OVER-SPECIFICATION DUE TO LACK OF KNOWLEDGE

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ABSTRACT

In today's market place a few main developments can be noticed, e.g.:

1) The growing lack of technical background knowledge on both the user and manufacturer side, due to lack of training on the job

2) Decisions are made too much from the financial side, too far from the technics. Both user and manufacturer are very well equipped with lawyers and general managers, but not with the overall grid knowledge carriers

3) The rat race in spec selling on the manufacturer side, resulting in requesting too much for the application in the grid from customer side

Note 2) and 3) above seem to be contradictory, but they aren't. The user will ask more and more for the highest specifications, even if not needed at all, or not matching with other specs requested, but for the lowest (purchase) price. The motivation is always 'just to avoid any risk'. But the risk will never be zero.

INTRODUCTION

In todays high speed of economics, less and less time and effort is spent for newly hired people to really get acquainted with e.g. the application of high voltage (**HV**, includes Medium Voltage-**MV**) switchgear by training on the job. After a quite short period of time, these newbies are already considered to be able to take technical decisions. This inevitably results in asking for highest specs ever seen for an application, e.g. by a spec selling manufacturer, even if not needed at all, but just to be on the safe side. With this tendency, where all manufacturers have to deal with, the cost price can only rise.

IEC standards follow the market trend of ever increasing demands, by raising the bar on a continuous basis, e.g. by specifying extra classes and/or extra tests. In the end the only winners are the test-labs.

These tendencies, present both for the primary and the secondary switchgear are discussed in the paper with several examples. The terms used are taken from the IEC 62271 series, for HV switchgear and controlgear **[1]**.

EXAMPLES OF OVER-SPECIFICATION

Rated duration t_k of short time withstand current

The rated Short Time withstand Current (**STC**) $\mathbf{I_k}$ must be withstood for a rated duration of short circuit $\mathbf{t_k}$. IEC 62271-1, defining the common clauses for the whole series of IEC 62271, states in cl.5.8 a preferred value for t_k of 1 s **[1a]**. Despite modern protection relays with their accurate settings, even for switchgear far downstream in the network, like Ring Main Units, 3 s duration is most often specified. But in practice the Circuit-Breaker (**CB**), feeding the ring is set on 0,3 s with upstream back-up set on 0,6 s waiting time (these time-delays could be even shorter with modern protection relays). The consequence for defining t_k at 3 s instead of 1 s is that, especially for low continuous current ratings I_r, the cross-section of the conductors has to be increased with 74% for the whole length of the installation, for all three phases. This means a lot of extra material and therefore costs.

STC for earthing circuits I_{ke}

The rated Short Time withstand Current (**STC**) for the earthing circuit $\mathbf{I_{ke}}$ is often requested to be the same as the three-phase value ($\mathbf{I_k}$): In practice I_{ke} is strongly dependent on the neutral earthing of the network and will always be lower than I_k:

Isolated / Resonant earthed neutral:

For systems with Floating / Peterson coil neutral, the single phase-to-earth fault current I_{ke} can theoretically reach levels up to 87 % of the three phase fault current I_k under conditions of double-earth fault.

IEC 62271-200 **[1e]** states in table 103 that "*However, double-earth faults at independent locations in the proximate vicinity of a single phase-to-earth fault subjected switchgear and controlgear have a very low probability. Therefore this condition may not be applicable and the user may specify a reduced single phase-to-earth fault current rating*".

Low impedance earthed neutral

For networks with impedance earthed neutral, the single phase to earth current will generally not exceed 3 kA.

solidly earthed neutral

In solidly earthed networks, the 1-phase value I_{ke} will generally not exceed 60 % of the 3-phase value I_k. (60 % corresponds with kpp≈1,3 as IEC prescribes for testing for effectively earthed networks (see '*neutral treatment*' further on).

Rated peak factor for earthing circuits I_{pe}

Because of the highly resistive component of the return path through earth, the peak factor will be almost absent, so there's no need to request a peak factor equal to the 3-phase situation which is 2,5 for the standard 50 Hz IEC network (τ=45ms, see '*timeconstant.....*' further on).

Rated lightning impulse withstand voltage U_p

For most of the rated voltages $\mathbf{U_r}$ two values for the common "rated lightning impulse withstand voltage" $\mathbf{U_p}$ are defined in IEC 62271-1 **[1a]**.

In practice only the highest value of the two options for this BIL (Basic Impulse Level) is prescribed for switchgear, although in cl. 9.2 it is stated: "*For most of the rated voltages, several rated insulation levels exist to allow for application of different performance criteria or overvoltage patterns. The choice should be made considering the degree of exposure to fast-front and slow-front overvoltage, the type of neutral earthing of the system and the type of overvoltage limiting devices*"

Especially for cable connected switchgear, many times the highest rating is not needed. Also for the sake of insulation coordination the highest rating may be overdone, as e.g. (dry type) transformers might comply with the lowest value **[2]**.

Hi-Pot Cable testing

The dielectric test on HV cables (36 to150 kV) after laying can be too heavy. The (European) HD 632 S3 **[3]** specifies in Part 1, cl. 16.3 the generally accepted test level of appr. Um for 1 hour. However, Part 2 of this HD defines in cl. 8.3 as alternative an (expensive) resonant test set-up with test levels of 2,5 Uo for 10 minutes or even 3 U0. In the Netherlands this test is now generally required, leading to lot of breakdowns, as this test is unnecessarily severe. This leads to high repair costs, but even a pass does not result in "fit for purpose" for the total cable circuit as Partial Discharge (**PD**) information is lacking.

Much better as after laying test would be a **DAC** test setup (Damped Alternating Current) which is already accepted in the standard IEEE 400.4 **[4]**. It is non-destructive and contains calibrated PD localization during the complete duration of the test; in about 1 minute the cable is charged to a certain voltage level and then a full electronic switch is closed to earth to start a resonance between the cable capacitor and the external inductance, see figures 1, 2. During the oscillation on every sinewave information about the possible PD's is registered (level and distance). In case of no PD's the voltage level can be increased with e.g. 10 % for the next shot. This operation is repeated until the level of 1,73 Uo is reached. If PD's are detected, the test is stopped. In this way no damage is created to the cable and accessories during the testing. It is then known in which joint or termination the discharges occur. Thanks to common sense knowledge that is still available inside Alliander the HD 632 standard as stated in the contracts will be ignored from now on. With the DAC test three 150 kV cable-circuits in Amsterdam could be put in service in 2018 after creating a lot of damage before with the 2,5 Uo resonant tests.

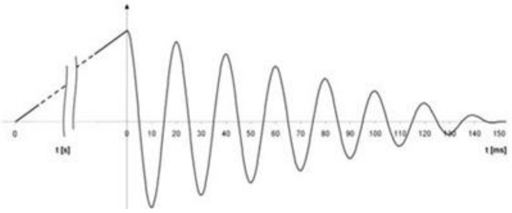

Figure 1: *DAC voltage test*

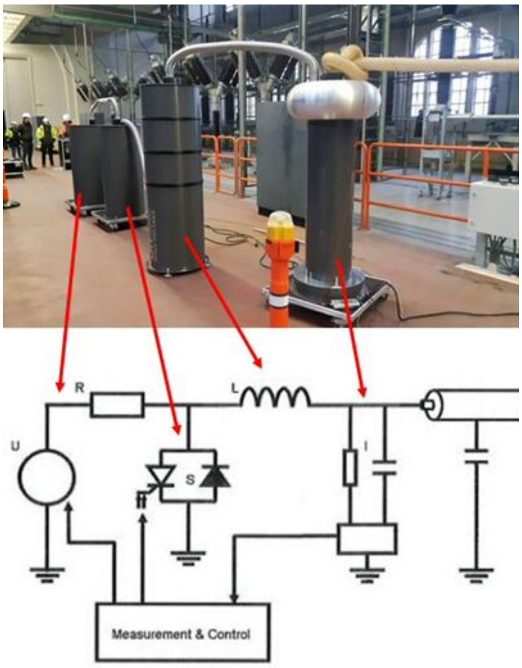

Figure 2: *DAC test in 150 kV substation in Amsterdam*

Switchgear Loss of Service Category LSC

IEC 62271-200 describes the LSC explicitly not as a class but as a category, stressing that there is no ranking in reliability or whatsoever (cl. 3.131, note 2 of **[1a]**). Despite this motivation users ask in practice per definition for the "highest" number LSC2B. This implies that in principle more than 1 compartment per functional unit should be user accessible. Modern switchgear however, simply don't need to have HV switching compartments accessible, because no maintenance or overhaul is needed inside these HV-compartments. So instead of only requiring a LSC category, the user should firstly consider which compartments are distinct-able, and then to which access is needed (provided).

The sense and nonsense of internal arc testing

An enormous amount of money is spent on internal arc testing of especially MV-switchgear. But a grid operator is responsible for the safety of the whole grid. Money can only be spent once. Within Alliander about 90 % of the immense grid is very old. But, if clever managed and maintained, this 'museum' can last for another 50 years.

The total infrastructure should be safe under all circumstances for the general public. Figure 3 presents the 3 s of the explosion of the oil content of an oil filled paper cable joint below the sidewalk (Amsterdam, 2018). The reason was the failing of the protection of an outgoing 10 kV feeder. Both the first maximum current protection and the second did not function due to the lack of 110 V auxiliary voltage. A blown fuse of less than one euro was the root cause.

When a 1-phase short circuit occurred, 1,5 km from the substation, nothing reacted and 7 kA short circuit current could sustain for about 25 s. The 10 kV cable burned out in the soil over the complete 1,5 km and finally a joint broke due to the enormous heat. On the moment the oil vapor came in contact with the oxygen in the air the explosion started.

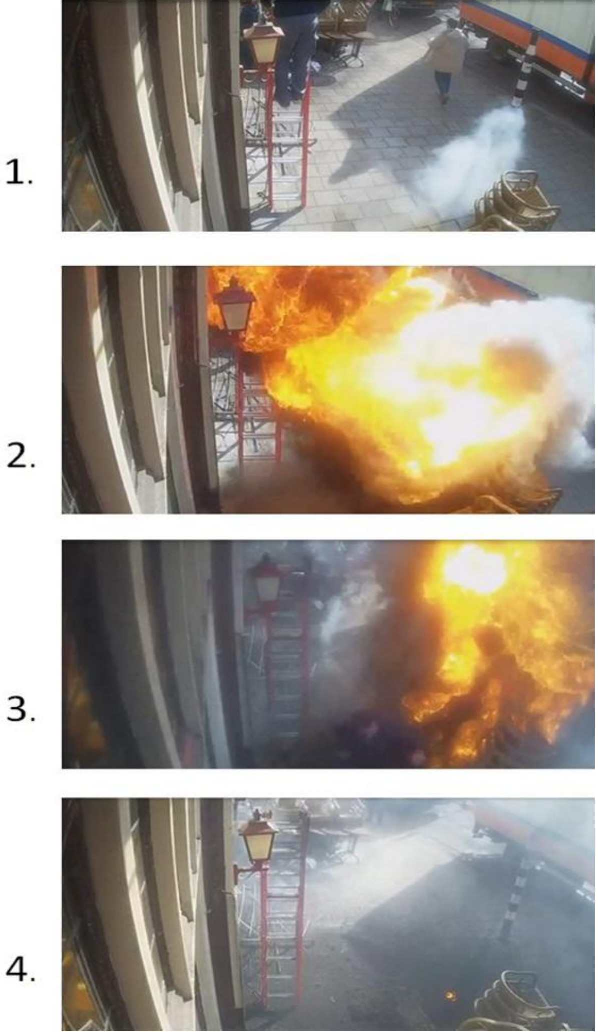

***Figure 3**: explosion of an oil filled MV Paper insulated cable joint below the pavement.*

1. *Smoke from overheated joint below pavement*
2. *The oil explosion hits the workman on the ladder*
3. *The workman jumps beside the explosion crater*
4. *Leaving a smoking hole in the sidewalk*

The only way to limit the impact of a short circuit is to make the short circuit time as short as possible. Every kind of (self-) diagnosis of, a.o., the protection can bring more profit to the society than an internal arc test. Key for the grid is, that we can always rely on quick response of the protection devices.

Switchgear Internal Arc Classification IAC

Internal Arc Classification (**IAC**) for metal enclosed switchgear finds its origin in the German "Pehla test", in the mid 70's of the former century. This test has developed over the years for the (MV-) switchgear only, without taking notice of other potential sources of arcing, like transformers, LV racks, cable joints etc. for which no ratings and tests are foreseen.

Although cl. 4.101.5 of IEC 62271-200 **[1e]**, also specifies 0,1 s and 0,5 s as recommended values, nowadays 1 s is always requested in practice, even for low end Ring Main Units. This highest recommended value of 1 s is still not in line with the 3 s STC, but can in practice not be enlarged without unrealistic strengthening measures of the enclosure (to prevent burn through).

IEC 62271-200 allows testing with air instead of SF6, stating that the results are '*considered representative*'. Apart from other aspects, this excludes the environmental and highly toxic aspects when testing with SF6.

Regarding other components, like "the low voltage section of prefabricated substations", 80% of the National Committees in IEC SC17C confirmed in 2015 the conclusions of the special IEC task force 17C/AHG3:

LV internal arc testing does not improve significantly safety in public distribution substations. Instead a higher IP degree could bring a more immediate and relevant improvement. LV arc fault testing remains as agreement between user and manufacturer in special cases. **[5]**

Also for MV switchgear money can better be spent on other aspects than on constantly increasing test demands.

Neutral treatment of network

IEC 62271-100 is the basic IEC standard for CB's **[1b]**. With the issue of Amendment 2 in 2017, extra full short circuit switching tests for CB's were introduced to cover "effectively earthed" networks (**k_{pp}=1.3**) more accurately for MV. This request does not origin from lack of knowledge, but from a surplus of (academic, HV) knowledge, not solving a practical problem for MV applications as no problems are known in this respect from the field.

Introduction of these extra tests was based on theoretical considerations of the Transient Recovery Voltage (**TRV**) on the second-pole-to-clear during current interruption. In line with the revised cl 6.102.10, Table 1 can be set-up as an example. It applies to interruption of a full rated 3-phase short circuit current, including earth in cable-connected 24 kV networks, one with floating neutral (k_{pp}=1,5) and one effectively earthed (k_{pp}=1,3). The requested TRV over - and the transferred charge (refer to **[6]**) through the opened contacts of a Vacuum Circuit Breaker (**VCB**) is presented. The minimum arcing time is set at 2 ms, as applicable for this rating of VCB.

pole-to-clear	First	Second
k_{pp}	kV / C/kA	kV / C/kA
1,5	41 / 6,7	24 / 15,2
1,3	36 / 6,7	35 / 14.3

***Table 1:** TRV requirements for TD100a at 24 kV*

Table 1 shows that indeed the second pole to clear in a effectively earthed network has to withstand a higher TRV after having a slightly lower transferred charge compared to the floating neutral network (35 kV instead

of 24 kV).
In MV both effectively ($Z0 < 3Z1$, so directly earthed in practice) as floating or impedance earthed neutral systems are present. In fact the Single earth fault testing (Full rated short-circuit current as single phase to earth fault current) is by far overdone for practice situations.
The consequence is that covering all kind of neutral treatments of a network, again extra testing is introduced which is not validated by reported problems in practice.

Time constant of the network τ, impact on CB

The IEC standard for Circuit Breakers (CB's) **[1b]** states in 4.101.2 that the standard DC-time constant τ is 45 ms and that 120 ms is stated as special case for **MV** (rated voltages up to and including 52 kV); this special case time constant recognises that the standard value may be inadequate in some systems. It is provided as unified value for such special system needs, taking into account the particular system structure in MV, design of cables, lines, etc.
A higher time constant than the standard value has its impact both on the first dynamic peak (contacts closed) and the breaking of the short circuit current.

Keeping contacts closed at first peak

According to IEC the standardized time constant τ=45 ms implies a peak factor of 2,5 (2,6 for 60 Hz) where τ=120 ms implies 2,7 (for both 50 and 60 Hz).
Examples of more precise calculation:

60Hz: {1+ e^(-8,33/45)}*√2 = 2,589, for τ = 45 ms
50 Hz: {1+ e^(-10/120)}*√2 = 2,715 kA, for τ =120 ms

Full asymmetry implies initiation of the short-circuit current at system voltage zero in at least one phase, which is generally not the case, as there always will be some pre-ignition.

Breaking the current after contact opening:

Requesting τ =120 ms implies in general a derating of 2 ratings from the R10 series, so for a 25 kA application, a standard CB 40 kA rating should be chosen, refer to **[6]**.
The alternative time constant τ of 120 ms in MV as an addition to the standard 45 ms is intended for application close to big HV/MV transformers.
The following example is given as a case from practice:

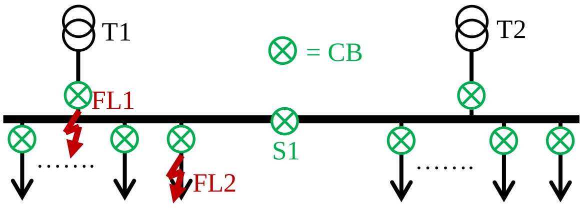

***Figure.4:** Substation MV switchgear lay-out*

In Fig. 4, T1 and T2 are HV/MV transformers, like the Alliander standard rated 150/10 kV-50 MVA or 150/20 kV-80 MVA, both having $\varepsilon_k \approx 20\%$. This implies a max short circuit current Isc≈14,4 kA, depending on tapchanger setting.

The CB's for T1 and T2 may have to interrupt this 14,4 kA with possibly a high time constant of 120 ms, when there's a short circuit directly behind the CB at busbar side (e.g Fault Location FL1). To get the τ =120 ms the connection between transformer and the corresponding CB must be very short.
If a short-circuit takes place at FL2, so at an outgoing cable, Isc could be doubled (in case the sectionalizer S1 is closed- which is generally not the case) to 29 kA and the CB of this outgoing panel has to interrupt, but now the time constant will be much lower to about 45 ms, due to the longer distances at MV side.

To determine whether or not a CB is applicable for higher time constants, calculations can be made, based on actual switching tests with other time constants, as performed in test T100a of the IEC certification tests for a CB. This testduty prescribes 100% short-circuit current with full asymmetry and is worst case scenario for a CB regarding transferred charge as described in **[6]**.
The basis for the calculations, as often used by interrupter manufacturers, is the max amount of Coulombs (A.s) with opened contacts of the CB when tripped, assuming the arc voltage is stable.
This max amount of I*t shall not be exceeded for the, under worst-case conditions, calculated values of the current with the requested higher time constant, e.g. τ=120 ms. (the peak factor will not be a problem, because the higher τ implies a lower Isc).
For example, take a (vacuum) CB with minimum arcing time 2 ms at 50 Hz with opening time between 36 and 56 ms. The corresponding peak of maximum transferred charge (refer to fig.11 in **[6]**) defines as worst case a reduction factor of 0,74 for the max short circuit current Isc when τ = 120 ms compared to the (type-tested) value of Isc for τ = 45 ms

For the Alliander example above, the CB's for the transformer could be (standard) rated $\geq$ 14,4/0,74 = 20 kA where the outgoing panels could be rated 31,5 kA if requested to interrupt with the sectionaliser CB closed.
Although the maximum short circuit rating of such transformers is often less than half of the requested overall short circuit rating, the combination of the high time constant with the overall short circuit current is usually requested.

Classes for switching devices

Several classes in the IEC 62271 family **[1]** apply to more than one switching device, like:

Mechanical endurance class M switching devices

Mechanical endurance classes are demonstrated by tests in no-load conditions. They are defined in the IEC 62271 family for several switching devices, like:

Circuit Breakers (IEC 62271-100, **[1b]**)

The "normal mechanical endurance" rating M1, good for 2.000 mechanical operations (**2k ops**) will in general not be reached in practice. However, M2 is also defined as maximum rating with corresponding 10k ops ("extended mechanical endurance").

M2 is often requested, because the customer relates this to higher reliability. But, it is of far more importance how the CB behaves when it has to trip on a fault situation after several years of inactivity; M1 or M2 gives no clue in this respect.

The number of 30k ops is already seen on the market.

Load Break Switches (LBS) (IEC 62271-103, **[1d]**)

The IEC choice for LBS is between M1 (1k ops) and M2 (5k ops). Needless to say that M2 is generally requested, even for LBS's with only manual operation.

Disconnectors (IEC 62271-102; **[1c]**)

Disconnectors have their three mechanical endurance classes: M0, being the standard one with 1k ops, M1 (2k ops) and even M2 (10k ops).

Class M2 is intended for disconnectors that are operated automatically when the corresponding CB acts.

Earthing Switches (IEC 62271-102; **[1c]**)

With the introduction of the latest edition (2018) even earthing switches have their extra M1 class (2k ops), next to the normal M0 (1k ops).

Capacitive current class C switching devices

Capacitive current switching class C1 versus C2 are distinguished both for Circuit breakers (**CB**) and Load Break Switches (**LBS**). C1 stands for **low** probability on restrike where C2 stands for **very low** probability on restrike, as restrike free does not exist.

Although the "user guide" IEC 62271-306 **[1f]** states in cl. 3.3 that class C1 is sufficient for MV CB's and for cable systems in general, in practice C2 is requested.

However, in contrast with puffer type SF6 breakers, for Vacuum CB's (VCB), if a restrike would occur, it will only be beneficial for the VCB, as the current has a curing effect on the contacts themselves, and the obvious irregularity on the contact will smooth out, resulting in the high dielectric withstand-ability across the opened contacts; the VCB is self-healing in this respect, and class C1 would be more than enough in practice for a MV Vacuum CB or LBS.

Electrical endurance class E switching devices

Regarding Electrical Endurance several classes are defined across the IEC 62271 family of standards **[1]**.

Of course no E-rating is applicable to a disconnector as no switching of currents is foreseen for such a device.

The various IEC 62271 standards pick from the list E0, E1, E2, E3, where each standard has its own interpretation

Circuit Breakers [1b]

IEC 62271-100 distinguishes between E1 and E2.

E1 stands for basic electrical endurance, and E2 for extended electrical endurance. This extended endurance means that no maintenance of the interrupting parts of the main circuit during its expected operating life is required. E2 is more or less the de facto demand in practice.

Load Break Switches [1d]

Except for E1 and E2, E3 is also specified as maximum rating with corresponding ability of 5 times closing on the full short circuit current (E1: 2 times and E2: 3 times). For application in a MV cable network, the class E1 would be sufficient for a LBS, but E3 is many times requested.

Earthing switches [1c]

For earthing switches, IEC defines classes E0, E1 and E2. **E0** has no short circuit making capacity. E0 is sufficient when absence of voltage with a voltage **detector** (refer to IEC 61243 series) can be demonstrated before closing the earthing switch. E0 can also be applied in case the actual earthing is realized by the main switching device in series with this E0 earthing switch. E1 stands for 2 times and E2 for 5 times closing on the full rated short-circuit current. In general E2 is offered / requested although in practice this rating will (should) never be needed.

CONCLUSIONS

It's a rat race to the top with specifications. Users just ask 'to be on the safe side' while manufacturers try to outspec competitors in combination with minimized cost of designs. In the end the network is not safer at all and has no higher availability, but in the meantime the use of materials and money spent have increased. It would be wise to stop this road to over-specification.

Every way of possible (self) diagnosis, e.g. to secondary stuff, brings more to safety than concentrating on over-specification of HV-installations. Money can be better spent when common sense is used more often.

An interesting question would be how many catastrophic accidents were really avoided to this overrated assets over the past 25 years.

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