European Network of
Transmission System Operators
for Electricity

DISPERSED GENERATION IMPACT ON CONTINENTAL EUROPE REGION SECURITY

- ENTSO-E Position Paper -

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1. Contents

1. Background

In the last decade, the Dispersed Generation (DG) capacity, mainly from Renewable Energy Sources (RES) has increased significantly all over Europe.

In the first years of installation of DG units appropriate standards and connection requirements were not yet developed. As a result, high capacities of DG units were installed with **frequency disconnection settings** in the ranges between 49.5 and 50.5 Hz, whereas the standard disconnection limits of generating units are between 47.5 and 51.5 Hz. The rapid growth of RES also led to a **reduction of inertia** (e.g. frequency changes faster than earlier when an imbalance between load and generation occurs), because, unless otherwise required, the power generating modules used by DG provide no inertia or contribution to the Frequency Containment Reserve (FCR).

With large penetration of RES, combined with increasing imbalances resulting of variable exchanges, this situation led to higher frequency deviation as in the past and a **significant decrease in the security of operation** of the interconnected synchronous network in Continental Europe (CE). The current situation challenges the fulfilment of one of the basic design principles of the CE system: the system has to react without load shedding[1] in case of loss of generation or load (the reference case for loss of generation as defined in the Load Frequency Control & Reserves draft Network Code (LFCR NC) equals to 3000 MW for the CE region).

In the future, DG will need to be compliant with the Requirements for Generators Network Code (RfG NC) stipulating broader frequency disconnection ranges for these units, thus ensuring appropriate capabilities to maintain the aforementioned overall system design requirement. Therefore, this document refers to the existing units with more sensitive frequency disconnection settings as **"non-compliant"**, although the new requirements were not applicable at the time of their installation**.**

As it will be shown below, with a large share of non-compliant units in the system, significant load shedding can occur even under the assumption of the reference case. The **risk of experiencing load shedding** (or equivalently: a blackout event) is increased; the reliability of the system is degraded.

It should be emphasized that the system has been designed to withstand frequency deviations originating from the reference case having 50 Hz as starting point, but in normal operation, the frequency often deviates from this value. For the last few years, practically all synchronous areas of ENTSO-E (similarly to other synchronous systems in the world) have been experiencing significant frequency deviations corresponding to sudden and simultaneous changes of generation due to standardized time intervals introduced by market schedules [1]. These frequency deviations activate a significant share of FCR, which is initially intended and dimensioned for large generation and load outages, hence **increasing the overall probability of contingency events exceeding the designed assumptions of the reference case**. The risk of using up all available FCR is calculated in [2]. This can happen through a market induced system frequency deviation which occurs prior to an imbalance due to a large generation trip. It can be observed that the probability of needing more than 3000 MW of FCR has dramatically increased in a period of 10 years. In 2002, the probability was **1 event in 32.5 years**, and in 2011: it was **1 event in 20.9 years**. This last probability is close to the probability of 1 event in 20 years required by the LFCR draft NC. The insufficiency of FCR does not mean in itself that load shedding will occur. However, running out of FCR means entering into frequency areas where an uncoordinated disconnection of a high amount of DG will lead the frequency to drop down to the load shedding level. Therefore, it can be assumed that the CE power system has a probability of **1 event in 20 years** of being in a situation where the risk of facing a partial or total blackout is real. In order to re-establish the system security and bring the overall quality of supply to its designed level, it is necessary to bring the frequency disconnection settings of non-compliant DG units to acceptable values. Two countries, Germany

[1] Load shedding is a set of coordinated measures defined in the Defence plan, which aim to keep the integrity of the system in case of abnormal system conditions resulting from extreme contingencies. For Continental Europe, if frequency reaches 49.0 Hz, load shedding of customer consumption is mandatory, and at least 5 % of Reference Load has to be shed. At range 49.0 to 48.0 Hz, in total 30-50 % of Reference Load shall be shed.

and Italy, in which most of the non-compliant DG units are installed, have started large programmes to retrofit the main parts of the existing non-compliant units. **This retrofit programme must be extended to all countries which contribute to the risk.**

2. Reasons leading to the current situation

The reasons why some European Regions (especially Continental Europe) suffer the above mentioned problems are rather complex, and lie in the fast expansion of DG and its accommodation in the present systems before the consolidation of Europe wide technical codes designed to take into account the system power needs.

Dispersed generation is mostly connected to Distribution Systems. In most cases, DG at national level has to comply with DSO connection rules. On the other hand, Transmission Grid Codes generally apply to generators of rated power greater than those of DG units.

The distribution systems are in most cases operated as radial, passive networks. However, the growth of DG in distribution systems makes this assumption is no more valid.

Accordingly, the most common technique to deal with faults in passive structured networks containing generation is to disconnect any source of power before re-energizing the feeders. The simplest and most inexpensive technique consists of disconnecting the DG units as soon as frequency deviations exceed given narrow bands. The narrower this band is, the faster the re-energisation and the higher the benefits in terms of quality of supply. Around this concept different frequency bands have been adopted country by country in Europe. Most of them are incompatible with the interconnected power system needs. This way of triggering DG disconnection is incompatible with balancing a system with a large penetration of RES. There is the risk of premature disconnection of DG with the loss of thousands of MW, which is impossible to countermeasure.

A second concern of the DSO is the islanding, i.e. situations when a portion of distribution system is isolated from the transmission system and the dispersed generation of this island matches the load. DSOs are of opinion that keeping DG connected in the range between 47.5 and 51.5 Hz increases the probability that the island is sustained. While islanding can be a concern for DSOs from a personal safety point of view, it needs to be handled in a manner compatible with the global system needs.

In 2011, after preliminary evaluations, ENTSO-E sent several letters to the European Commission warning of the risks for the interconnected CE power system. These letters contributed to the decisions of undertaking the retrofitting policies in Italy and Germany.

This position paper attempts to give a better understanding of the risks of facing a blackout due to non-compliant DG frequency disconnection settings based on the last update of ENTSO-E Report: “Dispersed Generation Security Impact on CE Region” [3].

3. Technical considerations

The interconnected power system of Continental Europe covers a load between 220 and 440 GW and is operated in a synchronous way; meaning that, aside from phenomena with time constants smaller than a few seconds, the system frequency is identical everywhere. During the last few years frequency deviations have been observed with peak values up to +/-150 mHz within a time window of 10 minutes centred on the change of the hour. This is mainly observed during the load ramping periods in the morning and in the evening [1]. In this context it is meaningful to recall the reasons for setting different frequency disconnection thresholds in the past. These are summarised in chapter 2. In some countries high capacities of installed DG units disconnect at 50.2 (upper limit), 49.8, 49.7 and 49.5 Hz (down limit) as shown in Figure 1. These disconnection limits are not in line with the standard limits of the transmission system (47.5 and 51.5 Hz as confirmed by the draft Network Code on Requirements for Generators RfG NC).

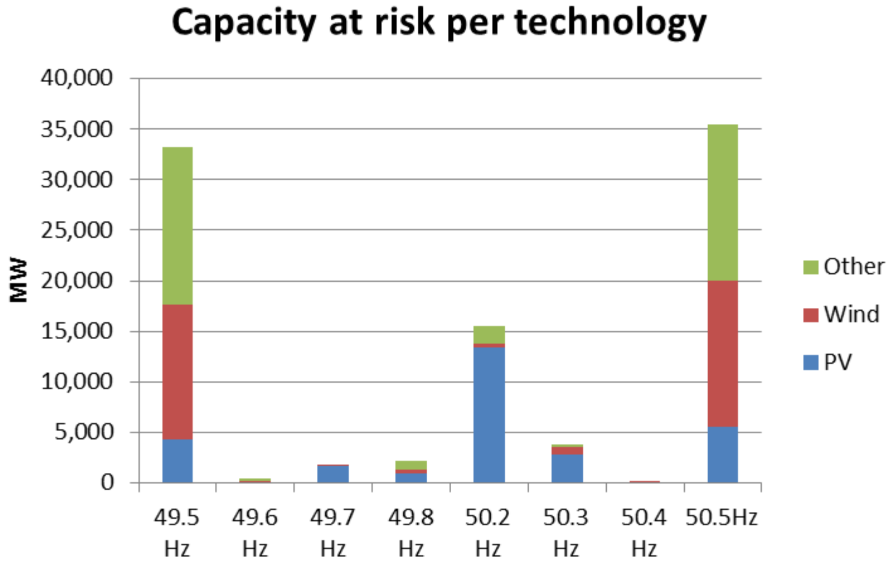

Figure 1 Total capacity of Dispersed Generation at risk in 2014 (source: ENTSO-E SPD SG 2014 questionnaire)

Considering real incident cases and taking into account the ongoing retrofit actions performed by Germany and Italy, Subgroup System Protection and Dynamics identified two situations leading to a real risk of load shedding:

Under-frequency deviation

In low load conditions (220 GW), after a normal contingency such as the reference case (outage of 3000 MW generation), a large frequency deviation will be faced. Immediately, the 49.8 Hz threshold will be reached and, as Figure 2 shows, a high volume of non-compliant DG units will start to disconnect in a cascading manner. As a result, the system frequency will reach the first load shedding stage at 49.0-49.1 Hz, at which point a huge amount of load will be automatically disconnected in order to stabilise the system. However, even the automatic load shedding may not always prevent the system collapse due to high frequency transients and extreme variation of the load flow pattern causing risk of overloading transmission lines. This is not acceptable, because the loss of 3 GW of generation is considered as a normative contingency.

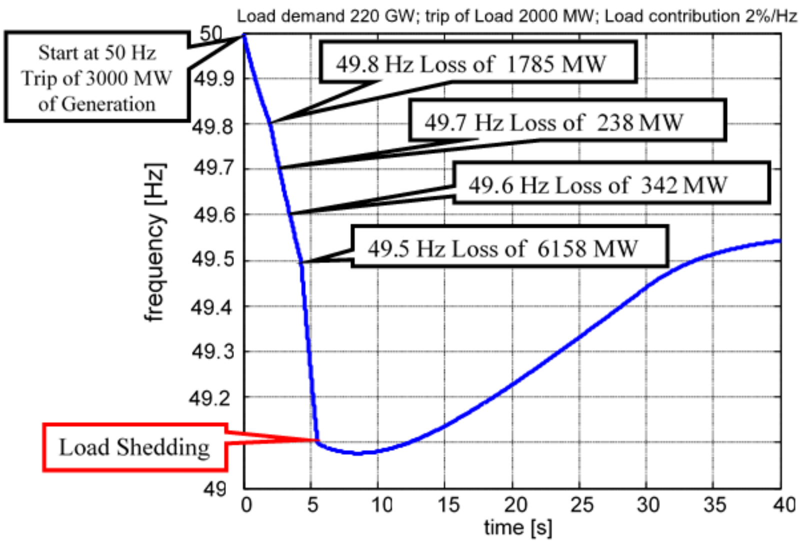

Figure 2: Simulation of 3 GW generation loss after Italian and German retrofit (MW) in Continental Europe. The proposed but not confirmed retrofit of the German wind, biomass and cogeneration units are also considered.

Over-frequency deviation
In low load conditions (220 GW) the combination of market induced frequency deviations (producing by itself a frequency deviation of +100mHz) with a single contingency according to the n-1 criterion (i.e. disconnection of a HVDC cable of 2 GW) leads to a further increase of the frequency deviation reaching 50.2 Hz. At this limit a large volume of non-compliant DG disconnects causing the frequency to decrease below 49.8 Hz with, as in the previous case, load shedding as the final consequence (Figure 3). From the current experience, this scenario is probable during midday when there is a high in-feed from solar panels. Recent operational experience, shows a real possibility to reach a steady-state frequency over 50 Hz in normal operation during midday.

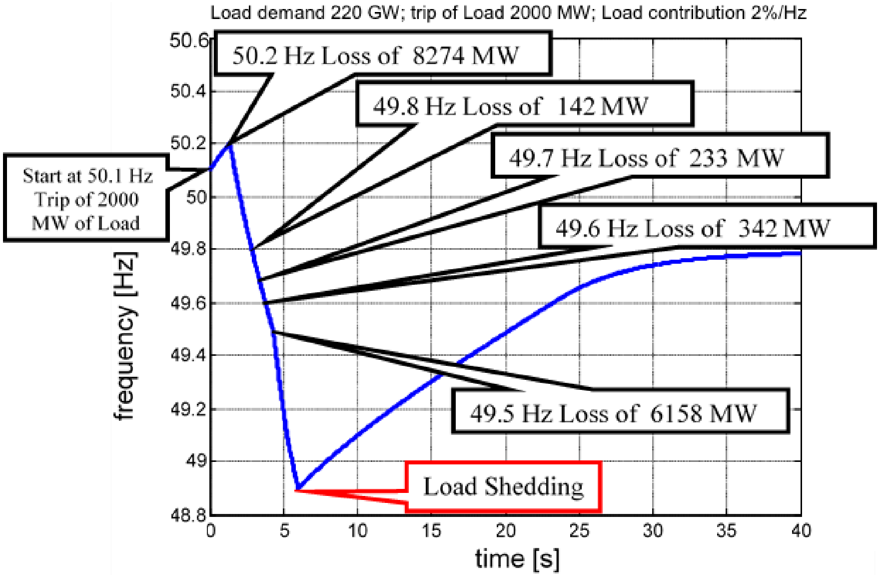

Figure 3: Simulation of 2 GW load loss after Italian and German retrofit (MW) in Continental Europe. The proposed but not yet confirmed retrofit of the German wind, biomass and cogeneration units are also considered.

This means that in the current situation with inadequate DG frequency disconnection settings, the overall effect of new generation mix reduces the frequency tolerance margins deviations from 1000 to 200 mHz.

Both simulations show that the System is no longer meeting n-1 security. While a simple contingency requires load shedding in order to avoid the system collapse; simulations demonstrate that an increase of FCR itself is not able to contrast the instantaneous loss of dispersed generation.

4. Recommended retrofit actions

In order to re-establish the system security, the not compliant DG capacity (disconnection band 47.5 – 51.5 Hz) has to be reset. Therefore, a retrofit program involving all countries which contribute to the risk is considered urgent.

Increasing FCR cannot be considered as an alternative to retrofit because it cannot cover all the situations in which frequency deviations exceed 200 mHz. For example, in case of large generation outages, the frequency deviation occurs too rapidly for the FCR to be effectively activated and prevent the frequency to reach values below 49.8 Hz, thus triggering the disconnection of retrofitting DG with inadequate frequency disconnection settings. At best, increasing FCR may be considered as a potential temporary mitigation measure until the retrofit programme is completed. However, as will be shown below, its cost is significant compared to the overall cost of the retrofit programme, and it is therefore more cost effective to launch this programme urgently.

The first action to be taken by all countries of CE is to guarantee that the new installed DG is compliant with the frequency disconnection requirements stipulated in the draft Network Code on Requirements for Generators (NC RfG). This code is presently in the comitology process of the European Commission. Modifications of connection rules at national level should be carried out in the anticipation that the current draft code will become European law, in order to ensure national compliance with the relevant requirements of the code.

Additionally ENTSO-E assessed that for the whole CE synchronous area, the maximum tolerable generation disconnecting at 50.2 Hz shall not exceed 4500 MW in-feed (which corresponds to around 6000 MW of installed capacity) and the maximum DG in-feed with disconnection settings between 49.2 Hz and 50 Hz shall not exceed 2350 MW (which corresponds to around 3000 MW of installed capacity).

Figure 4 and Figure 5 show simulations based on the above retrofit assumptions proving that, the system frequency will not trigger the load shedding after the instantaneous loss of 3 GW of generation or 2 GW of load.

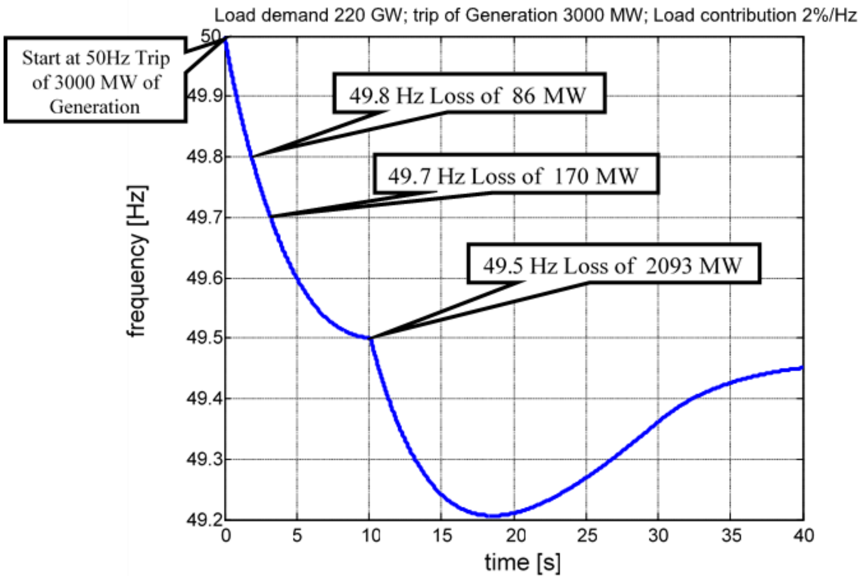

Figure 4: Simulation of 3 GW generation loss with retrofit

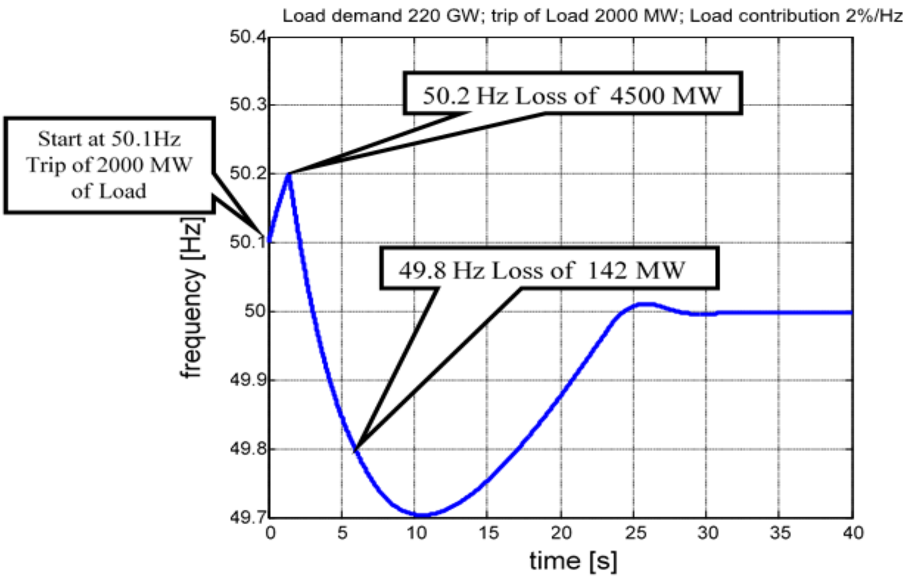

Figure 5: Simulation of 2 GW load loss with retrofit

ENTSO-E suggests that retrofitting of a non-compliant generation unit should be decided considering the technical and economic difficulties of its retrofit and that accordingly, the generation units that are the most difficult to retrofit can be kept as non-compliant, as far as the maximum amount of non-compliant generation does not overreached the maximum tolerable generation. This non-compliant capacity share per country is calculated proportionally to the share of the total non-compliant DG capacity at risk before retrofit.

5. Current state of retrofit

Several countries, such as Germany, Italy and France, have updated the connection requirements of new DG units in order to ensure that power generating modules are capable of staying connected to the network and operating in the range between 47.5 Hz and 51.5 Hz, as defined in the draft NC RfG.

In addition, Italy (Figure 6) and Germany (Figure 7) have started programs to systematically retrofit (e.g. upgrade) the main part of the existing non-compliant units to standard thresholds. The upgrade programs are expected to be finalized by end of 2015.

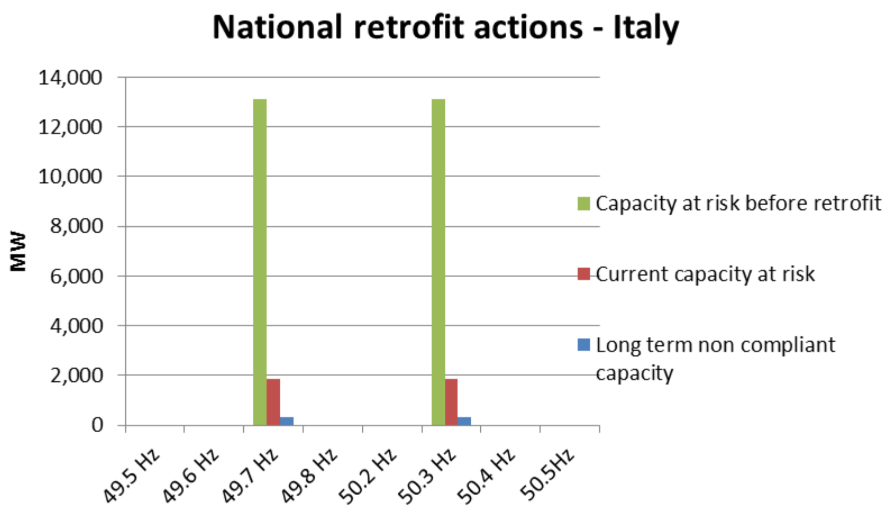

Figure 6: Impact of the committed retrofit program in Italy for PV and wind. The "current capacity at risk" is from September 2014

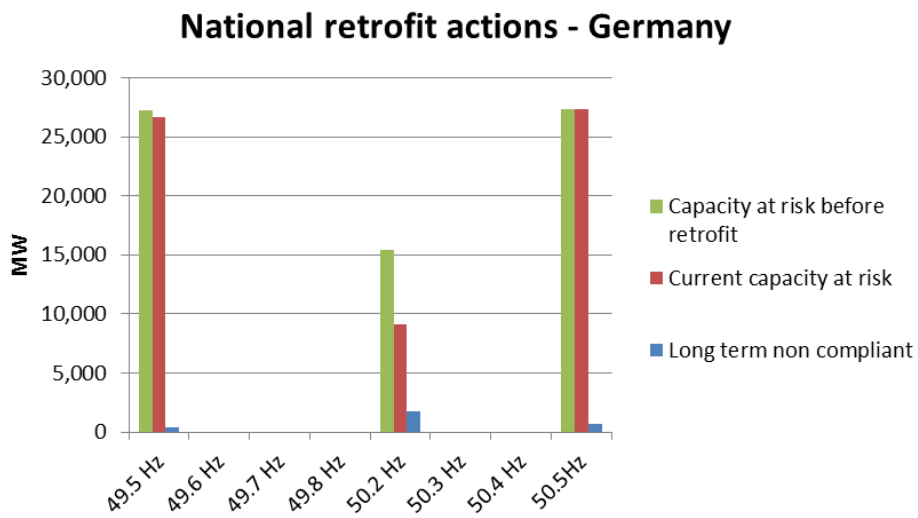

Figure 7: Impact of the committed retrofit program in Germany for PV, wind and other dispersed generating units. The "current capacity at risk" is from September 2014.

However, the total quantity of generation loss according to the remaining non-retrofitted dispersed generation capacity is still too high and needs further retrofit programmes in all concerned countries.

6. Cost benefit analysis

Probabilistic calculations have shown that market-induced imbalances and related deterministic frequency deviations result in an increased risk of needing more FCR than available [1]. In order to decrease this risk of frequency deviations to the level of 1 event in 32.5 years (as it was the case in 2002, before the degradation of frequency quality), an increase of FCR by 120 MW would be necessary resulting in an increase of costs which according to the best estimations available are in the range of 31 million euros per year. However, this would only reduce the risk of frequency deviations in the range in which non-compliant DG unit will be disconnected, but it does not constitute an effective alternative to long term retrofit measures.

Concerning the cost of the retrofit programme, a basic calculation can be done by using the costs of Italian/German retrofit which amounts to 3.5 M€ per GW retrofitted. Using these values, the overall cost of retrofitting all non-compliant DG units in CE (46 GW) can be estimated at 161 M€. This cost also includes the interface to receive signals from the network.

On the other hand, the benefits of retrofit measures will stem mainly from avoiding load shedding (or black out) in case of large frequency deviations. The financial impact of load shedding is commonly calculated through its estimated cost for society as a whole, in terms of euros per kilowatt not supplied per interrupted hour. This value is agreed between national authorities, regulators and operators in each country; here we can take the one used in Italy, which could rise to 40€/kWh [4]. For a single event, the corresponding benefits of retrofitting are quite significant even with conservative assumptions : assuming 10% of load shedding during low demand period (220 GW) in one single event due to non-compliant DG, the avoided cost amounts to 880M€ per interrupted hour. As already described in the background chapter, the probability of a partial blackout is 1 in 20 years due to the inadequate disconnection settings of DG, resulting in a benefit of 44 M€/h per year. Assuming that the remaining life of the disconnection devices is 10 years (after which they will be substituted by compliant ones), the benefit of avoiding a blackout during that time would be 440 M€/h. This means that if a partial blackout lasts for e.g. four hours, the total benefit would be 1,760 M€ against the retrofit cost of 161 M€. As the duration of the historical major blackouts is within a range of a few hours up to a few days, and such an event may occur in the next 20 years or so, as shown above, it is clear that the benefits of the retrofit programme are significantly higher than its costs.

7. Summary of ENTSO-E recommendations

1. **Each Member State is asked to take appropriate actions to ensure that the new installed DG is compliant with the frequency disconnection requirements stipulated in the draft Network Code on Requirements for Generators (NC RfG), without waiting for its coming in force and, later on, its applicability**
2. **Each Member State is asked to initiate discussions between national authorities, regulators and operators to determine the scope of the needed retrofit programme at the Member State level, and execute that retrofit program**

The retrofit programme should take into account that:

- Some units are non-compliant both with respect to under-frequency and over-frequency 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 prioritized

Each Member State is expected to meet targets in table 1 below:

- Maximum in-feed of units with non-compliant thresholds in the 49-50 Hz range (the range is justified by the cascading effect)
- Maximum in-feed 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.

The scope and priorities can be adjusted to each national context, taking into account size, age and technical characteristics of plants, network, regulatory aspects, local grid constraints etc…

Country	**TSO**	**49..50 Hz**	**50..50.2 Hz**
AL	OST	0	0
AT	APG	39	7
BA	NOS BiH	0	0
BE	Elia	0	273
BG	ESO	0	0
CH	swissgrid	0	0
CZ	CEPS	81	257
DE	German TSOs	1,345	3,161
DK_W	Energinet.dk	0	1
ES	REE	0	0
FR	RTE	116	477
GR	IPTO	108	0
HR	HEP-OPS	0	0
HU	MAVIR	0	0
IT	Terna	581	0
LU	Creos	0	0
ME	CES	0	0
MK	MEPSO	0	0
NL	TenneT NL	0	0
PL	PSE	3	0
PT	REN	76	219
RO	Transelectrica	0	0
RS	EMS	0	0
SI	ELES	0	0
SK	SEPS	0	104
TR	TEIAS	0	0
UA_W	UKRENERGO	0	0
Total		**2,350**	**4,500**

Table 1: Maximum allowed infeed in MW of non-compliant units per country in the ranges 49.0-50.0 and 50.0-50.2 Hz.

8. References

[1] ENTSO-E & EURELECTRIC, "Deterministic Frequency Deviations," 2012.
[2] ENTSO-E, "Operational reserve ad hoc team report, final version," 2012.
[3] ENTSO-E, "Dispersed Generation Security Impact on CE Region Report," 2014.
[4] ENTSO-E, "Cost Benefit Analysis Methodology for Projects of European Significance," 2013.