# THE IEC/ANSI DUAL-STANDARD FOR GENERATOR CIRCUIT-BREAKERS: BACKGROUND, CHARACTERISTICS AND HOW IT CHANGES THE GAME

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***Abstract*** - The continuously growing energy demand worldwide combined with the distributed electrical power generation structure has brought a rapid spread of generator applications.

The natural and essential need for utilities or independent power producers to ensure safety, continuous operation and full protection of the generation assets with potential unique fault conditions, make a better definition of the performances that a generator breaker must fulfill necessary.

The latest IEC/IEEE 62271-37-013 Standard, also called Dual Logo Standard, aims to define and regulate the circuit breakers used to protect these assets. This paper presents the main characteristics between this latest standard~~s~~, the previous IEEE C37.013 (now superseded) and the IEC 62271-100 for distribution circuit-breakers, in terms of requirements including short circuit conditions, typical electrical parameters and selectivity logic.

Finally, the impact on the generator circuit breakers market is shown, in terms of consequences on available products, main players' GCB offerings and why their customers should care.

*Index Terms*
GCB – Generator Circuit Breaker
SLD – Single Line Diagram
SSF – System-source fed Fault
GSF – Generator-source fed Fault
OoP – Out-of-Phase (fault)
LCS – Load Current Switching
MV – Medium Voltage

## I. INTRODUCTION

The energy market trend cannot be predicted precisely due to the multitude of variables involved, such as economics, world population and energy demand growth, government stability and political scenarios, renewable and energy efficiency initiatives, and fossil fuel availability and price.

According to projections by the U.S. Energy Information Administration [1], based on a specific reference case (cfr. International Energy Outlook 2017), the industrial sector is expected to have a growth rate of about 0,7%/y from 2015 to 2040.

The growth rate is expected to be led by buildings sector, with 1,1%/y trend (same period), followed by transportation sector, with 1,0%/y trend:

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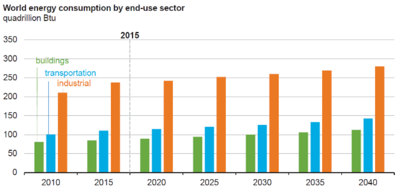

Fig. 1 World energy consumption by end-user sector (from U.S. - E.I.A., "International Energy Outlook 2017")

Further, the EIA provides a projection of energy demand split by energy source: under certain assumptions, every primary energy source is expected to considerably grow, with the only expectations being coal and nuclear:

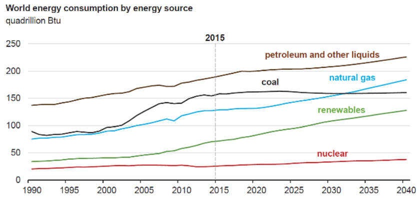

Fig. 2 World energy consumption by energy source (from U.S. E.I.A., "International Energy Outlook 2017")

## II. PROTECTION OF GENERATION PLANT

The expectation of such an increase in energy demand makes it reasonable to foresee a growth in investment in new power plants, combined with the clear focus on the complete and sustainable protection of the relevant assets.

The generator and the step-up transformer are the most important electrical components to protect in a power plant.

The generator breaker (GCB) must be designed to efficiently and safely protect both of these, in order to ensure the continuity of energy supply without any impact to the power plant.

Further, the peculiarity of a power plant from the electrical point of view prescribes more and more demanding performances that such a GCB should fulfill.

The number of possible fault conditions and their likelihood are higher than in distribution networks.

They include:

i. Fault between the generator and the GCB, called system-source fed fault

ii. Fault between the GCB and the step-up transformer, called generator-source fed fault

iii. Out-of-phase fault (OoP)

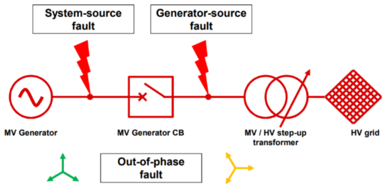

Fig. 3 Simplified Generator plant single line diagram (SLD) and main fault conditions identification

Depending on the point of occurrence and the different elements involved, the transient behavior of the electrical system is unique. Furthermore, the fault voltage can depend on the synchronization grade between the generator phases and the network phases, e.g. in the case of out-of-phase faults.

In particular:

i. The system-source fed fault reveals the contribution of the network via the step-up transformer. This circuit usually has a time constant of 133ms, resulting into high asymmetric fault currents with a peak factor of 2,74 and rates-of-rise of recovery voltage of 3,5kV/us. Both are causing much higher stress at the fault interruption than in distribution networks.

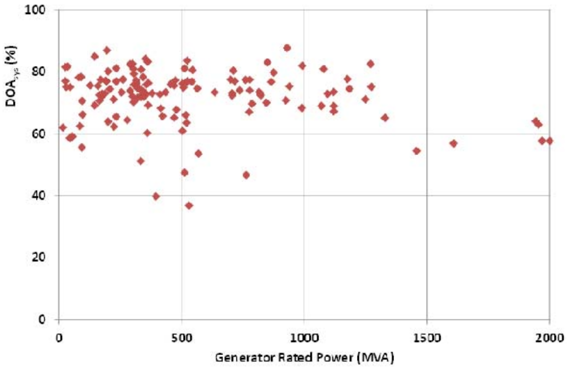

Fig. 4 Statistics from real applications: evaluation of the dc time constant of 133ms at SFF [10]

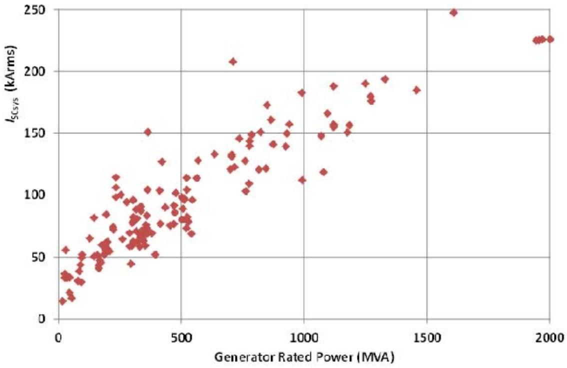

Fig. 5 Statistics from real application: the fault current level at SFF increases with the rated power of generator [10]

ii. The generator-source fed fault gets all its contribution from the generator(s), which is a complex, non-linear behaving machine. The direct consequence are fault currents with an even higher DC component and delayed current zeros.

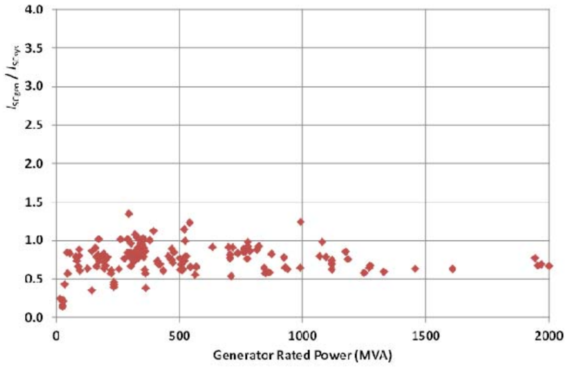

Fig. 6 Statistics from real applications: the rms value of GSF fault current is in average 80% of SFF [10]

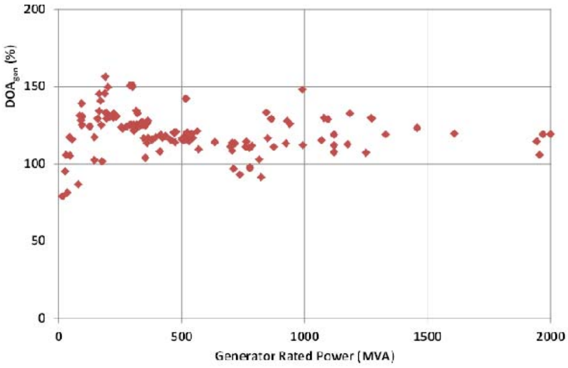

Fig. 7 Statistics from real applications: the dc-component of GSF fault current can be above 130% [10]

To withstand such technical challenges, several quenching technologies and circuit breaker types have been developed along the years, from compressed air breakers to SF6-breakers and vacuum-breakers.

Typically, the construction of such a product requires a bigger size structure compared to breakers used in distribution networks.

The technology allowing a consistent space saving is the MV circuit-breaker equipped with vacuum interrupters.

The vacuum interrupter (VI) can demonstrate a high dielectric strength with minimum contacts distance, and especially in the case of current-zero crossing, it can sustain high and fast rising transient recovery voltage and extinguish the arc, even few milliseconds after the contacts' separation.

The geometry, and in general the performance of the quenching technology, are crucial to fulfill the highly demanding technical challenges brought by the presence of the generator. Latest test results show that VI´s based on an optimized CuCr contact material and transverse magnetic field (TMF) contact shape are a reliable, compact design to interrupt generator source fed fault currents up to 50 kA @15 kV. They are able to handle the extreme high switching energy resulting from the delayed current zeros and are able to withstand the very fast TRV. This contact geometry results in a switching arc voltage in the range of 150 to 200V and is therefore able to decrease the time constant (τ = L/R) of the network and to influence the first current zero to happen earlier [9].

The following picture shows a typical current waveform during such a type test in case of a generator-source fed fault; the highlighted area is proportional to the arc energy passing through the contacts after their separation and till the current zero ($\int_{t_2}^{t_1} i(t)\ dt$ with and the instantaneous current i(t) in amperes and the switching arc time t in milliseconds).

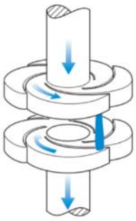

Fig. 8 TMF contacts in vacuum interrupter

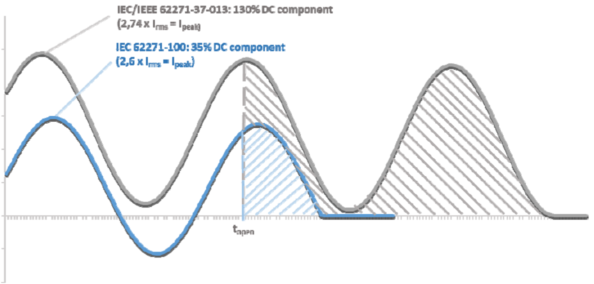

Fig. 9 Comparison between fault current DC component of breaker according to Dual Logo and IEC 62271-100

Another crucial parameter to be carefully taken into account for this peculiar application is the TRV rate, the phenomenon visible in the following picture:

- RRRV above 3.5 kV/µs

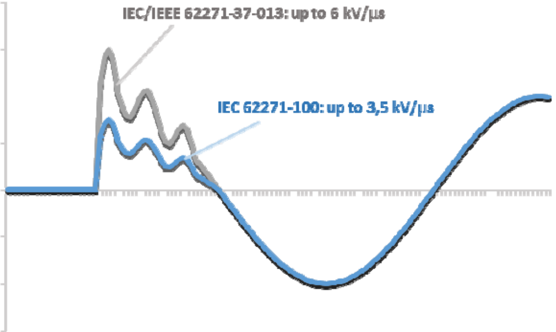

Fig. 10 Exemplary comparison between TRV according to Dual Logo and IEC 62271-100

- Time Delay 0.5 µs (GSF) and 1 µs (SSF, OoP, LCS)

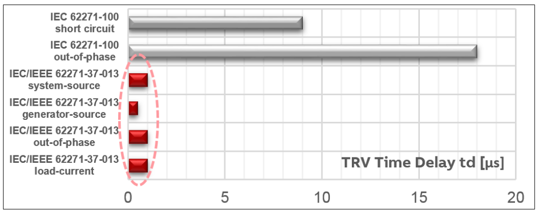

Fig. 11 Schematic comparison between TRV time delay according to Dual Logo and IEC 62271-100

## III. STANDARD SCENARIO

All these strict technical requirements provided, given by the peculiarity of the generation application, a complete Standard was needed to be developed in order to uniquely state the performances that a GCB should fulfill, to efficiently and safely protect the generation assets.

This was the scenario up to October 2015 [2][3][4]:

i. IEEE C37.013 as IEEE Standard for Generator breakers
ii. IEC 62271-100 does not include any Generator application
iii. In the IEC standards the Generator breaker application is not captured (only Cigre task force paper in 1997)

After October 2015:

i. IEEE C37.013 superseded/inactive
ii. IEC 62271-100 still does not include any Generator application
iii. The IEC/IEEE 62271-37-013 is the global GCB standard, and hence also the first IEC standard capturing the Generator breaker application

In October 2015, the new and first global IEC/IEEE 62271-37-013 Standard was developed and subsequently released to replace the old IEEE C37.013 and to close the gap in the IEC standards.

Browse Standards

**C37.013-1997 - IEEE Standard for AC High-Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis**

Reaffirmed 26-9-2008
An interpretation is available http://standards.ieee.org/findstds/interps/C37.013-1997.html
Superseded by IEEE Std C37.013a-2007 (Amendment to IEEE Std C37.013-1997)
Revision of IEEE Std C37.013-1993
Status: Active - Superseded

Fig. 12 Official note that IEEE C37.013 is superseded

The new Standard, also called “Dual Logo” Standard, is now the global reference for the Generator circuit-breakers, to be used in power plants from 10 MVA above, at rated voltages from 1 kV to 38 kV and frequencies of 50 Hz and 60Hz

## IV. HOW IT CHANGES THE GAME

Compared to the IEC Standard for typical distribution network, there is a quantum leap in terms of technical performances:

TABLE I
COMPARISON BETWEEN DUAL LOGO STD. FOR GCB AND IEC STD FOR DISTRIBUTION CIRCUIT BREAKER

| Parameter | IEC/IEEE 62271-37-013 | IEC 62271-100 |
|---|---|---|
| Short-circuit current d.c. time constant | 133 ms (corresponding to about 70% of DC component required to the CB for SSF)<br>In case of GSF, the DC component required to the CB is up to 130% | 45 ms (corresponding to 30% - 40% of DC component required to the CB) |

| Parameter | IEC/IEEE 62271-37-013 | IEC 62271-100 |
|---|---|---|
| Delayed current zeros | Requires the CB to break under fault conditions even in presence of delayed current zero phenomena | Not required – no delayed current zero phenomena considered. Intentional CB opening delay may be needed |
| Generator-Source fault Class | Introduces generator classes for the CB: G1 and G2. | No generator classes required |
| Out-of-phase breaking current | 50% of system-source short-circuit current | 25% of rated short-circuit current → CB not tested to break at high value of short circuit current in Out-of-Phase conditions (max half value of IEC 62271-37-013 one) |
| TRV rate of rise - terminal faults | Up to 6 kV/µs | Up to 3.5 kV/µs → additional equipment to be added to the plant might be needed i.e. surge arresters/capacitors/ RC filters |

Also, the dielectric level required is 1-grade higher than the IEC one: the 15 kV GCB must withstand to an insulation level corresponding to 17,5 kV IEC one (38 kV PF – 95 kV BIL).

To ensure the proper selection of the GCB for the dedicated and varying parameters of new power plants the clause 8 "Guide to the selection of generator circuit-breakers" is introduced. Here it is explained in detail how to use the dual logo standard type tests as reference to evaluate the GCB capability to meet the requirements of the quite unique characteristics of each real application.

Just to mention the main improvements introduced by the Dual Logo Standard to cover the requirements of the real application.

Similarly, some crucial differences can be highlighted comparing the GCB standard for ANSI market and corresponding IEEE std for distribution CB:

TABLE II
COMPARISON BETWEEN DUAL LOGO STD. FOR GCB AND IEEE STD FOR DISTRIBUTION CIRCUIT BREAKER

| Parameter | Unit | IEC/IEEE 62271-37-013 | IEC 62271-100 |
|---|---|---|---|
| | | Custom Design | Standard Design |
| Making capability | kA | 2,74 x Irms = Ipeak | 2,6 x Irms = Ipeak |
| Rated short-circuit cycle | | CO–30 min–CO | O–0.3s–CO–3m–CO |
| X/R ratio taken as reference (60 Hz) | | 50 | 17 |
| Time constant taken as reference | ms | 133 | 45 |
| Delayed current zeroes | | to be calculated with tool and model | No calculation required |
| Short-circuit current d.c. time constant | | 130% | |
| Out-of-phase breaking current | kA | 50% of system-source short-circuit current | 25% of rated short-circuit current |

and more in particular, even more significant the differences between the old IEEE C37.013 std. for GCB and the newly introduced and current valid one, the Dual Logo IEC/IEEE 62271-37-013:

TABLE III
COMPARISON BETWEEN DUAL LOGO STD. FOR GCB AND IEEE STD FOR GCB

| Description | IEEE C37.013 | IEC/IEEE 62271-37-013 |
|---|---|---|
| Generator-Source fault Class | No generator classes required | Introduces generator classes for the CB: G1 and G2. |
| Mechanical Endurance Class | 1000 ops | M1: 1000 ops<br>M2: 3000 ops |
| Sound test measurement | Not required | Required |
| Three-winding transformers fault case | Not detailed | Detailed |
| Degree of asymmetry calculation | Not detailed | Detailed |
| Attention for transport/storage method, safety, environment | Not detailed | Detailed |

## V. GCB MARKET SITUATION

At the moment, the main players' portfolios for medium voltage circuit breakers for generator application offers solutions for plants up to 200 MVA power level, with a breaking capacity up to 72 kA and rated voltage up to 24 kV.

More specifically, available products included in MV GCB portfolio offer:

- Standard rated voltage levels comprised in the range 15 kV – 17.5 kV, which corresponds to the most frequently rated voltage level of generators (including tolerances)
- Less frequent rated voltage levels:
  - 5 kV GCB
  - 24 kV GCB

Each voltage level/range corresponds to a specific insulation level according to the Dual Logo:

TABLE IV
(EXCEPT FOR TABLE I OF DUAL LOGO STD.) – RATED INSULATION LEVELS FOR A.C. GENERATOR CIRCUIT BREAKERS (IEC/IEEE 62271-37-013 STD.)

| Rated voltage Ur (kV) | Rated power-frequency withstand voltage Ud (kV) | Rated lightning impulse withstand voltage Up (kV) |
|---|---|---|
| Ur ≤ 7,2 | 20 | 60 |
| 7,2 < Ur ≤ 12 | 28 | 75 |
| 12 < Ur ≤ 15 | 38 | 95 |
| 15 < Ur ≤ 17,5 | 50 | 110 |
| 17,5 < Ur ≤ 27 | 60 | 125 |

- Rated current: bigger sized frames/core components and complex ventilation systems allow the current design GCB to reach even 8000A nominal current level. For current levels up to 12000A the “phase-segregated” design is crucial to guarantee the performance without overheating.
- Rated system-source-fed fault breaking capacity: typically the short circuit happening between the generator and the GCB, then fed by the rest of the network via the step-up transformer, tend to have a higher absolute value compared to the corresponding generator-fed one. This resulting from a low transformer impedance and a network connection usually near to core supply nodes to ensure an efficient infeed of energy.
  Thus, the current offer of GCBs in the market consists of products able to manage up to 72 kA short circuit currents in system source-fed fault (higher levels are possible in case of “phase-segregated” design) while the corresponding generator-fed fault level can reach up to 50 kA.
- Compliance to the Standard: the current offer in GCB market consists of:
  - Products certified according to IEC 62271-100 only, therefore usually to be used for Distribution applications and in some cases adapted to protect generator plant assets [5]. According to *Table 1*, these breakers are not tested for the more demanding conditions and all the types of faults described by the Dual Logo. Therefore the selection of such breakers for protecting the assets of a power plant should always include the evaluation of the liability aspects. Usual consequences of their use are:
    - Limited protection of the assets as some fault scenarios have to be excluded, e.g. the out-of-phase condition and sometimes also the “island mode” of the generator plant (all generators are running on one common bus, but not yet connected to the network).
    - Delay of the CB tripping to ensure that the dc- component of fault currents has decayed to a level which the CB is able to handle. This comes together with all its consequences of the protection scheme.
    - installation of RC-elements at the generator and/or at the step-up transformer to effectively decrease the TRV parameters

  Further,
  - Products certified (totally or partially) according to the IEEE C37.013, as they have been developed before the releasing of the new Dual Logo std.
    It must be taken into account that this Standard has been put in “inactive” status and that these GCBs are by nature not complying with any IEC GCB standard.
    Besides this there are different requirements in type testing as highlighted in *Table 3*. Also the proper selection of interruption ratings and classes for the real application in accordance to clause 8 of the new Dual Logo standard is only partly possible, as these are based on the type test results with specific parameter given in the new standard, e.g. 110%/130% dc component.
  - Products certified according to the new Dual Logo IEC/IEEE 62271-37-013 are the state of the art GCBs. They are type tested and certified for global use and selected in accordance with the technical requirements that reflect in the most accurate way the real field application challenges. Therefore this Standard is being more and more considered in the requirement specification of Utilities and EPC’s.

Picture 1: Sample of Generator Circuit Breaker

## VI. CONCLUSION

The alignment and creation of the first global Dual Logo IEC/IEEE 62271-37-013 standard for generator circuit breakers, and its replacement of IEEE C37.013, is a clear breakthrough. For the IEC standard it closes a white spot, which created a lot of discussions and delays in projects for decades of years, with the subsequence that customers were exposed to a liability point that can be overcome now by using Dual Logo – labelled products. It accelerates projects by detailed technical support and guidance in the correct GCB selection and global harmonization of technical solutions. It supports safety and utmost protection of generation assets by covering all highly demanding fault scenarios, e.g. including the out-of-phase condition and structuring and standardizing the delayed current zero interruption tests in such a way that the real application parameters can be proven.

In order to fully protect the generation assets, the core components of a generation plant, the Circuit Breaker must be designed and labelled according to the new Standard.

Picture 2: Sample of generator machine

## VI. REFERENCES

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