breaker and disconnector in the same enclosure, gave immediate advantage of compactness and overall cost reduction, while being not too disruptive in the conservative world of power generation.
Thanks to the use of full spring mechanism, which technically do not request to be operated after maintenance, the previous architecture could be improved toward a far better current carrying efficiency and a severe reduction of environmental footprint.

The GCB with integrated air disconnector architecture, is an innovative rethinking of GCB systems, with entire focus on the maximum efficiency of the resulting architecture while maintaining first-rate operational qualities in terms of installation, testing, powerplant operation as well as maintenance needs.
The design principles of this range of equipment are based on the merging of redundant functions and the use of material restricted to where it is strictly needed. These principles lead automatically to the smallest environmental footprint by the search of maximal efficiency for each function (Fig. 5).

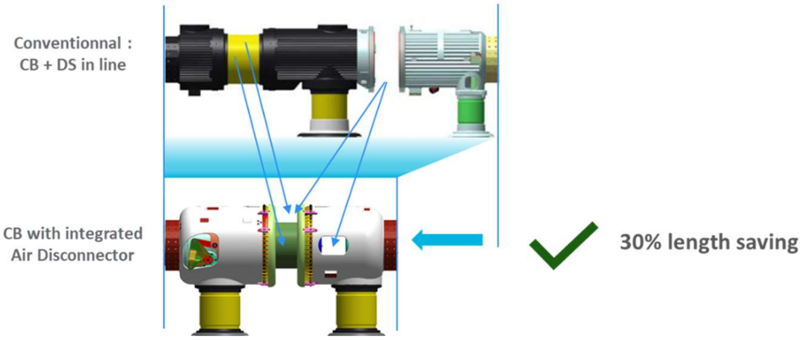
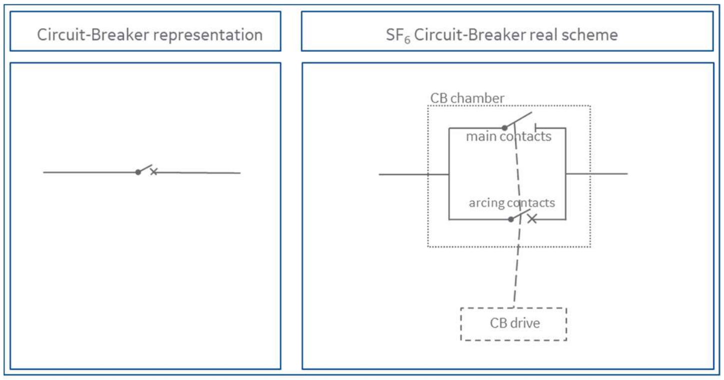


Figure 5

To explain the genesis of this architecture it is necessary to bear in mind that a circuit-breaker is made to fulfil basically two types of duty:
- carrying current, on daily basis,
- and interrupting current, mostly on emergency basis.

Technically speaking, electrical contacts that are the most efficient to carry current are not well suited to interrupt current because they cannot resist to the erosion of the electric arc. Reciprocally, contacts that are efficient to withstand electrical arcs are not good at current carrying because the dedicated material presents a higher electrical impedance.
For these reasons, the use of two types of contacts, one for current carrying (the “main contacts”) and one for current interrupting (the “arcing contacts”), is widely preferred, even necessary, to build the most efficient heavy-duty circuit-breakers.
These two contacts functions are working synchronously, in a way that the “main contacts” are used when the circuit-breaker is closed, the current being commuted to the “arcing contacts” to be properly interrupted during breaker opening.

These two functions, encapsulated in the circuit-breaker chamber, are working automatically, without the knowledge of most operators. For this reason, it is possible to represent a circuit-breaker (Fig. 6) as a single switch, when in fact it is made up of two:

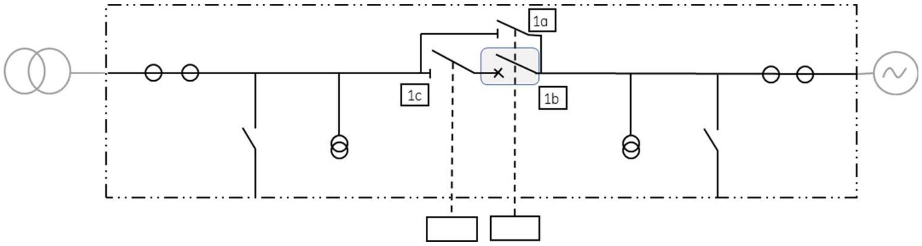


CB and its graphical representation

Figure 6

The corollary of the existence of two sets of contacts in the circuit-breaker is that it is possible to separate and recombine it in a way, possibly with the functions of other equipment, that reduce the overall environmental footprint.
That is where a consideration concerning the “main disconnector function” comes in line:
The purpose of a “main disconnector function” is to show a suitably sized open gap in the circuit, for people to effectively see that the circuit is open. With the addition of the closing of an earthing switch on the “dead” side of the disconnector it is then possible to work on a safe portion of circuit while the other portions are energized.
This important function is then used for a very small amount of time during the life of an electrical system. In the remaining time, which is more than 99% of the lifetime, the disconnecting function is not used as such, thus becoming a necessary evil that must be designed as best as possible so as not to disturb the permanent flow of current.

In an architecture of a circuit-breaker with integrated air disconnector, the disconnector function and the circuit-breaker main contact function are merged to only one set of contact in air, which gives the maximum efficiency for current carrying capability, also eliminating the inevitable current derating of other solutions in the event of loss of insulating gas.
The SF_6 volume is then reduced to the area of arcing contacts where the quenching properties of SF6 helps to interrupt the current.

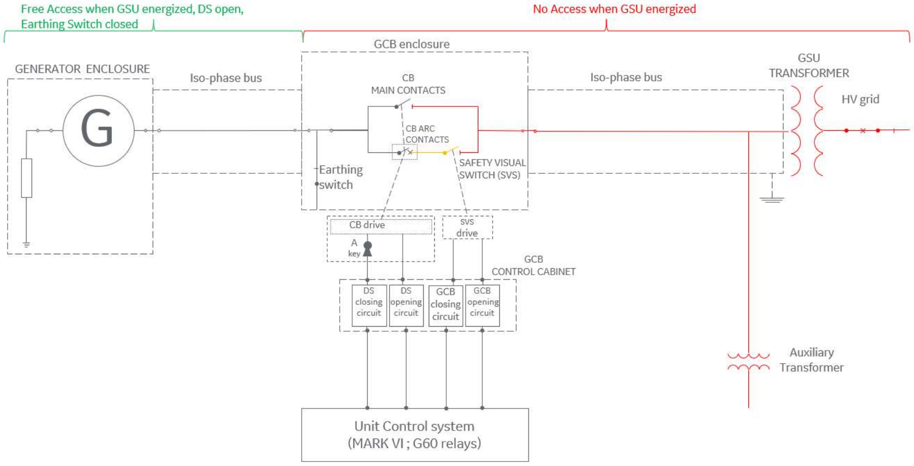


1a. Main contacts in Air / 1b. Arcing contacts in SF6 / 1c. Safety Visual Switch (SVS) in Air
1a + 1b = Circuit breaker / 1a + 1c = Air- Disconnector

Figure 7

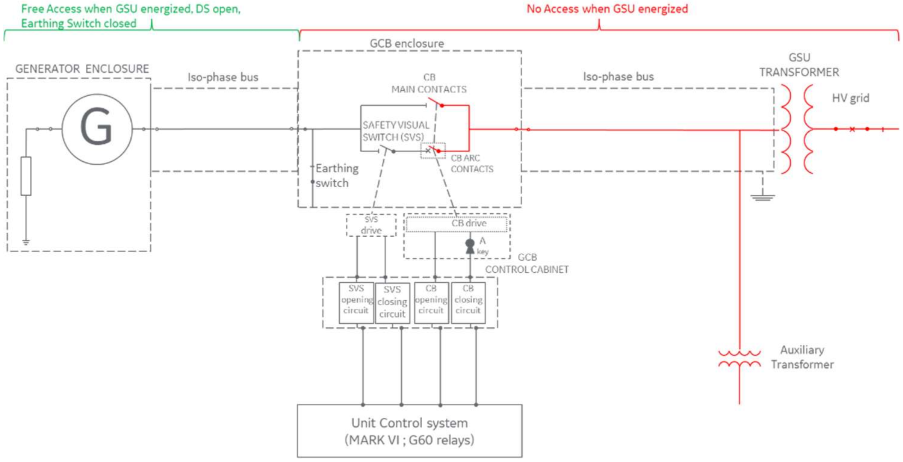
The circuit-breaker function is realized by opening the main contacts and the mechanically linked arcing contacts by the operation of the circuit-breaker mechanism (1a +1b) (Fig. 7).
The disconnector function is additionally realized by the voluntary and occasionally opening of the Safety Visual Switch (SVS) (1c), interlocked to operate only if breaker is already open.
The result is an open airgap in the circuit, made of the opened main contacts of the breaker and the opened contacts of the SVS (1a+1c). This open airgap gives the requested reliable information of the open state of the circuit.
This Generator circuit-breaker system is alternatively a circuit-breaker or a disconnector with the full characteristics of each functions.

As for the previous architecture, the disconnector function being in the same enclosure as the breaker function, the location of the SVS on transformer side (Fig. 8) or on generator side (Fig. 9) gives the same operational result.



Power unit equipped with GCB and Integrated Air Disconnector

Figure 8



Power unit equipped with GCB and Integrated Air Disconnector – alternative layout

Figure 9

This architecture provides the same operational functions and enclosure access than the usual architecture with circuit-breaker and disconnector in a common enclosure, while offering some rather interesting progress for maintenance teams to assess very quickly the health of the breaker contacts, as well as in the reduction of environmental footprint of a GCB system.

The environmental footprint of the solution is drastically reduced by the resulting global downsizing and the SF_6 volume reduction.

Material	gain
SF_6	58%
Aluminium	26%
Steel	35%
Copper	50%

Material gain in mass of GCB with integrated air disconnector compared with classical architecture (same ratings)

The integration of the circuit breaker main contacts and disconnector function into a single piece of equipment of main contacts of both circuit-breaker and disconnector is particularly effective in the reduction of Joules losses. On top of dividing by two the number of contact function in line on the current path, placing the resulting unique main contact function in the air of the enclosure makes the dissipation of heat far easier than when it is confined in a chamber. For the same current, the lower electrical impedance, being less than half of what it is with the classical solutions with circuit-breaker and disconnector in line, reduces drastically the heat loses for the whole operational lifetime of the system.

Figure 10 compares, over a lifetime of 40 years, the environmental impacts of different architectures for each criterion where operational Joules losses are significant. The greatest efficiency of the integrated air disconnector architecture is visible on the vast majority of environmental criteria.

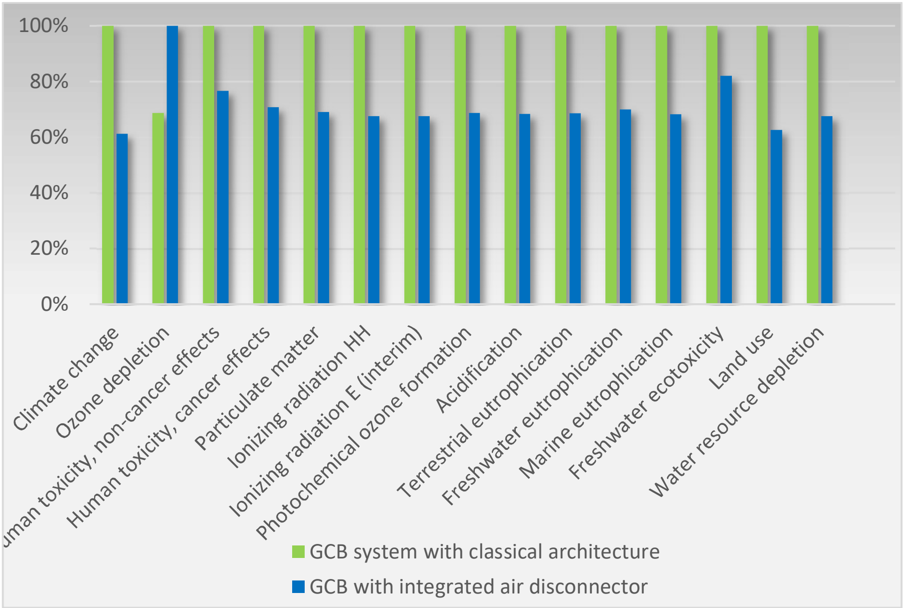


Figure 10 - Comparison of Life Cycle Assessment for different GCB architectures of the same ratings

As an interesting consequence of having main contacts in air, the current that can then be carried on without exceeding the contact temperature limit is then multiplied without need of any cooling solution.

From an asset management point of view, direct access to main contacts given by this architecture is a major contribution to health assessment time reduction. For other architectures, where main contacts subjected to hot gas flow are hidden in a sealed envelope containing pressurized SF_6 gas, main contact inspection consumes a large portion of maintenance time: it is actually not possible to inspect the contacts without long time scheduled complete overhaul sessions of some weeks.

The interest of main contacts accessibility is justified by the fact that contact resistance measurement cannot alone be considered as reliable evidence of contact health as mentioned in the GCB standard IEC/IEEE 62271-37-013 2021 [4] §7.101.1.4. where a note states that "Experience shows that an increase of the voltage drop across the generator circuit-breaker cannot alone be considered as reliable evidence of an increase in temperature rise. "In the same paragraph, it is also expressed that visual inspection is the effective way to assess the contact health ("visual inspection is usually sufficient for verification of the capability of the generator circuit-breaker to carry the rated continuous current "). The technical background behind is the fact that heavy-duty GCB systems are using generally much more than 50 contacts to ensure their current carrying capabilities. The wear of even half of these contacts would not be noticed with electrical resistance measurement but can be seen by visual inspection. In addition, electrical resistance measurement is made inaccurate, even unrealistic, by the use of fluorinated greases which have excellent contact properties when hot, that is when current is flowing through the contacts, but presents other characteristics at room temperature. False alarms are

then raised for no reason because the electrical properties of the grease are restored as soon as current is heating the contacts again.
Electrical resistance measurement is in fact only a last resort, useful for circuit breakers which have only a very small number of inaccessible contacts, when no other method can be applied, like vacuum breakers, for example.

The GCB system with integrated air-disconnector architecture presents the same electrical behaviour during powerplant operation as the previous solution. The interlocking rules that apply with this solution follow the same logic as for other architectures: just as it is forbidden, for the previous architectures, to operate the main disconnector when the circuit breaker is closed, it is here forbidden to operate the safety visual switch if the circuit breaker is closed.
It also presents the possibility to perform the few maintenance operations that may be needed for a breaker operated by a spring mechanism and mechanical linkage, when busbar is energized on one side of the GCB.

Although these mechanisms are redundantly equipped with all critical elements, in the unfortunate event that the redundancy would be consumed, it is still possible to lock these drives safely in open position, allowing to replace operating coils or charging motors, which are the only elements that may fail in operation. The drive technology doesn’t require to operate the breaker after such operation just “to see if it works”, the next synchronization of the unit will prove it.

This architecture layout has some minor consequences on the commissioning procedure where the classical tests must be slightly re-sequenced to achieve the usual outcome. A re-thinking of the real purpose of some tests is also necessary to avoid prohibited breaker operations during the tests.
The “dummy test”, which is meant to check the behaviour of the system in different synchronization conditions, is a good example to illustrate this point: This test is not a test of the circuit breaker itself, which is already known to work since it has just been previously and repeatedly tested. It is a test of the control system, to check if closing orders are sent to the breaker when good synchronization conditions are met, and more importantly, to check that closing orders are not sent to the breaker in case of bad synchronization.
With the classical architectures, it is easy to perform the test by cheating the system on the position of the disconnector and artificially allowing circuit-breaker remote operations even if disconnector is physically open.
This operation is obviously not allowed when there is no disconnector in line with the breaker, but the result of the test can be easily achieved by simply locking the breaker in open position with the dedicated locks, creating various synchronization conditions across the breaker, and checking if closing orders are wisely sent or not. During these operations the safety visual switch remains in its normal closed position, without need to cheat the system on its real position.
Once the control system is checked against synchronization conditions, the breaker is simply unlocked and ready to operate.

4 Conclusion

The choice of a GCB architecture has a direct impact on the powerplant's environmental footprint. While compactness plays an important role in the resource consumption during manufacturing, the efficiency gain for the most frequently used functions in service is an additional asset to reduce heat losses during the 40 years of the operational life of the equipment.

Nowadays, there are GCB’s architectures that meet these maximum efficiency criteria which allow the environmental footprint of a GCB to be drastically reduced.

There is no doubt that considering environmental constraints will lead powerplant operators to adopt these architectures which combine compactness and maximum efficiency in service. It is worth questioning some old habits of the profession to participate in the environmental protection of the planet…

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