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Impact of the New European Grid Code - Requirements for Generators - on Existing Conventional Generation Plants – Focus on HV Equipment

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SUMMARY

The integration of renewable energy sources into the high voltage transmission system results in fundamental changes in the load regime of the European grid. The new European Network Code "Requirements for Generators" requires high flexibility in the operating conditions of power plant generators and output substations to maintain secure power supply and grid stability. The aim of this paper is to provide some first analysis on the impact of the new voltage and frequency ranges on conventional generation plant output substations and especially on circuit breakers.

KEYWORDS

ENSTO-E – grid code – power plant output substation – voltage range requirements – frequency range requirements – high voltage circuit breaker – generator.

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1 - INTRODUCTION

Since 1986, European Authorities have the objective to develop the internal market for gas and electricity. In 2009, they set 2014 as a target for the completion of the internal market. To achieve this goal and facilitate the integration of renewable energy sources, they asked the European Transmission System Operators to write network codes in order to provide common rules, legally binding in all European countries.

Three categories of codes have been developed:

- Connection codes, that establish minimum technical design and operational requirements for grid users connection to the system
- System operation codes, that establish minimum requirements and principles concerning operational security
- Market codes that defines the rules of the internal electricity market.

The pilot code was the “Requirements for grid connection of Generators” code (RfG). This code defines technical capabilities to be fulfilled by generators to be allowed to connect to the grid.
The RfG code has just been published end of April 2016. This code is now mandatory all over Europe, in substitution to previous national laws. However, some requirements have to be specified at national level, before 2018.

The code establishes different levels of requirements, depending on the size of the generating facility and depending on the voltage level at the connection point (4 categories).

The main point of disagreement between grid operators and generation companies was the minimum time period for operation at different frequency and voltage ranges, especially in continental Europe synchronous area.

For example, the frequency range to withstand during unlimited time is doubled compared to previous rules in France (49 - 51 Hz now, 49.5 - 50.5 Hz before). At the same time, the system operation codes set frequency quality targets inconsistent with this evolution: the system must be operated between 49.95 and 50.05 Hz, the maximum instantaneous frequency deviation should be 800 mHz.

In one hand, the RfG code seems to anticipate frequency degradation, in the other hand Operating System code seems to anticipate stability. If the frequency quality stays at the current level, the new requirements are useless, but otherwise how will the existing facilities withstand the new conditions?

No one has answered to this question in a convincing way until now.

2 - FOCUS ON THE VOLTAGE RANGES

There were also a lot of discussions about voltage ranges.
The Table 1**Error! Reference source not found.** below lists the voltage range requirements of the RfG code for generation plants, first for facilities connected to the synchronous continental Europe system in the range of 110 kV to 300 kV, and secondly for the ones connected from 300 to 400 kV.

Table 1 : RfG code - Voltage range requirements

Voltage range		**Time period for operation**
110 – 300 kV	**300 – 400 kV**	
0.85 pu – 0.90 pu	0.85 pu – 0.90 pu	60 minutes
0.90 pu – 1.118 pu	0.90 – 1.05 pu	Unlimited
1.118 pu – 1.15 pu	1.05 – 1.10 pu	To be specified by each TSO, but not less than 20 minutes and not more than 60 minutes

From EDF's point of view, these tables are unsatisfactory.
To design its equipment, EDF needs voltage levels and withstand times but also the probabilities of occurrence of extreme deviations during lifetime. So do the manufacturers.
On the top of that, the maximum voltage levels are not consistent with the IEC standards. How and when will the standards be modified?

Meanwhile, how to be compliant? How to manage the risks to buy non-compliant equipment?
Generation companies have to identify the impacts of these new ranges for all parts of their facilities (from alternator to connection point). EDF began to study these impacts last year.

You can find hereafter the first results about output substation high voltage equipment.

3 - HV EQUIPMENT PROTECTION REGARDING HIGHER OPERATING VOLTAGES

An evolution of the voltage range requirements, and particularly of the maximum voltage reachable on the grid, needs to be taken into account for the equipment protections in high voltage output substations. An estimation of the different types of overvoltages that can occur in the substation, based on classical study cases, is therefore important to fix the thresholds of the apparatus used to protect the substation (metal oxide surge arrester and spark gaps) and the minimum clearing distance ensuring the overall dielectric strength. Temporary overvoltages, switching and lightning impulses have to be considered. In this paper, we consider that lightning impulse protection should remain at the same level as in the actual 420 kV grid. The consideration for switching impulses is similar but brings the issue of tripping occurrence (if the switching impulses are higher, then the surge arrester will be triggered more often) and therefore their impact on quality of service and arresters ageing through thermal stress.

For a singular operation, the calculation of the energy dissipated during a surge arrester trip on a switching impulse is supposed to stay in the limit of the conventional surge arresters used in output substations: 2000 kJ for a switching impulse on a 440 kV grid compared to 2520 kJ, the energy that can be dissipated by the arresters ($\approx 7\text{kJ/kV}_{\text{rated}}$). But from an operating point of view, the thermal ageing of surge arresters needs to be considered. A cause of the degradation of the protective characteristic of a MOSA[1] is an increase with time of the resistive component of the continuous leakage current flowing through the arrester. Increase in the resistive leakage current will cause an increase in the power losses and then an increased temperature of the arrester.

Temporary overvoltages levels depend on the local characteristics of the grid but an estimation of the maximum value can be determined, based on theoretical and real condition measurements, for the whole grid. In France, EDF has estimated this level at 1.45 pu for the 420 kV grid. Considering an elevation of the voltage up to 440 kV, the level of temporary overvoltages should not exceed 368 kV - phase to earth voltage – compared to 350 kV TOV[2] in the actual 420 kV grid. The equipment used in generation plants output substations, and more generally in the transmission system, should be able to be operated normally during those temporary overvoltages. Hence, the apparatuses used for high voltage equipment protection should stay passive. For spark gaps, the voltage threshold initiating their action is high so they can only be triggered during lightning and harsh switching impulses. Surge arresters have a defined rated voltage at industrial frequency, this value is then important to manage to check their contribution in protecting the equipment. MOSA used in generation plant substations have a rated voltage of 360 kVrms so the level of TOV will be higher than the arrester rated voltage. However, these surge arresters are able to withstand a 10 seconds TOV up to 390 kVrms so a margin still exists but will be reduced. Also, the CIGRE brochure on MOSA arresters in AC systems recommends choosing a rated voltage higher than the maximum TOV reachable at the connection point considered, a 378 kVrms rated arrester would fill this requirement.

Regarding these elements, it seems necessary for the generation plants owners to have a better vision on the frequency of the voltage ride between 420-and 440 kV on the grid to estimate the additional stresses that will occur on the protection apparatuses and eventually engage some modifications.

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[1] Metal Oxyde Surge Arrester
[2] Transient Over Voltages

4 - IMPACTS ON TRANSIENT RECOVERY VOLTAGES FOR CIRCUIT BREAKERS

The TRV (Transient Recovery Voltage) is a decisive parameter that limits the breaking capacity of a circuit breaker. In case of an increase of the transmission system's voltage near the output substation, this phenomenon has to be re-evaluated to ensure the circuit breaker breaking capacity. The risk considered here is the defect of the dielectric strength of the circuit breaker during a tripping leading to possible re-strike. Such defects would cause additional thermal and voltage stress on the equipment and a decreased availability of the power plant connection to the grid. For TRV studies, the two most important factors are the maximum voltage reached depending on the normal system operating voltage and the RRRV (Rate of Rise of the Recovery Voltage) during oscillation, which is also dependent on the frequency of oscillations. For short-circuit and out-of-phase faults, the standard IEC 62271-100 provides a two (T10, T30) or four (T100, T60, OP) parameters model to calculate the envelope under which the real TRV should be. The parameters specified in the standard for 420 kV and 550 kV grids are listed in Table 2.

$$U_c = k_{pp} * k_{af} * U_r * \sqrt{\frac{2}{3}}$$

k_{pp} first-pole-to-clear factor
k_{af} amplitude factor
U_r rated voltage
U_c TRV voltage peak

Table 2 : IEC 62271-100: parameters for TRV calculation

Rated voltage	Test duty	First pole to clear factor (k_{pp})	Amplitude factor (k_{af})	Rate of rise
kV		p.u	p.u	kV/µs
420 to 550	T100	1,3	1,4	2
	T60	1,3	1,5	3
	T30	1,3	1,54	5
	T10	1,5	0,9 x 1,7	7
	OP1-OP2	2	1,25	1,54

In the standard IEC 62271-100, the parameters used to calculate the TRV are identical between 420 and 550 kV. Therefore it is possible to extrapolate the calculation for a 440 kV rated voltage using the same parameters (see Table 3).

Table 3: Projected withstand levels of CBs in a 440 kV system according to IEC standards

Test duty	U_m = 420 kV	U_m = 440 kV
T100	624 kV	654 kV
T60	669 kV	701 kV
T30	687 kV	719 kV
T10	787 kV	824 kV
OP	857 kV	898 kV

According to the IEC definition, the TRV peak values for the different breaking types will be increased proportionally with the maximum operating voltage. In generation plant output substations, the short-circuit faults to be considered are mostly T10 and T30. The short-circuit current is indeed limited by the high reactance of the generator and the power transformer.

Higher operating voltage for capacitive current interruption is also to be taken into account and will be particularly constraining for the circuit breaker:

- The amplitude of the interrupted current is low so the arc is extinguished quickly;
- The current and voltage phase is close to π/2 due to the capacitive behaviour of the load so the voltage will be at its maximum value at current zero;
- The contact separation speed will have to be fast enough to withstand the rising voltage across the circuit breaker (1-cos wave shape) up to 2 or 3 p.u.

As we cannot detail the impact of an operating voltage increase for every breaking type, we chose to detail only the out-of-phase case because there is already a gap between what is specified by the IEC standards and the actual situation in EDF output substations.

In the case of an out-of-phase interruption, the TRV is highly dependent on the neutral grounding on both side of the circuit breaker. The IEC standard 62271-100 makes the difference between isolated neutral or directly grounded neutral for rated voltage ranging between 100 kV and 170 kV. For the 420 kV network, this standard considers that the neutral is directly grounded. However, in the French 420 kV output substations, the neutral is generally in an in-between configuration and is grounded through a 25 Ω reactance. However, in a few cases - in some hydropower plant for example – the neutral can be directly grounded.
This choice is under the responsibility of the French TSO and leads to keep the zero and positive sequence ratio (Z_0/Z_d) within the following limits:

- $Z_0 > Z_d$ in order to have $I_{sc\text{-single phase}} < I_{sc\text{-three phase}}$ which implies the neutral not to be directly grounded;
- $Z_0 < 3Z_d$ in order to limit the transient overvoltage on healthy phases during a single phase to earth fault which implies the neutral not to be isolated.

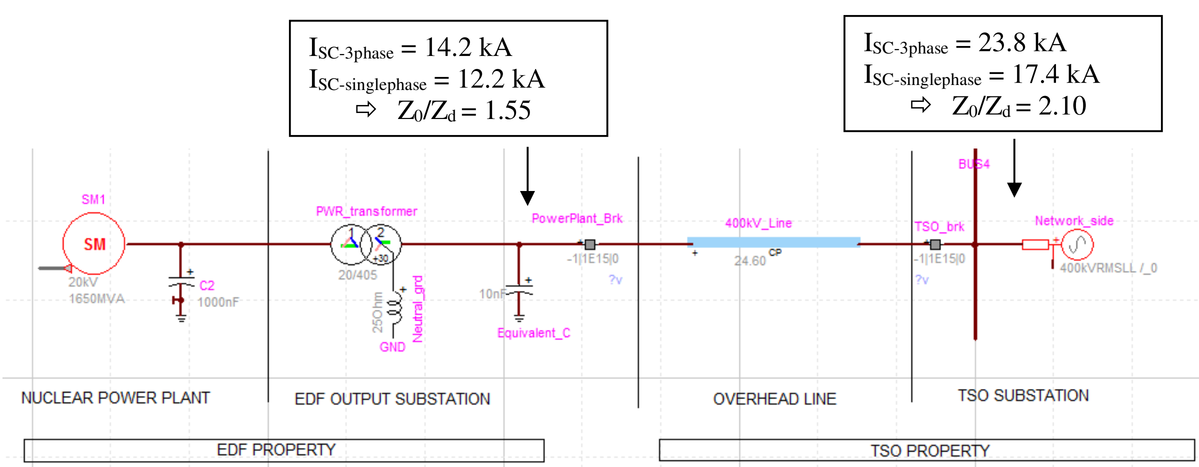
The first-pole-to-clear factor is impacted by the zero and positive sequence impedances ratio at both side sides of the circuit breaker according to the following formula:

$$K_{pp} = \frac{6p}{1+2p} \qquad p = \frac{Z_0+Z_{0'}}{Z_d+Z_{d'}}$$

K_{pp}: first-pole-to-clear factor
Z_0, $Z_{0'}$: Zero sequence impedance for both sides
Z_d, $Z_{d'}$: Positive sequence impedance for both sides

The IEC 62271-100 recommendation to consider the neutral is directly grounded leads to the minimum first-pole-to-clear factor ($Z_0/Z_d = 1$, $K_{pp} = 2$). However, this is not representative of the real situation as less than 5% of EDF output substations are covered.

We propose to calculate the first-pole-to-clear factor in a real situation. Let us consider a circuit breaker installed in a nuclear power plant output substation connected to a TSO substation through a 25 km overhead line.



In this configuration, the calculated first-pole-to-clear factor is 2.32 p.u hence 16% higher than the IEC recommendation. The TRV peak in an out-of-phase scenario would then be up to 1041 kV if the continuous operating voltage is 440 kV (compared to 994 kV if the operating voltage is 420 kV). Also, the zero and positive sequence impedances ratio of the line (between 2.5 and 2.9 p.u) might increase even more the TRV peak value.

Table 4: Specified withstand levels regarding the calculated peak value of the TRV

Specification	**TRV peak value**	**ΔU_c (%)** compared to the calculated peak value (1041 kV)
IEC 62271-100 for U_m = 420 kV	857 kV	**- 18 %**
EDF (K_{pp} = 2.3)	986 kV	**- 5%**
IEC 62271-100 for U_m = 550 kV	1122 kV	**+ 8 %**

Finally, considering the fact that an elevation of the operating voltage will increase the TRV peak value and that the IEC standard already underestimate this phenomenon, it seems that a 550 kV circuit breaker is actually the best option to support the TRV during out-of-phase interruption in a 440 kV operating voltage network (see Table 4). This refurbishment is costly, therefore before any change, a discussion with the TSO will be necessary.

5 - OTHER IMPACTS

EDF has launched R&D programs about frequency and voltage new requirements impacts on:

- Alternators
- Transformers

The question of premature ageing will be particularly considered.

Manufacturers begin to investigate on their side. The question of hypothesis to take into account about network extreme events occurrences is crucial. What about system operators?

6 – CONCLUSION

The extension of the operating voltage range for the French 225 and 400 kV grid will have an impact on the equipment, especially the circuit-breakers;

- The impact on transformers is presently under consideration; it was too early to present the results in this paper but the transformers are also a critical element in the substation regarding the new requirements from the European grid code;
- Other requirements, as frequency ranges, ROCOF, fault ride through will also have major impacts on generator's design;
- Every stakeholder (generator, customer, manufacturer and grid operator) needs to evaluate the impact on his equipment (technical and financial)..;
- Realistic operating conditions need to be described: normal operation, occurrences and characterization of extreme grid events;
- The standards need to evolve with these new requirements to be in line with the reality of the operating conditions;
- A comprehensive discussion among the grid users and the TSOs about the impact on the equipment and a revision of the IEC standards are now needed for the right application of the new RfG code.

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