European Network of
Transmission System Operators
for Electricity

DISPERSED GENERATION IMPACT ON CE REGION SECURITY

DYNAMIC STUDY

2014 REPORT UPDATE

11-12-2014

ENTSO-E SPD REPORT

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1 EXECUTIVE SUMMARY

2014 Dynamic Study release

Data and simulations of present study are updated with the latest 2014 figures collected until June 2014, after ENTSOE Regional Group inventory, based on individual TSOs information; these new elements are mainly related on a more complete picture of Dispersed Generation with additional at risk quantities not only to PV and Wind production but also introducing "other dispersed sources" (as e.g. small thermal, hydro, cogeneration,…).

A few new chapters, with aim to give a more comprehensive overview were added as well, namely:

- Pan European retrofit program proposal;
- Risk assessment concepts;
- Explicit reference to real Dispersed Generation infeed at risk.

Introduction

The interconnected power system of Continental Europe extends from Portugal to Poland and from Denmark to Turkey, and feeds a load between 220 and 440 GW.

This large system is operated in a synchronous way, meaning that, when we neglect phenomena with time constant smaller than a few seconds, the frequency is identical everywhere.

In the last decade, the penetration of distributed energy sources has increased significantly in some countries. Mostly of the renewable type, these generating units are connected to distribution systems and have been subjected to connection requirements compliant with the historical planning and operating principles of distribution systems, which were designed for passive loads. In areas of distribution grids with increased amount of dispersed generation capacity certain electrical faults cannot be managed by the existing protection schemes in a sufficient manner leading to islanding and undefined system conditions. As people safety is a major concern, the detection of the loss of connection to the main network (loss-of-mains detection) is crucial. Loss-of-mains detection is often performed through the measurement of frequency deviations and triggers generation disconnection to avoid keeping isolated networks energised. However, if applied simultaneously to a large number of units, unique frequency thresholds can jeopardize the security of the whole interconnected system in case of frequency deviations.

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Some countries have high capacities of installed distributed generation units whose protection settings for automatic disconnection from the grid are not in line with the standard disconnection limits within the transmission system.

By request of the Regional Group Continental Europe (RG CE) of ENTSO-E, several countries, led by Germany and Italy, have updated the connection requirements of new distributed generating units in order to ensure that Power Generating Module shall be capable of staying connected to the Network and operating in the range 47.5 Hz or 51.5 Hz[1] (this security requirement is also requested by Network Code on Requirements for Generators). At the same time more efficient techniques are investigated for the detection of loss-of-mains. In addition, Germany and Italy have started large programs to upgrade (or *retrofit*) a main part of the existing noncompliant units to these new thresholds. The upgrade programs are expected to be finalized by end of 2015. Due to the large number of devices, a delay until the end of 2016 might be possible.

Scope of work

The work reported here aimed at assessing the risk for the security of the interconnected system in relationship with the big amount of existing dispersed generation with disconnection settings (over and under frequency) that may jeopardize system security and identifying, if any, needs for further retrofit programs.

Work performed

The analysis was performed through simulations in Matlab/Simulink. A dynamic model of the European Continental power system was developed in order to represent the dynamic frequency behaviour. This model was validated against field measurements and generation behaviour was modelled according to currently available, approximate figures of distributed generation in Continental Europe. The principles of the RG CE Policy 1 “Load frequency control” were taken as basis and, where uncertainties subsist or for scenarios selection, realistic but pessimistic assumptions were taken.

In addition, the model includes the various disconnection settings applied to different generation technologies according to the national regulations and standards of practices in the respective countries. The main factors influencing the frequency stability in the context of this study are:

[1] In some Countries this is applied to old installations with “stage disconnection” that emulate the overfrequency regulation by droop with a gradual disconnection of clusters of plants. This is not in contrast with general connection requirement because it helps to control frequency above 50.2 Hz.

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- the amount of generation capacities tripping at given thresholds,
- the primary frequency control behaviour,
- the total system inertia provided by conventional generation depending on the system load demand and the amount of dispersed generation,
- the load characteristic during transient frequency deviation.

The simulations involve a set of rare but realistic triggering events (loss of large amounts of infeed or consumption) and take into account realistic system conditions, including initial steady-state frequency deviations due to power imbalances, e.g. caused by market effects.

Conclusions

The risk is higher at low load and in case of high generation by distributed generating units (high solar radiation and high wind), because this results in less rotating electric machines and a smaller system inertia.

The most critical thresholds are at 49.5 Hz, 49.6, 49.7 49.8 Hz and 50.2, 50.3, 50.4 and 50.5 Hz. The installed cumulated capacity *after finalization of* ongoing *retrofit* programs (assuming no new units are installed with these thresholds) is resumed in table 1.

	49.5 Hz	49.6 Hz	49.7 Hz	49.8 Hz	50.2 Hz	50.3 Hz	50.4 Hz	50.5Hz
PV	3,985	0	307	959	6,657	1,337	0	4,804
Wind	1,333	201	10	388	415	690	201	2,513
Other	1,783	201	0	894	1,109	290	0	1,674
Total	**7,101**	**402**	**317**	**2,242**	**8,182**	**2,317**	**201**	**8,992**

Table 1: Frequency disconnection thresholds and installed capacity at risk **after Italian and German retrofit** (MW) for dispersed generation in Continental Europe (source: ENTSO E questionnaire inventory of 2014). The proposed but not confirmed retrofit of the German wind, biomass and cogeneration units are also considered.

The inventory is based on data from the 17 countries comprising more than 99% of the total wind and PV capacity in Continental Europe. In order to speed up the process the remaining countries are not considered[2].

For a “normal type contingency” (loss of 2 GW of load or 3 GW of generation) the likelihood to reach one of the critical frequency thresholds is significant or even high, if the initial steady-state frequency deviation is higher than 50 to 100 mHz. For an

[2] Based on a decision by Regional Group Continental Europe (RG CE) of ENTSO-E, in order to give priority criteria, in this phase the “small contributors” are not considered; this approach don’t change the validity of results and retrofit criteria suggested.

initial deviation not exceeding 50 mHz, this probability is low except at very low demand periods.

If these thresholds are reached after *retrofit* and in case of maximal generation by the dispersed units, the consequence of the massive disconnections is that the frequency will drop to the first steps of the automatic under frequency load shedding (starting down from 49 Hz). This automatic action is able to save the system from a major system break down, but clearly consequences and events during so strong transients (additional conventional generation lost, network splitting) are unpredictable.

As long as the ongoing *retrofit* programs are not completed, however, the frequency gradient after massive disconnection of distributed generation is so high that the first step of under frequency load shedding is not sufficient to prevent the frequency to collapse in situations with high dispersed generation infeed.

Simulations demonstrate that ongoing German and Italian retrofit programs significantly reduce the likelihood of load shedding. However, even after the completion of the German and Italian programs, the probability to trigger load shedding remains significant (see table 1) with severe perturbations on the system during transients (more than 10 GW of installed capacity lost at 50.2 Hz).Therefore, additional retrofit programs in other TSO control areas are required to avoid reaching of the load shedding threshold of 49 Hz.

The maximum admissible non-retrofitted generation disconnecting at 50.2 Hz shall not exceed 4500 MW infeed (around 6000 MW of installed capacity) for the whole synchronous area.

Quantification for under frequency thresholds is less straightforward due to the existence of multiple disconnection settings between 50 Hz and 49 Hz and because these thresholds are part of a cascade after disconnection from higher frequency thresholds. However 2350 MW (around 3000 MW of installed capacity) of non-retrofitted DG infeed with disconnection settings between 50 Hz and 49 Hz is a maximum for the whole synchronous area.

Recommendations

The first action to be taken by all CE ENTSO-E members is to avoid the increase of the capacity at risk through new installations. This should be achieved through the compliance of new DG installations to the requirements given by the network code Requirements for Generators; the code is presently in the comitology process of the European Commission, modifications of connection rules at national level should be carried out in anticipation to ensure compliance to the relevant requirements. TSOs can help with these initiatives which local authorities are urged to initiate and support.

After this first step is achieved, member states should collectively ensure that the infeed of DG which can disconnected simultaneously at 50.2 Hz or in cascading effect between 49 Hz and 50 Hz remains with the limits specified above. The collected data on existing capacity at risk shows that the global infeed for the synchronous system of Continental Europe is still at present much higher than these limits. Therefore actions are needed, which may include retrofitting existing installations at member state level.

In order to share the effort throughout Europe in each member state in a fair and optimal manner, ENTSO-E recommends allocating the allowance for maximum loss of DG in over-frequency and under-frequency in each country proportional to the share of the capacity at risk. In order not to penalize countries which have already taken retrofit actions, the considered capacity at risk is counted before retrofit.

The proposed allocation is indicated in Table 2 for over frequency and Table 3 for under frequency. Each member state is urged to take measures accordingly, in order to respect these values on their system.

Future work

While member states take actions, ENTSO-E will continue to keep track (possibly in a common data base) of the characteristics impacting system security of all units connected at the distribution level in order to check that the installation at critical thresholds has been stopped.

SPD group performs periodic inventory updating numbers. The last 2014 inventory revealed additional capacity, giving a more complete picture about all sources involved in DG. The study will be periodically updated based on new findings from continuous activity of SPD group.

2 INTRODUCTION

Due to significant financial incentives and corresponding attractive producer prices for renewable and decentralized energy production the percentage of this type of generation has been increased considerably in some European countries reaching more than twenty per cent of the system load of these systems. These generation units are mainly connected to the distribution system on low voltage levels.

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In the same time, based on the re-structuring of electricity markets and the related operational boundary conditions, the quality of the common system frequency has also decreased. More and more often and for longer time periods the system frequency of the Continental European system deviates from the setpoint by exceeding 49.9 or 50.1 Hz which corresponds to an activation of more than 50% of the positive or negative primary control reserve.

Currently for most of the distributed generation units the protection settings for automatic disconnection from the grid are not in line with the standard disconnection limits within the transmission system. This results in some countries with a significant capacity of installed non-compliant generation units with respect to interconnected system stability.

The settings for distributed generation are in the range of 50.2 - 50.5 Hz for over frequency and around 49.8- 49.5 Hz for under frequency while the ranges to mandatory remain connected within the transmission system is 47.5 - 51.5 Hz. The complete picture related to 2014 is depicted in Figure 1.

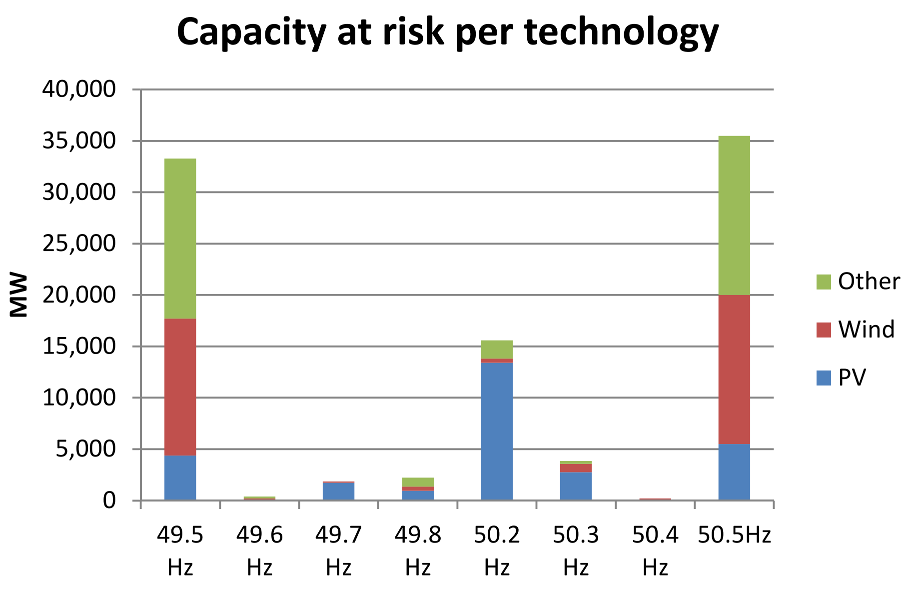

Figure 1: Total capacity of Dispersed Generation at risk in 2014 (source: ENTSO E SPD 2014 questionnaire)

Consequently the risk of serious system disturbances due to an uncoordinated disconnection of a high amount of distributed generation corresponding to a multiple of the available primary control power reserve cannot be excluded anymore. It can be foreseen that the resulting system balance might be managed only by the activation of large scale under frequency load shedding.

The present report describes the analysis performed for defining the required amount of distributed generation, which will have to be refurbished by changing the disconnection settings in order to mitigate the above described risk.

The report is based on a dynamic model analysis with related model parameters derived from the input of the major affected TSOs impacted by significant infeed of distributed generation as well as on dynamic model calibration based on comparison between measurements and simulation of recent important events.

3 SCENARIO SELECTION

With respect to the security analysis it is necessary to consider load/generation scenarios in the whole possible range from the most critical to the less critical values. To this aim the load demand curves in Continental Europe for the third Wednesday in each month of 2012 are used, see Fig. 2 (The demand of Turkey is not included in these figures, which is estimated in the range between 20 GW and 40 GW).

Figure 3 shows the load duration curve, which corresponds to the load demand curves in Figure 2. Based on these figures the total demand of the CE region including Turkey varies in the following range:

- Maximum demand: 440 GW
- Mean demand: 360 GW
- Low demand: 220 GW

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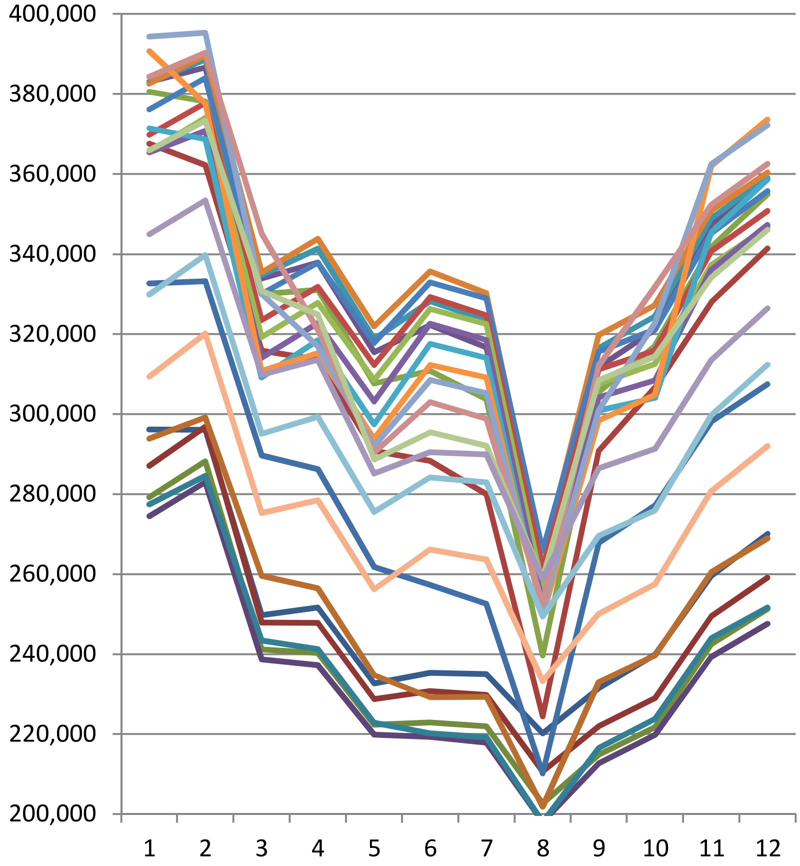

Figure 2: Total demand in MW of the Continental Europe region, third Wednesday of each month in 2012 (without Turkey) /Source: ENTSO-E

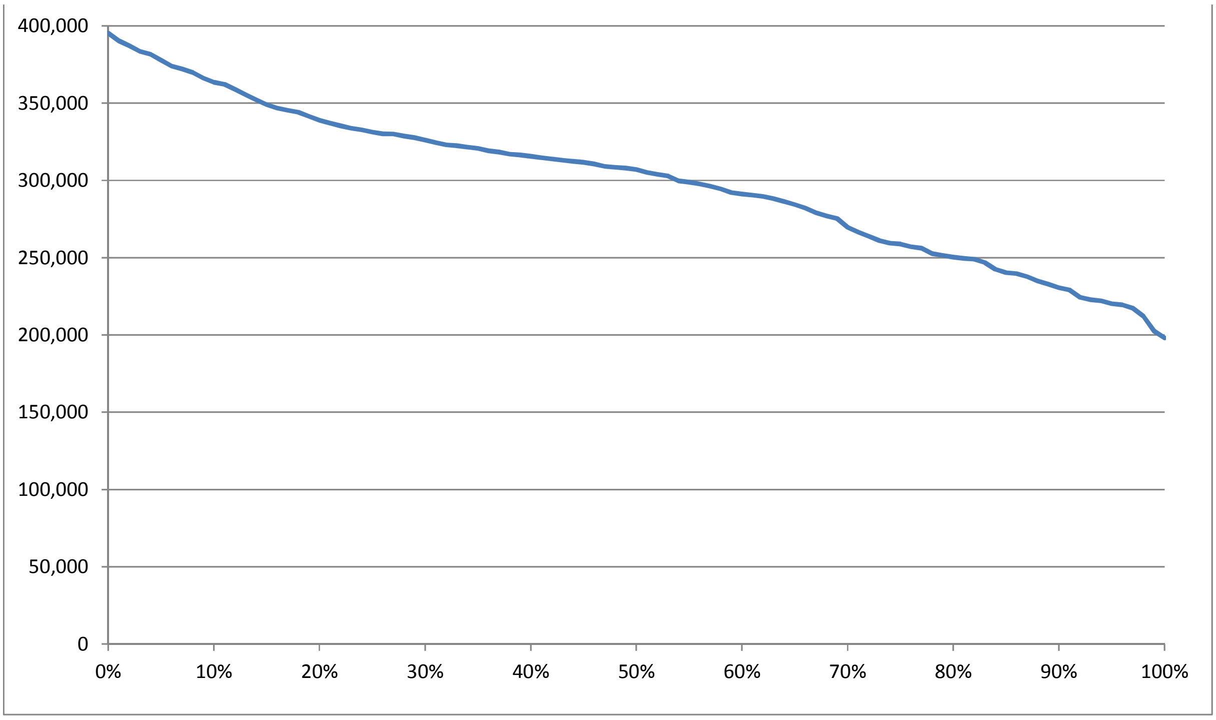

Figure 3: Load duration curve in MW for the third Wednesday of 2012 (without Turkey)

The scenario with maximum infeed of dispersed generation was estimated from the installed capacities tripping at different frequencies (Table 1, Figure 1) and the corresponding coincidence factors of each generation technology given by the TSOs. The table shows the status of dispersed generation in continental Europe, based on data collected by ENTSO-E up to the year 2014. The most critical frequencies are 50.2 Hz; 49.8 49.7 Hz and 49.5 Hz, where high amounts of PV, wind and other generation sources disconnect. Figure 4a and 4b report the detailed Italian and German retrofit plans.

As can be seen from Figure 5 and Figure 6 the capacity at risk is very unevenly distributed across the system.

The data in Figure 5 and Figure 6 is based on the best information available for the TSOs. However, it should be emphasized that not all information has been crosschecked with national DSOs. In any case, it is a good estimation of total quantities, in agreement with public data and sufficient starting point for the study evaluations.

It must be underlined that figures 4, 5 and 6 reflects the ongoing status of retrofit programs basing on the current status as provided by TSOs.

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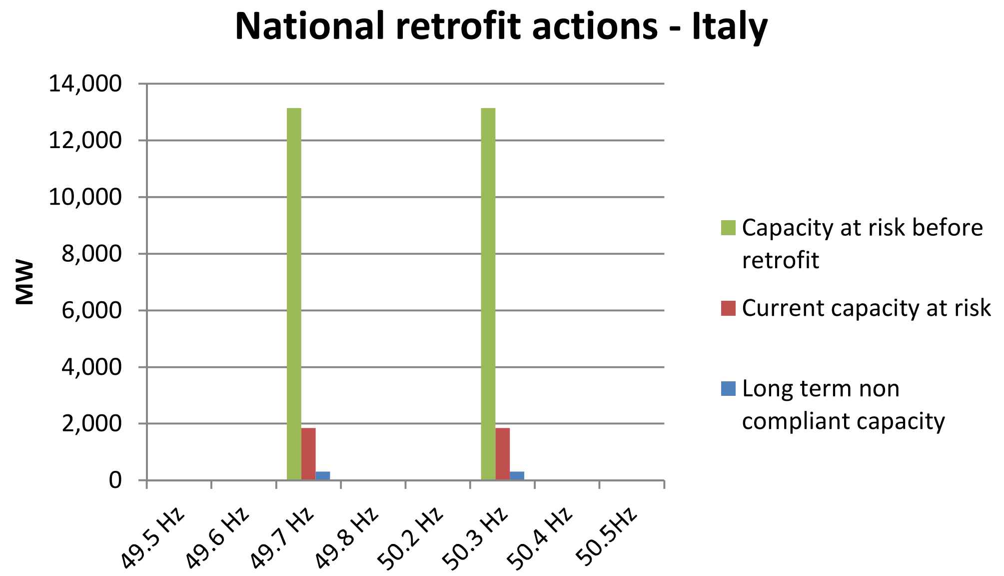

Figure 4a Impact of the committed retrofit program in Italy for PV and wind. The “current capacity at risk“ is from September 2014.

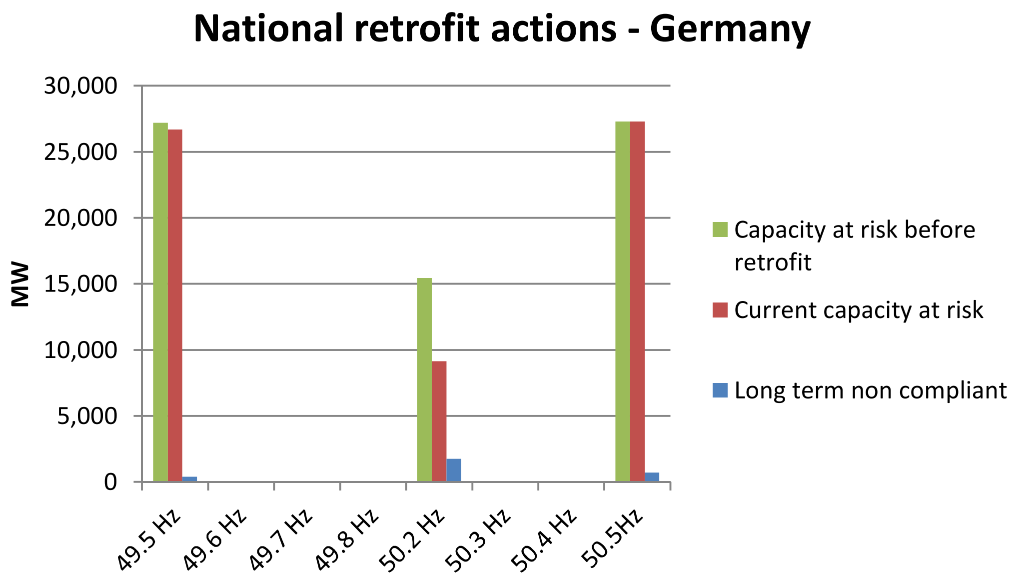

Figure 4b Impact of the committed retrofit program in Germany for PV, wind and “other”. The long-term situation is expected at the end of 2015. The current capacity at risk is from September 2014.

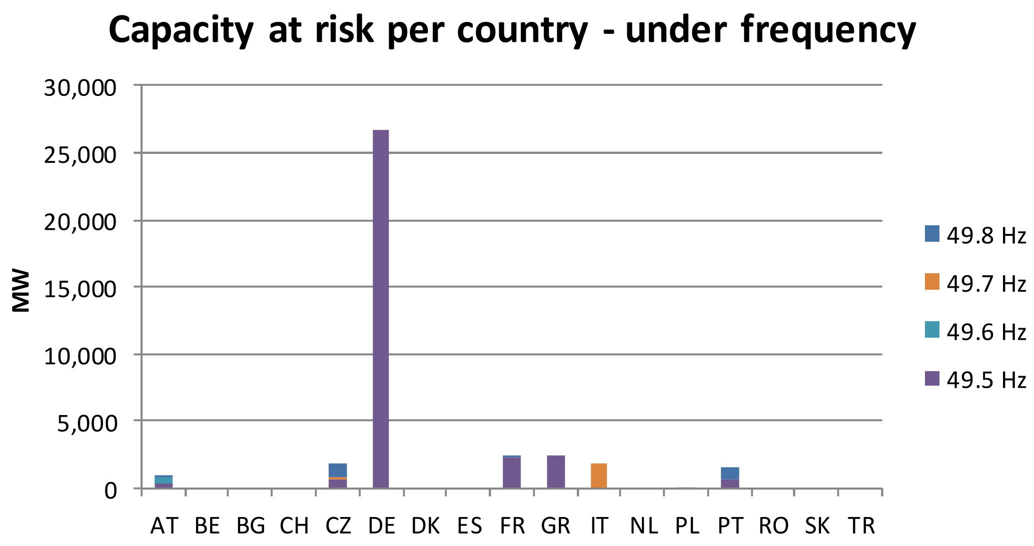

Figure 5: Installed capacity at risk for country and under frequency considering the currently implemented retrofit actions in Germany and Italy. Only countries which have indicated a risk above 49.5 Hz are included.

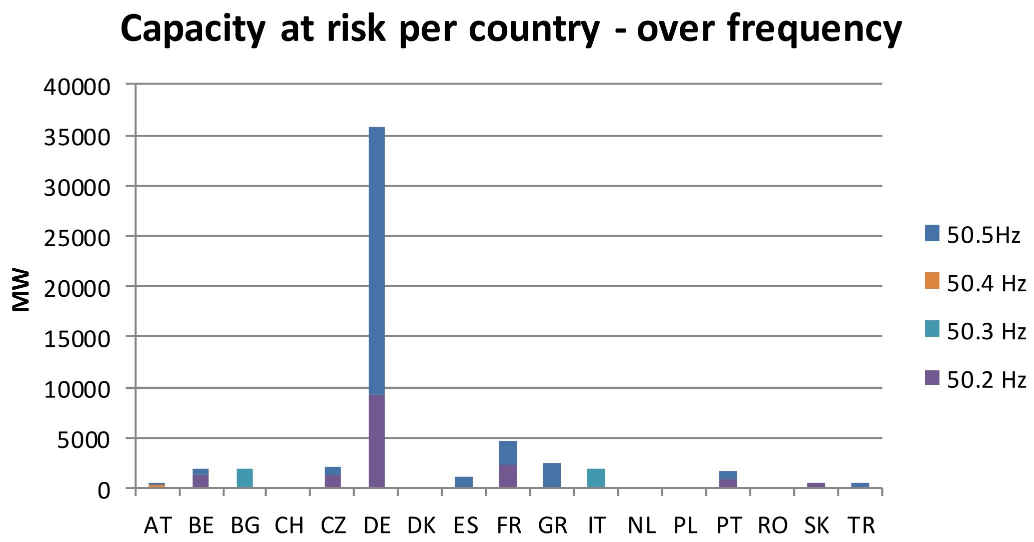

Figure 6: Installed capacity at risk for each country for over frequency considering the currently implemented retrofit actions in Germany (September 2014) and Italy. Only countries which have indicated a risk below 50.5 Hz are included.

4 RISK ASSESSMENT IN THE CE REGION

4.1 CLASSIFICATION OF INCIDENTS

With respect to risk assessment it is worth to recall the following standard classification of incidents according to Operational Security Network Code[3] of ENTSO-E:

- Normal incidents,
- Exceptional incidents,
- Out of range incidents.

Incidents are classified as normal, when the triggering event is a single failure. Normal incidents have to be managed by the system in a secure manner, which means that the function of the system has to be maintained without violation of any technical limits. In case of exceptional contingencies interruption of transits or supply is accepted, however the integrity and stability of the system must be ensured. Out of range contingencies might have severe consequences and might be not controllable for the system. In order to avoid a total blackout in such a case a Defence Plan is generally implemented.

In the context of this study such incidents are relevant, which are related with power imbalances and frequency control. Using the above mentioned principles **normal incidents** are:

- loss of load ≤ 2 GW or
- loss of generation ≤ 3 GW,

which might be caused by single events like:

- trip of the HVDC link between France and Great Britain in export conditions or
- busbar failure with generation loss.

The combination of two or more events is considered as **exceptional incident** like:

- loss of load > 2 GW,
- tripping of generation with deficit between 3 GW and 6 GW,

An example for **out of range incidents** are multiple contingencies leading to system splitting with high surplus/deficit of the power balance in different areas.

Normal incidents are investigated in the simulations reported in following chapters.

[3] draft version submitted to ACER by 1 March 2013.

4.2 DETERMINATION OF CRITICAL CONDITIONS TO REACH 50.2 HZ

This chapter is dealing with the security risk in the current situation until the ongoing retrofit program in Germany is finished. It is obvious that the frequency shall not cross the first disconnection threshold at 50.2 Hz during time periods of high infeed by solar panels, as a huge amount of PV panels are disconnected at 50.2 Hz. The resulting power deficit cannot be managed by the system; even automatic load shedding might not prevent the system against system collapse due to high frequency transients and extreme variation of the load flow pattern causing risk of overloading of transmission lines. That means in the current situation it has to be ensured that the frequency remains below 50.2 Hz after normal incidents during daytime.

Several simulations in the different scenarios considered by the study were carried out in order to determine the admissible amount of load to be lost, when 50.2 Hz shall not be reached. The results are resumed in Fig. 7, where the box coloured in violet represents the loss of 2 GW of load, which has to be considered as the maximum load, which can be lost after a single fault/normative incident in CE.

The simulation results can be summarized as follows. In case of a single fault/normative incident with loss of 2 GW of load:

- starting at 50.0 Hz there is practical no risk to reach 50.2 Hz,
- starting at 50.05 Hz the risk is evident only during very low demand periods (around 220 GW),
- starting at 50.1 Hz the risk is real also at typical load demand (around 360 GW).

The dynamic frequency behaviour can be confirmed by real incidents recorded by WAMs. Figure 8 shows the frequency after loss of 2000 MW during typical load condition. The transient frequency deviation was 80 mHz and the steady state value around 60 mHz.

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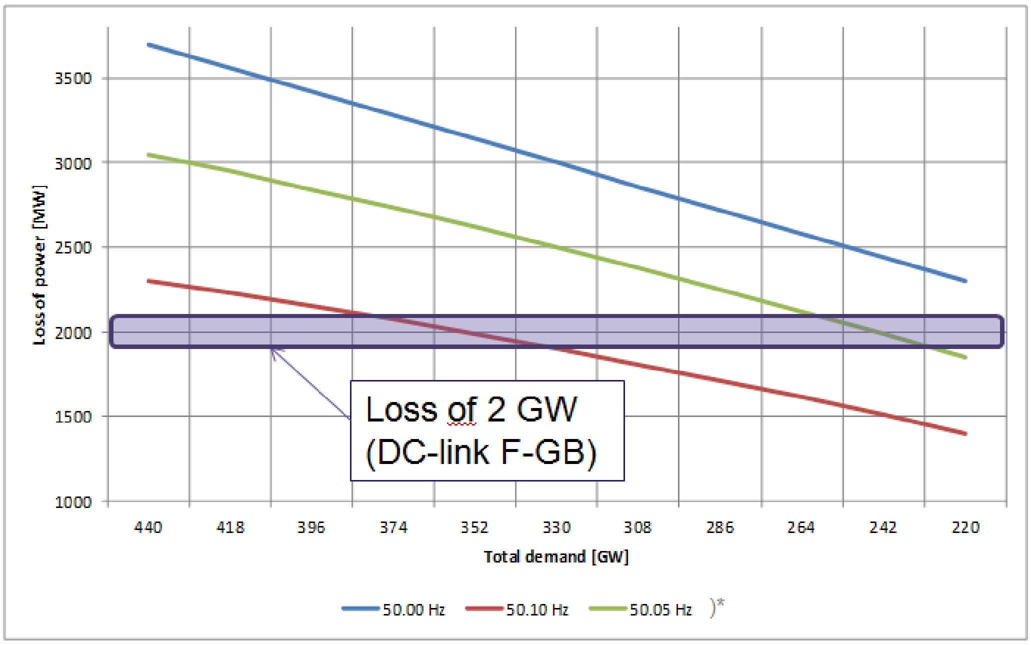

)* stationary frequency before the incident

Figure 7: Loss of load leading to 50.2 Hz depending on total system load based on the model results

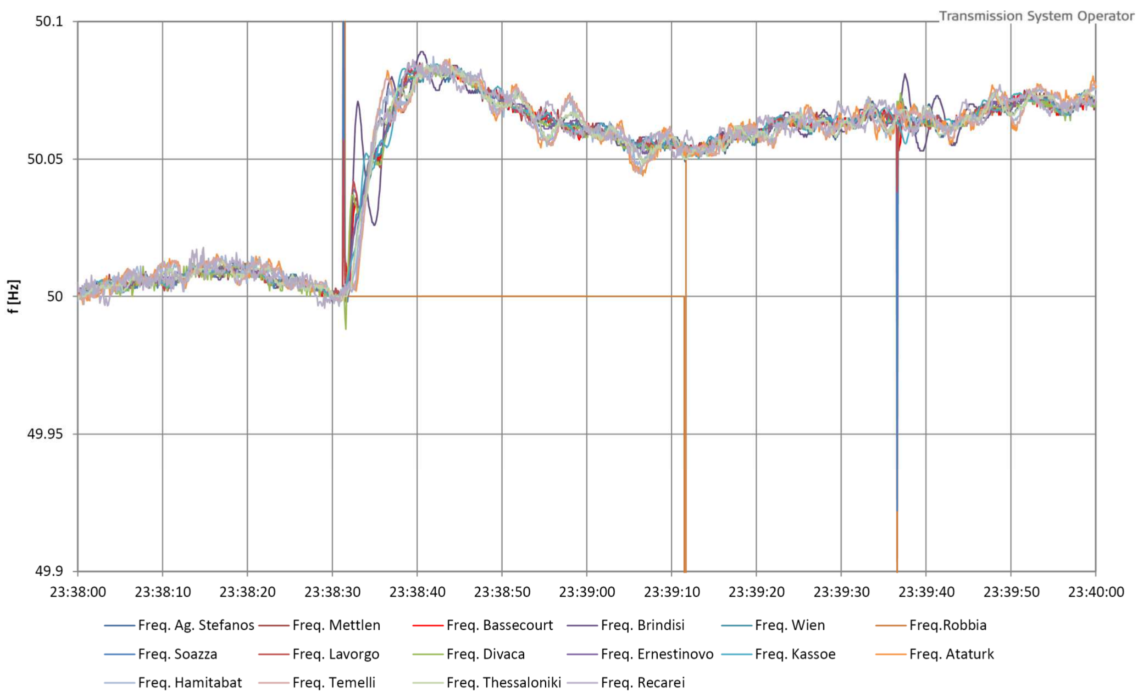

Figure 8: Recording of system frequency after loss of load on 4th July 2012 (Source: Swissgrid).

Considering the report "Assessment of the System security with respect to disconnection rules of Photovoltaic Panels" it can be quoted that two new phenomena cause significant increase of frequencies up to about 150 mHz:

- *during the daily main load ramping period during morning and evening hours and simultaneous connection/disconnection of large amount of generation units*
- *loss of a DC link with interruption of power export from the CE system to other* synchronous areas

The combination of these events might lead to a higher increase of the frequency of more than 200 mHz and consequently to an over frequency above 50.2 Hz. From the current experience this scenario is less probable during midday, when there is high infeed from solar panels.

In contrast to this previous assessment it must be noted based on recent operational experience that there is a real possibility to reach a steady-state frequency over 50 Hz in normal operation during midday. This risk is evident, like 04/05/2012 midday, Figure 9, when a frequency around 50.1 Hz was reached as steady-state frequency during normal operation.

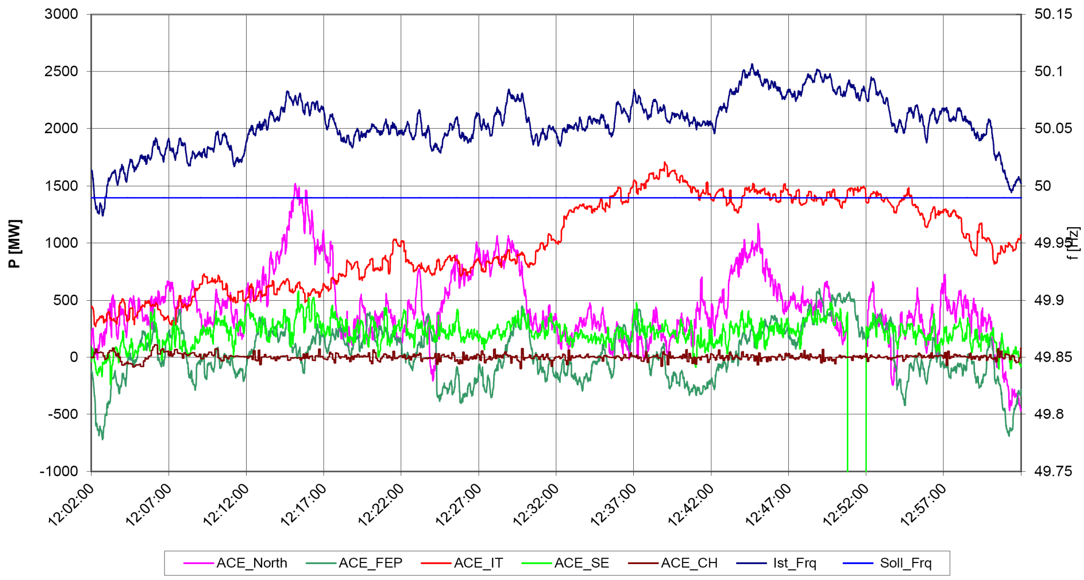

Figure 9: WAMs recording of the frequency on 4/5/2012 (Source: Swissgrid).

Figure 10 shows that the duration and number of occurrences of frequency deviation from nominal value outside the range +/- 75 mHz was increasing during the last years; in particular this phenomena was present during 36.6 hours in 2012 against 28.5 hours in 2011. This corresponds to an increase of 28% within one year.

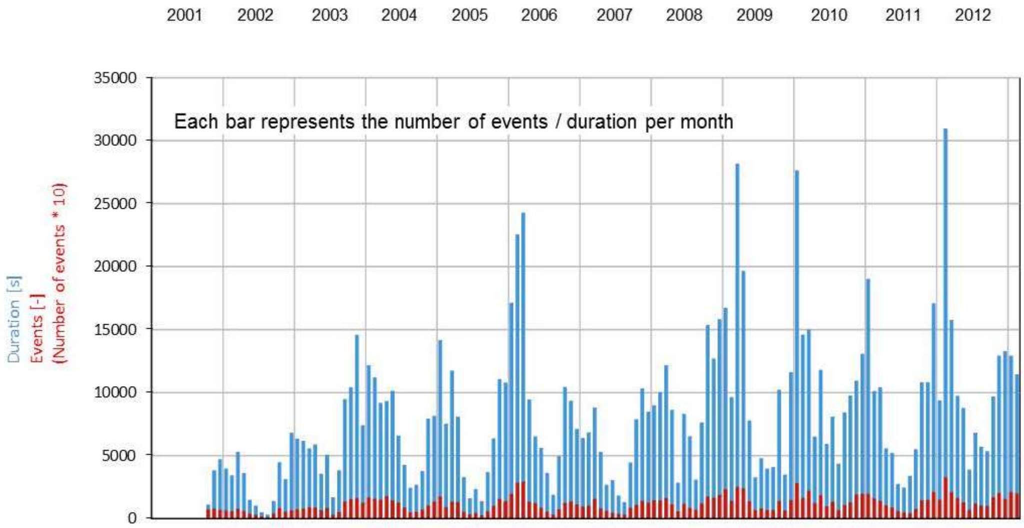

Figure 10: Duration and number of occurrences of frequency deviation (exceeding ±75 mHz), year 2001 - 2012

It shall be considered that during normal operation, significant power export over the existing DC links from CE to other synchronous areas and forced outages of those links corresponding frequency deviations might occur. These considerations show that

- at typical load demand, a load trip around 2000 MW (or, in worst case, 3000 MW) causes a frequency increase around 100 mHz
- during normal operation, without events, frequency can be in steady-state between 50.05 Hz and 50.1 Hz or even higher

The coincidence of these situations can drive the system to 50.2 Hz and consequently cause a severe risk for the system to collapse. Therefore there is a need for actions in order to keep the steady-state frequency below 50.1 Hz during daytime. Operational measures were already implemented by the TSOs in the CE region.

4.3 Analysis of Retrofit Scenarios

The effect of different contingencies on the system frequency was analysed under consideration of different scenarios for retrofit programs. The applied contingencies are to be considered as normative incidents and therefore have to be managed in a secure manner, especially load shedding should not be activated; in case of load shedding the assumption is that ENTSOE system activates load shedding plan according to Policy 5 prescriptions.

Case 1: Over frequency behaviour

Initial contingency: Stationary over frequency at 50.1 Hz and loss of load causing frequency above 50.2 Hz, see Figure 11.

Case 1a – After actual retrofit programs: Loss of 6253 MW of dispersed generation capacity (corresponding to 8182 MW of installed PV (mainly) at 50.2 Hz). Worst case scenario at a sunny day.

The 50.2 Hz threshold is reached after loss of 2 GW load starting at 50.1 Hz. Due to the generation loss the frequency decreases and reaches the threshold 49.8, 49.7, 49.6 Hz after a few seconds, where additional generation of 717 MW trips (corresponding to 893 MW of installed dispersed generation, which are currently not included in the ongoing retrofit programs). The simulation in under frequency take correctly into account the generation already tripped at 50.2 Hz, subtracting it from "at risk" quantity). When the threshold at 49.5 Hz is crossed triggering the loss of 6158 MW of dispersed generation capacity (corresponding to 7805 MW of installed estimated amount of dispersed generation, which trips due to non-retrofitted PV, wind generation and "from other sources" units). In this case the impact on the system is only managed with heavy intervention of the automatic load shedding schemes.

The simulation shows the need for further retrofit programs. Especially the remaining amount of generation from PV and wind, PV and other sources tripping at 50.2 Hz and 49.5 Hz respectively is too high.

Case 1b – after retrofit recommendation: Loss of 4500 MW of dispersed generation capacity (corresponding to 6000 MW of installed PV (mainly) at 50.2 Hz.

In order to prevent any further cascading effects due to crossing other disconnection thresholds the frequency must not cross 49.7 Hz, because at this threshold generation capacities would trip followed by frequency excursion to the next lower disconnection threshold at 49.5 Hz.

On the other hand, the crossing at 49.8 Hz causes some additional trips, but great part of this trips are already activated at 50.2 Hz, so this threshold it is included into needed retrofit programs.

The simulation shows that the dynamic frequency deviation is stabilised just above 49.7 Hz. Consequently the loss of 4500 MW of infeed (corresponding to 6000 MW of installed capacity) is the maximum amount of generation trip at 50.2 Hz in order to meet the requirement, that crossing this critical threshold shall be managed without further cascading effects or activation of load shedding.

Case 2: Under frequency
Initial contingency: Loss of 3 GW generation starting at 50 Hz causing under frequency, see Figure 12.

Case 2a - **After actual retrofit programs:**
Disconnection of:

- 1785 MW of dispersed generation capacity (corresponding to installed capacity of 2242 MW) at 49.8 Hz;
- 238 MW of dispersed generation capacity (corresponding to installed PV capacity of 317 MW) at 49.7 Hz;
- 341 MW of dispersed generation capacity (corresponding to installed capacity of 402 MW) at 49.6 Hz;
- 5615 MW of dispersed generation capacity (corresponding to installed capacity of 7101 MW) at 49.5 Hz.

Due to the generation loss, the frequency is decreasing and crosses 49.8 Hz, 49.7 Hz, 49.6 Hz and 49.5 Hz. At each threshold the disconnection of dispersed generation is triggered. The simulation shows that the remaining non-compliant capacities still cause the risk of load shedding activation. This is not acceptable, because the loss of 3 GW of generation is considered as a normative contingency.

Case 2b - after retrofit recommendation:
Disconnection of:

- 86 MW of dispersed generation capacity (corresponding to installed capacity of 110 MW) at 49.8 Hz;
- 170 MW of dispersed generation capacity (corresponding to installed capacity of 230 MW) at 49.7 Hz;
- 2093 MW of dispersed generation capacity (corresponding to installed capacity of 2660 MW) at 49.5 Hz.

Based on this assumption the loss of 3 GW of generation can be managed without triggering the load shedding plan. In total the simultaneous loss of DG in the range between 49 Hz and 50 Hz amounts 2350 MW (corresponding to installed capacity of 3000 MW). The final numbers of the admissible non-compliant capacities at different thresholds shall be adjusted under consideration of technical aspects of possible retrofit programs.

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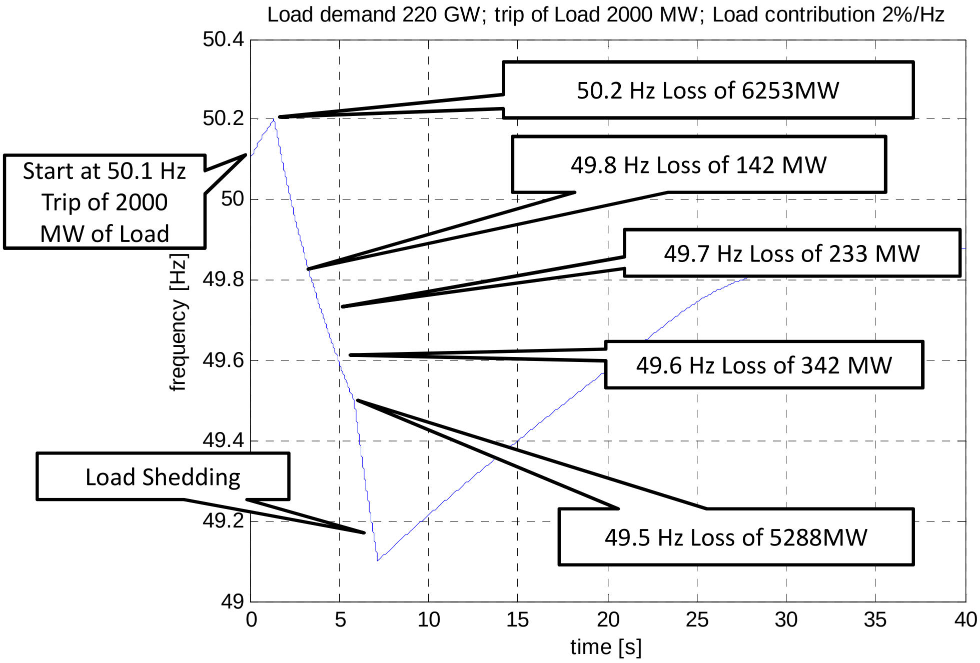
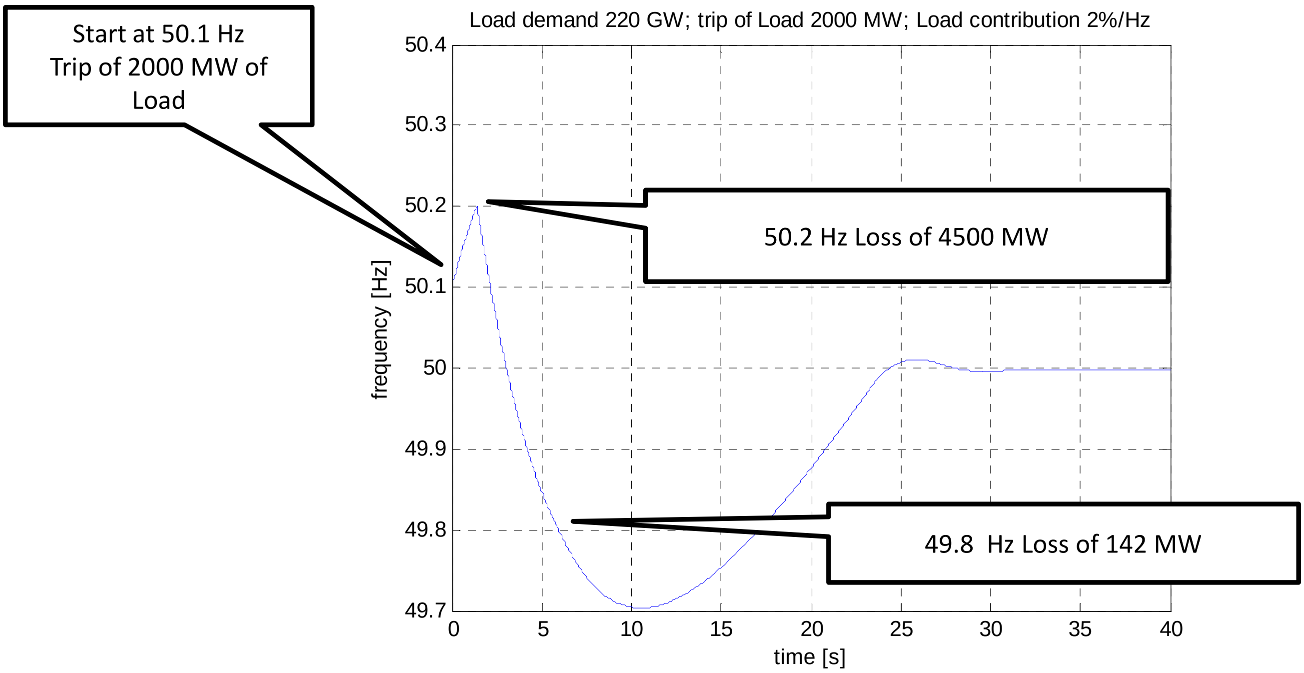
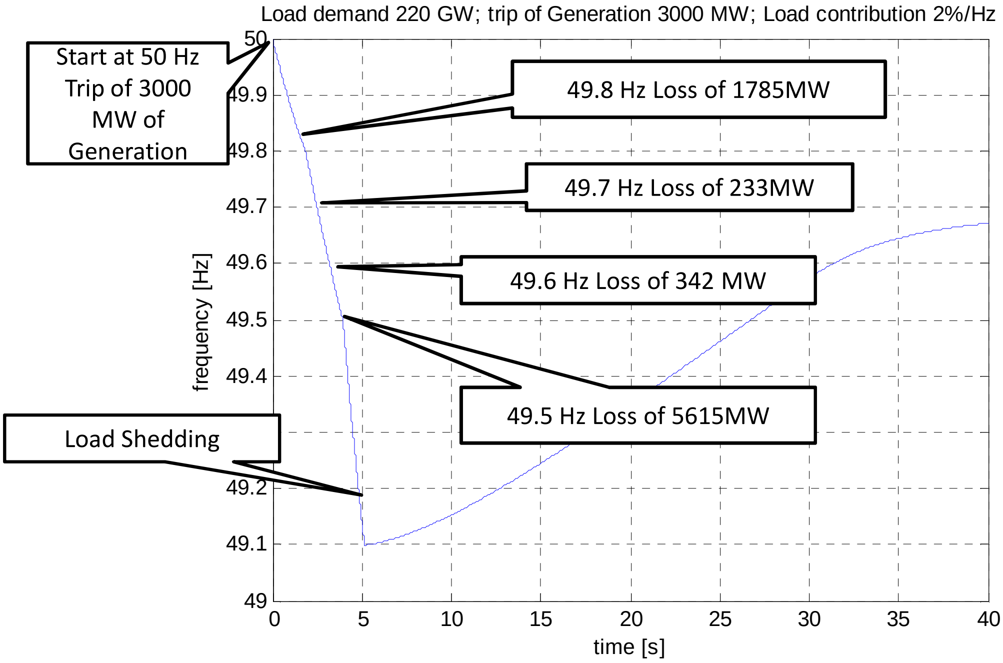


Case 1a: Simulation of 2 GW load loss after Italian and German retrofit (MW) for dispersed generation in Continental Europe. The proposed but not confirmed retrofit of the German wind, biomass and cogeneration units are also considered.

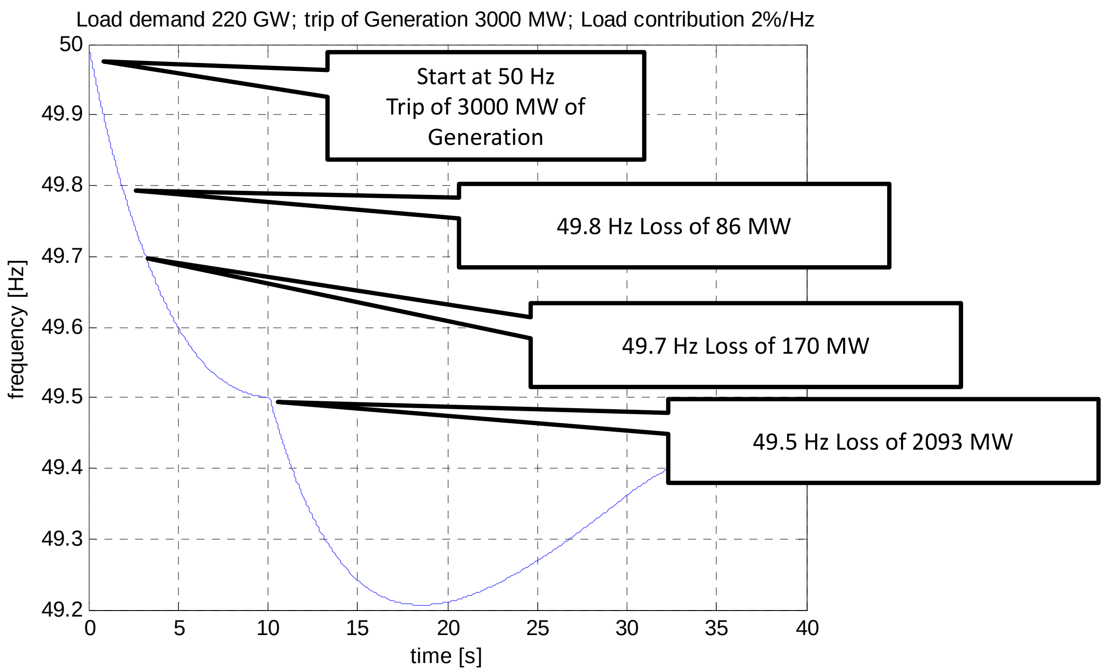


Case 1b: Simulation of 2 GW load loss with retrofit recommendation at 50.2 Hz

Figure 11: System frequency behaviour after crossing 50.2 Hz for different retrofit scenarios



Case 2a: Simulation of 3 GW generation loss after Italian and German retrofit (MW) for dispersed generation in Continental Europe. The proposed but not confirmed retrofit of the German wind, biomass and cogeneration units are also considered.



Case 2b: Simulation of 3 GW generation loss with additional retrofit for 49.5 Hz

Figure 12: System frequency behaviour after loss of 3 GW generation for different retrofit scenarios

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4.4 AUTOMATIC RECONNECTION

With reference to dispersed generation, it is possible to distinguish between different potential causes of trip:

1. Local fault, that involves a few plants in a limited area: this kind of fault must be selectively eliminated by corresponding protection settings;
2. System frequency excursion, that drives the frequency out from the range prescribed for the distributed generation plants (47.5 Hz … 51.5 Hz)
3. Abnormal over frequency excursion that implies a regulation obtained by controlled trip of cluster of plants.
4. Other local causes (voltage, internal fault, etc.)

Due to the enormous quantity of dispersed generation plants, it is not possible for the TSO under frequency coordination process, to manage the gradual reconnection acting on single site. On the other side, the system needs as soon as possible the contribution from dispersed generation, in order to restore balance between loads and generation.

Due to these reasons, it is necessary to assume a transitory phase that will bring the system toward the smart grid control where it can be handled with the following rules: an automatic reconnection rule can be accepted, but limited to type A, B and C plants, with reference to ENTSO-E Connection Grid Code. For D type plants, typically under direct TSO control, the automatic reconnection must be forbidden.

The main requirements for the system security are:

- The plant must recognise that frequency it stable;
- The ramp of the plants that are automatically reconnected must be sustainable by the system

The check of frequency stability can be done by defining a range where frequency is contained for at least a certain time interval; the proposed logic it is displayed in Figure 13.

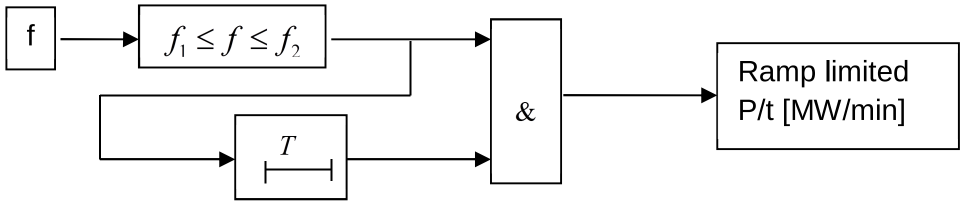

Figure 13: Block scheme for automatic reconnection

The recommended settings are:

- Frequency stable in the range between 49.9 (f_1) Hz and 50.1 (f_2) Hz
- Delay time T: from 60 to 300 s, established by single TSO
- Maximum gradient of ramp limited delivered power: ≤ 20% of maximum power / min

The suggested criteria imply a revision of ENTSO-E P5-C-S3.7 “RECONNECTION OF GENERATORS AFTER ABNORMAL FREQUENCY EXCURSION”, designed explicitly in order to avoid the uncontrolled automatic reconnection of large power plants (now in the ENTSO-E grid code, named “D” type).

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5 Cost Benefit Analysis

ENTSO-E approach to low probability risks with extremely high consequences in the area of Continental Europe is based on the current Operation Handbook (OH), Policy 1: "Load-Frequency Control and Performance". Furthermore, with respect to frequency control, the future Network Codes, are based on power system stability considerations. These prescriptions are "design oriented"; this means that the basic ENTSO-E approach it is deterministic and not probabilistic.

A power system is designed to meet specific security standards, i.e. to withstand a specific set of contingencies. Conventionally, the contingency list includes the contingencies that can be conceived in normal system operation without taking into account rare extraordinary events.

For example, a building has to have stairways for evacuation in case of fire regardless of whether they will ever be used and how low the probability of such an incident is. The consequences are too high. This is a matter of design. Similarly, there are defibrillators in offices. This too is a matter of design. Again, the consequences of not having them are too high regardless of the negligible probability that they will ever be used. Fire and heard attack are conceivable under normal circumstances and that is why the stairways and the defibrillator are foreseen.

The occurrence of contingencies not specifically foreseen in the design of a power system (named out-of-range contingencies) is conceivable too, but not in normal operation. Such contingences could result in a violation of operational limits, supply interruptions and, in the worst case, a system blackout. Such risks are in principle accepted for out-of-range contingencies, but in no event for designed contingencies. To mitigate the consequences of out-of-range contingencies TSOs generally implement special schemes in form of the Defence plan as a last resort measure. This, however, doesn't belong to normal operation.

5.1 Frequency management

The security rules of OH Policy 1 are deterministic based on TSOs' experience and expertise[4]. These principles are also the basis for Network Codes on load-frequency control. For the Continental European synchronous area, the maximum instantaneous power deviation is defined to be 3000 MW. Based on the operational

[4] N-1 conditions in which the largest outage of conventional power plants in Europe amounts to 3000 MW (outage of two nuclear power units connected to the same bus-bar) and the largest outage of conventional load amounts to 2000 MW (outage of the HVDC link France-England) or more, as demonstrated in the study

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characteristics concerning system reliability and the size of loads and generation units, a contingency leading to a power imbalance of 3000 MW is considered as a conceivable, but low probable contingency.

However, without adequate countermeasures the consequences of a 3000 MW power imbalance would be immense. Loss of frequency stability resulting in a total system blackout is a probable scenario. The consequences of a system blackout are not calculable.

This is a low probability / high impact contingency. As such, it is treated deterministically. A probabilistic approach or a cost-benefit analysis is not applicable. Therefore the Continental European power system has been designed (in terms of control reserve and control response) to withstand the power imbalance of 3000 MW in **all <u>operational situations.</u>**

On the other hand, the probabilistic approach, i.e. the cost benefit approach (CBA), is used in the case of a well-defined relation between the costs for protection against certain contingency scenarios and the prevented economic consequences. For example, CBA approach is feasible to assess grid investments versus higher generation costs due to re-dispatch in case of grid congestions.

Quantitative CBA is meaningful in case of retrospectively requesting the fulfilment of new requirements to individual generators except for cases where the overall system security is at risk and an urgent action to restore system security design margins is required.

5.2 STUDY RESULTS

The studies performed by SPD SG reveals that the Continental European power system is currently out of the design range in case of massive disconnection of dispersed generation at reaching certain frequency levels designed for normal operation (see Report “DISPERSED GENERATION IMPACT ON CE REGION SECURITY”), i.e. the security standards of the Continental European power system are violated.

This means that the Continental European power system is likely to experience a system black-out if designed contingencies occur (e.g. 3000 MW power imbalance).

In the consequence, a retrofit program for dispersed generation installed in the Continental European power system needs to be set up and performed urgently; in the following chapter, a proposed strategy about retrofit program implementation is given.

6 RETROFIT STRATEGY

In order to re-establish the system security the generation capacity which trip close to the operating frequency has to be dramatically reduced. Therefore, a retrofit program involving all countries which contribute to the risk is required. The approach has to consider that Germany and Italy have already started such a retrofit program. These national retrofit plans deals with generating units that trip in the range 49 Hz to 50.2 Hz.

The study identifies two situations leading to risk of load shedding :

1. Underfrequency deviation below 49.8 Hz with disconnection of noncompliant DG units in a cascading effect
2. Overfrequency deviation above 50.2 Hz leading to massive disconnection of non-compliant DG and frequency decrease below 49.8 Hz (cf point 1. above) resulting in an underfrequency collapse

The retrofit strategy should address both situations, recognizing that, again following from the technical analysis :

- Retrofit of units not compliant to under-frequency thresholds (49-49.8 Hz) addresses the risk of underfrequency deviation but also helps reducing the risk related to overfrequency deviation above 50.2 Hz
- As long as a substantial infeed is lost at or around 50.2 Hz, the risk of reaching frequencies higher than 50.2 Hz should be minimal (the two situations are not symmetrical)

With regard to installed DG units with non-compliant thresholds :

- Some units are non-compliant both with respect to underfrequency and overfrequency thresholds, therefore the retrofit may be optimised to address both thresholds at the same time when applicable
- Countries differ in the volume of non-compliant DG connected to Low Voltage (LV) and Medium Voltage (MV) networks, with a general trend that retrofit of LV units is much more costly than that of MV units ; in order to optimise the retrofit cost at European level, retrofit of MV units should be priority

Taking this into account, the study suggest following retrofit strategy:

- Maximum infeed of units with non-compliant thresholds in the 49-50 Hz range (the range is justified by the cascading effect, evident from simulations)
- Maximum infeed which can disconnect simultaneously at 50.2 Hz, taking into account the effects of risk reduction carried out by implementation of the first target in the 49-50 Hz range.

It is recommended that each member state in the CE zone will take actions to meet this target. The scope and priorities will however be adjusted to each national context, taking into account size, age and technical characteristics of plants, network, regulatory aspects, local grid constraints etc.

In line with the risk assessment in section 4 the following global criteria are proposed:

- Maximum 6000 MW installed capacity disconnection for over frequencies ≤50.2 Hz
- Maximum 3000 MW installed capacity for under frequencies ≥49.0 Hz

This translates into limit values for the infeed of DG which can be lost simultaneously at 50.2 Hz or in cascading effect between 49 and 50 Hz.

The non-retrofitted infeed limit per country is calculated based on the following principles:

- Shared between countries proportional to the share of the capacity at risk
- The German and Italian share is calculated based on the capacity at risk before the national retrofit program was started

The following algorithm was used to define the maximum infeed after retrofit:

$$\text{Maximum infeed after retrofit}_{\text{country k}} = \text{Maximum infeed after retrofit}_{\text{all countries}} \cdot \left[\frac{\sum_{country\ k} Installed\ capacity \cdot coincidence\ factor}{\sum_{all\ countries} Installed\ capacity \cdot coincidence\ factor} \right]$$

There will be slightly variations in the coincidence factors for each technology from country to country (especially for biomass and co-generation). To remain conservative and unless more detailed locally data is available, the capacity to be retrofitted for each country can be estimated from the data above by assuming the following coincidence factors:

- PV 75%
- Wind 90%
- Other 80%

The maximum non-retrofitted infeed can be seen in the following Tables 2 and 3, where real infeed capacity is reported..

50..50.2 Hz		Installed capacity in MW				
Country	**TSO**	**PV**	**Wind**	**Other**	**Sum**	**Non-retro-fitted infeed limit**
AL						0
AT	APG	36			36	7
BA	NOS BiH					
BE	Elia	1,340			1,340	273
BG	ESO				0	0
CH	swissgrid				0	0
CZ	CEPS	1,002	214		1,216	257
DE	German TSOs	14,500		950	15,450	3,161
DK_W	Energinet.dk	6			6	1
ES	REE				0	0
FR	RTE	2,286	4	46	2,336	477
GR	IPTO				0	0
HR	HEP-OPS					
HU	MAVIR					
IT	Terna				0	0
LU	Creos					
ME	CES					
MK	MEPSO					
NL	TenneT NL	0	0	0	0	0
PL	PSE				0	0
PT	REN	25	197	763	986	219
RO	Transelectrica				0	0
RS	EMS					
SI	ELES					
SK	SEPS	512			512	104
TR	TEIAS				0	0
UA_W						
Total		**19,707**	**415**	**1,759**	**21,882**	**4,500**

TABLE 2: INSTALLED CAPACITY AT RISK AND RESULTING INFEED LIMIT AT 50.2 HZ. NATIONAL RETROFITS WHICH HAVE ALREADY TAKEN PLACE ARE NOT CONSIDERED.

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49.0..50 Hz		Installed capacity in MW				
Country	**TSO**	**PV**	**Wind**	**Other**	**Sum**	**Non-retrofitted infeed limit**
AL						0
AT	APG	31	201	583	815	39
BA	NOS BiH					0
BE	Elia	0	0	0	0	0
BG	ESO	0	0	0	0	0
CH	swissgrid	0	0	0	0	0
CZ	CEPS	1,625	190	0	1,815	81
DE	German TSOs	1,000	12,300	13,900	27,200	1,345
DK_W	Energinet.dk	0	0	0	0	0
ES	REE	0	0	0	0	0
FR	RTE	574	835	1,001	2,410	116
GR	IPTO	2,415	25	0	2,440	108
HR	HEP-OPS					0
HU	MAVIR					0
IT	Terna	12,729	410	0	13,139	581
LU	Creos					0
ME	CES					0
MK	MEPSO					0
NL	TenneT NL	0	0	0	0	0
PL	PSE	0	60	4	64	3
PT	REN	207	215	1,190	1,612	76
RO	Transelectrica	0	0	0	0	0
RS	EMS					0
SI	ELES					0
SK	SEPS	0	0	0	0	0
TR	TEIAS	0	0	0	0	0
UA_W						0
Total		**18,581**	**14,236**	**16,678**	**49,495**	**2,350**

TABLE 3: INSTALLED CAPACITY AT RISK AND RESULTING INFEED LIMIT AT ABOVE 49.0 HZ. NATIONAL RETROFITS WHICH HAVE ALREADY TAKEN PLACE ARE NOT CONSIDERED.

7 CONCLUSIONS AND RECOMMENDATIONS

This report provides an assessment of the system security with respect to disconnection rules of dispersed generation.

The coincidence of steady-state frequency deviations and the loss of approx. 2000 MW load (e.g. HVDC link France-Great Britain) can drive the system to 50.2 Hz. The disconnection of a large amount of noncompliant generation capacity causes large power imbalances and consequently very high frequency transients, which can only be managed by large amount of under frequency load shedding. There is a severe risk for the system to collapse.

The already started PV retrofit programs in Germany and in Italy are essential for the overall system security. After completion of the program the security risk will be reduced. However, the total quantity of generation loss according to the remaining not retrofitted dispersed generation capacity is still too high and needs further retrofit programs as reported in present document.

Recommendations

1. **Automatic reconnection**
   After a severe frequency transient, the system can be partially split in some electrical islands or in a totally Blackout state; the frequency coordinator must manage the system re-meshing taking into account the single TSO PV generation at risk of trip during the manoeuvres. Due to the dramatic diffusion of PV panels on LV and MV networks, automatic reconnection is permitted, but specific logics are required in order to avoid reconnection during restoration phase and to guarantee a maximum total gradient of the PV power generation after resynchronization.

2. **Responsibility of the DSOs during restoration**
   During a single TSO restoration it is under responsibility of the DSOs to manage the PV plants in order to guarantee the requested total load/generation equilibrium requested by the National Restoration plans under coordination of the affected TSO.

3. **Implementation of Requirements for Generators (RfG-code)**
   According to Article 8, GENERAL REQUIREMENTS FOR TYPE A UNITS /5/ all generation units (capacity ≥ 800 W) shall fulfil the following requirements referring to frequency stability: in case of deviation of the Network frequency from its

nominal value, due to a deviation within the frequency ranges and time periods specified in /5/, table 2, any automatic disconnection of a generating unit from the network shall be prohibited and power infeed shall be maintained.

Figures for the CE region are:

47.5 Hz – 48.5 Hz	To be decided by each TSO pursuant to Article 4(3), but not less than 30 minutes
48.5 Hz – 49.0 Hz	To be decided by each TSO pursuant to Article 4(3), but not less than the period for 47.5 Hz – 48.5 Hz
49.0 Hz – 51.0 Hz	Unlimited
51.0 Hz – 51.5 Hz	30 minutes.

That means no automatic disconnection in the frequency range from 47.5 Hz to 50.2 Hz shall take place. This regulation should be implemented as soon as possible in all CE areas. In addition in the frequency range above 50.2 Hz a coordinated stage disconnection can help to control overfrequency transients.

4. **Maximum admissible amount of noncompliant generation capacity**
   Realistic scenarios like loss of generation due to disconnection at 50.2 Hz or loss of 3 GW generation shall be managed without further cascading effects and without load shedding.

   To this aim the maximum admissible amount of non-retrofitted installed capacity with disconnection settings at 50.2 Hz is 6000 MW equivalent to 4500 MW of real infeed for the whole synchronous area. The maximum admissible installed capacity of generation units with disconnection settings in the range between 50 Hz and 49 Hz is 3000 MW corresponding to 2350 MW for the whole synchronous area.

   When the retrofit programs in Germany and Italy are finished, the total installed capacity that would be disconnected between 50 Hz and 49 Hz is still too high and therefore further retrofit programs are required.

5. **European wide inventory about dispersed generation**
   It is important to initiate an inventory of the current disconnection settings and technical parameters of dispersed generation in the CE region. These parameters depend e.g. on the various technologies of dispersed generation and the different development of connection rules/standards during the last years in the respective countries. A huge amount of information has to be collected from different

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sources; the information must be detailed and synchronized in terms of transparent and reliable information of different countries at same time.

These data are needed for the assessment and implementation of further retrofit strategies; SPD group will prosecute this inventory activities also basing on cooperation with external organizations (i.e. CENELEC).

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