Technical background for the Low Frequency Demand Disconnection requirements

November 2014

Content

1. Introduction

The main scope of this report is to evaluate different load shedding strategies with the aim to define binding requirements for the coordinated under frequency load shedding plans of Continental Europe.

The under frequency load shedding (UFLS) approach represents a compromise between a quasi-linear control target and a rigid fixed pre-set load disconnection. The modern technical solutions (e.g. digital frequency relays, phasor measurement) give many possibilities to develop and realise effective UFLS schemes. An efficient UFLS plan shall be designed on the basis of the following general principles:

- Evenly geographically distributed and effective shed load between TSOs as well as within a TSO area,
- Same reference for frequency and shedding load steps across the interconnected system,
- Ability to compensate the maximum credible active power deficit of the system,

– System implementation ensures the effectivity of UFLS: it means a minimal necessary shedding of load,
– Compensate disconnection of dispersed generation at unfavourable frequencies [5],
– Avoid over frequency (overcompensation), overvoltage and power transients that can lead to an additional loss of generation.

The proposed review of the current UFLS plan has to take the next additional conditions into consideration:
– Compensate statistical failed trip by load shedding relays and conventional generation lost during the under frequency transient,
– Avoid splitting of network by intervention of line protection and, if necessary control network splitting scenarios,
– Duly consider the net effect of losing embedded generation located on the load feeders subject to load shedding

This document is planned to deliver useful input and technically support for the NC Emergency and Restoration [2] and OH Policy 5 [1] drafting teams.

A few basic considerations reflect the main principles that must drive the load shedding strategy design:

The first decision is the *range* of the load shedding action delimited by the frequency value of start of load shedding and the final step level. At frequencies below this threshold the system depends on TSOs individual extreme actions (Special Protection Schemes, islanding schemes) as a last defence before the permitted trip of all generating units.

Another important parameter is the *total load quantity* that will be activated if all steps of the load shedding plan are triggered. In addition the load quantity of the first and the subsequent steps must be defined jointly with frequency threshold with the aim to consider the activation delay which depends on relay technology (algorithm, measuring and filters, auxiliary relays).

Pumps from hydro-pump storage plants can also contribute to the load shedding scheme, if coordinated with load shedding; in this sense pumps could anticipate or compensate the loss of generation. However, as they act outside the standard UFLS scheme their consideration is out of the scope of this study.

At the end, also the frequency derivative steps (using ROCOF function) play an important role, because the frequency derivative has the advantage to anticipate the frequency transient. A proper range is fundamental to avoid false tripping i.e. due to local faults, where the frequency derivative is very sensitive. The application of this functionality shall be restricted to TSOs with a regular high import power balance.

By means of system simulations, the following recommendations will be established for:
– Optimal total shedding load in percentage of reference load (PSL,total),
– Optimal frequency stepping for a system with dispersed frequency relays implemented (fi, n),
– Optimal number of load shedding stages in percentage of reference load (Pi).

Additionally, some general considerations will be given for:

  – Acceptable time delay,
  – Optional use of frequency gradient (ROCOF function) and other additional inputs.

The study does not consider settings related to
– Load shedding schemes based on under voltage
– Load shedding schemes based on frequency derivative
– Pump storage control
– HVDC frequency support
The statistical dispersion of thresholds value and/or frequency measurements across the system, but in the conclusions chapter some corresponding recommendations will be given.

2. System modelling

The system is represented with a mean frequency model compliant with normative regulation and contribution from loads[1].

The model (represented in schematic way in Figure 1) is an ad hoc model for internal use implemented and fine-tuned by SPD experts.

Inertia of the system is adjusted according to the quantity of inverter based generators, in order to properly represent their influence on system behaviour.

The primary regulation and load contributions are referred to design hypothesis reported in ENTSO-E Policy 1.

Three kinds of production technologies are considered:
– Conventional plants (Primary regulation): the production from the synchronous generators including thermal and hydro power is considered by one equivalent group, with proper rate limiter function.
– PV production: frequency disconnection thresholds are modelled both for over and underfrequency
– Wind production: this production is represented by an equivalent group for the entire area with tripping threshold in underfrequency in way to emulate the particular settings on some TSOS (typically 49.5 Hz, see [5]); for these plants no threshold in over frequency.

Simulations are done with the dispersed generation capacity remaining at risk after full implementation of the German and Italian retrofit programs.

The PV and wind models are able to emulate:
– The percentage of power tripped in over/under frequency with associated threshold
– Over frequency regulation
– The tripping time, i.e. the time between the detection of the exceeding of the threshold and the effective triggering group.

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[1] According to normative model, load dependance from voltage is not considered; it is represented. only load self-regulating power
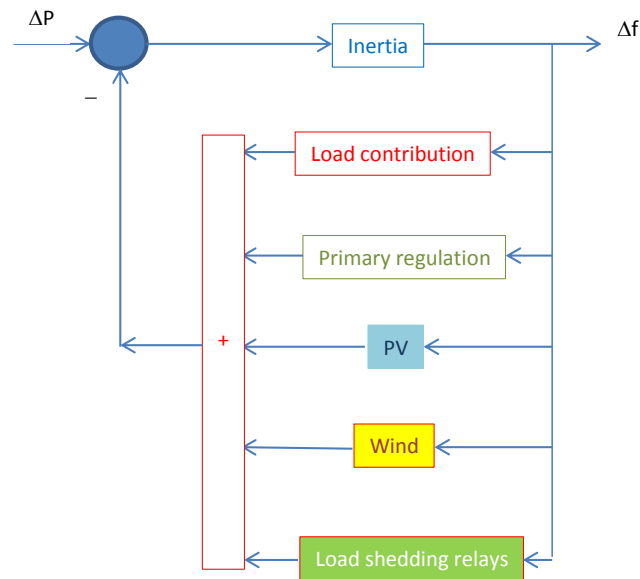
Figure 1: Overall block structure of the simulation model

2.1   Load shedding relay modelling

The maximum number of steps implemented into the model is equal to 10. For each step, a threshold and a percentage of disconnected load is associated, jointly with a delay that represent the internal computational time and time to execute and open the load feeder circuit breaker.

The implemented equations and more details can be found in the report "Dispersed generation impact on CE regions security" [5].

The self-regulation impact of the load k_{PF} (load contribution) was considered to be 2%/Hz

The same simulation model was used for [5] and validated by related comparison between measurement and simulation.

3. Scenarios

"Reference load" defines the "per unit base" of the load subject to UFLS while the simulations will be done on high and load scenarios deviating from the "reference load".

In the past the reference load determination was based on typical load situations as e.g. high load condition during winter or low load condition during summer. Due to the increasing impact of distributed generation this principle is no longer applicable for the reference load definition. Therefore the TF has decided to use the same principle as defined in [3]. The details of defining the correct reference load are described in the conclusions chapter.

In the following the specific distribution of load and generations for each TSO is not considered.

The simulations are based on the following 4 situations:

		Case 1a High load, no RES	Case 1b High load, high RES	Case 2a Low load, no RES	Case 2b Low load, high RES
Load	GW	440	440	220	220
Firm synchronous generation	GW	440	170	220	50
Wind	GW	0	181	0	75
PV	GW	0	75	0	80
"Other" at risk	GW	0	14	0	14

Table 1 Scenarios used to evaluate the UFLS performance.

Within this report the Wind and PV infeed is summed up as distributed (DG) generation.

4. General modelling assumptions

As explained in previous chapters, the system is modelled with a design oriented approach; this means that the system frequency response is analysed for different levels of imbalance. The following steps of lost generation related to total system load are imposed:

- 1 %, 5 %, 10 %, 20 %, 30 %, 40 %, 50%, 60%

The following ranges are assumed

The first step of load shedding is fixed at 49.0 Hz.	The reason is to reserve a range between 50 Hz and 49 Hz (1 Hz) where primary reserve is trying to recover the effect from the power deficit. The same range is also usable by TSOs to compensate other effects mainly due to the additional imbalances that could happen in their system. For example, a TSO could choose to shed load (i.e. pumping storage plants or interruptible customers) in order to compensate generator trips due to non-compliant frequency disconnection settings.
The last step is activated at 48.0 Hz	This choice provides a range of 1 Hz to control the underfrequency transient by loads shedding. Below this frequency there is a certain margin (around 0.5 Hz) where generating units can operate and hopefully recover without trip.

5. Simulation cases

In order to determine the recommendations, 16 different scenarios are assessed. As a reference case, the current implemented ULFS is also being simulated (case 0). A number of variables have been taken into account as described hereunder to define the different scenarios (case 1-15). Finally, the incident of November the 4th 2006 was simulated, since this incident can be used as reference to determine a likely contingency which provoked a network split on Continental Europe (case 16) and as good validation test of the model.

5.1 "Current" case simulation (UFLS plan 0)

The "curent" situation has been simulated in order to evaluate the present behaviour expected in case of load shedding. The global load has been distributed among the TSOs proportionally to the value of primary reserve . See Table 2.

Frequency (Hz)	Load shedding (%)	Cumulative (%)
49.2	0.03	0.03
49.0	13.29	13.32
48.9	0.81	14.13
48.8	2.31	16.44
48.7	7.29	23.73
48.6	2.41	26.14
48.5	4.76	30.90
48.4	8.56	39.46
48.3	0.41	39.87
48.2	1.53	41.4
48.1	1.12	42.52
48.0	5.44	47.96
47.7	0.18	48.14

Table 2 System load shedding based on UFLS settings of each country.

The current load shedding relays settings are derived from an internal questionnaire compiled by TSOs.

Load shedding plan and primary reserve distribution between each TSO are combined in order to estimate the proportion of load shedding for each threshold.

For example, REE first threshold represents 15% of its load. In order to know how many "MW" it represents at peak load, we can use primary reserve: 385 MW of 3000 MW and applying the same proportion for peak load scenario we found 56.47 GW of 440 GW. Then these values are used to know the load shedding at 49 Hz: 15% of 56.47 GW is equal to 8.47 GW.

The same approach is done for each threshold and each TSO. Then all the "MW" disconnected at each threshold are summed up: for example we have 58.49 GW lost at 49 Hz, which represents 13.29% of 440 GW. It is important underline that this is a criterion to put all load shedding plans under the same basis in terms of MW; simulations results are not influenced by this, because all the system is modelled in normalised (p.u.) of peak load.

To get these values the following assumptions have been made:
- The average value is calculated when an interval has been given. For example 12.5% when the table's value is "10-15%".
- No load shedding is taken into account for TSOs without data (West Ukraine and Albania).

5.2 Simulated Cases (UFLS plan 1-15)

The total load shed is parametrically tested from 20% to 60% of total load with step increase of 10%; the number of steps is varied from 4 to 10.

The first step is evaluated testing the system response from 4% to 12% and size of intermediate and final step is simulated between 2% and 10%.

Finally the load shedding is related to the theoretical load that does not include distributed generation.

An overview of all the applied scenarios is given in Table 3.

5.3 "4th November 2006 West area" case (UFLS plan 16)

As final verification a real event is selected with the aim to reproduce a load shedding; in particular the 4th November, 2006 was the last Continental Europe load shedding triggering.
In this case, only the following countries from west area have been taken into account:
- Belgium,
- Switzerland,
- Denmark,
- Spain,
- France,
- Italy,
- Netherlands,
- Portugal,
- Slovenia,
- Germany (3/4 of total load of the country),
- Austria (1/2 of total load of the country),
- Croatia (1/2 of total load of the country).

These countries represent around 2/3 of total RGCE Primary Reserve (estimated 2000 MW): it is assumed that they represent 2/3 of global load at peak load to estimate the proportion of load shedding at each threshold.
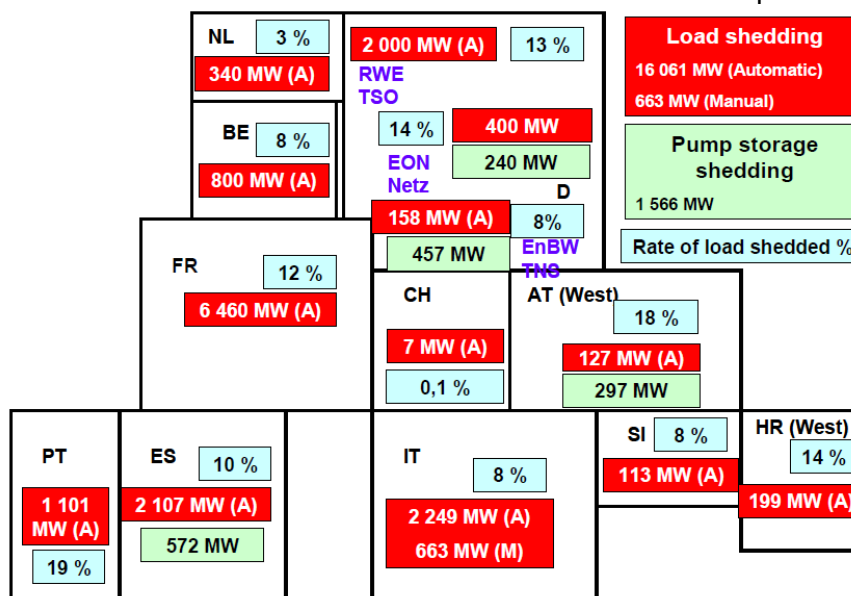It should be noted that the simulation is done based on the load values represented in Table 6.

Table 3 - ULFS for 4th of November 2006 (West Area)

This case is only used to simulate the 4th November 2006 when:

- total load of the west area was 190 GW,
- the initial imbalance was 8,940 GW (mainly exchange from East to West areas)
- due to the low frequency 10,909 GW of production tripped (not only renewable):

Figure 2 shows a comparison between simulation (left) and real recording (WAMS); the model seems adequate and realistic.
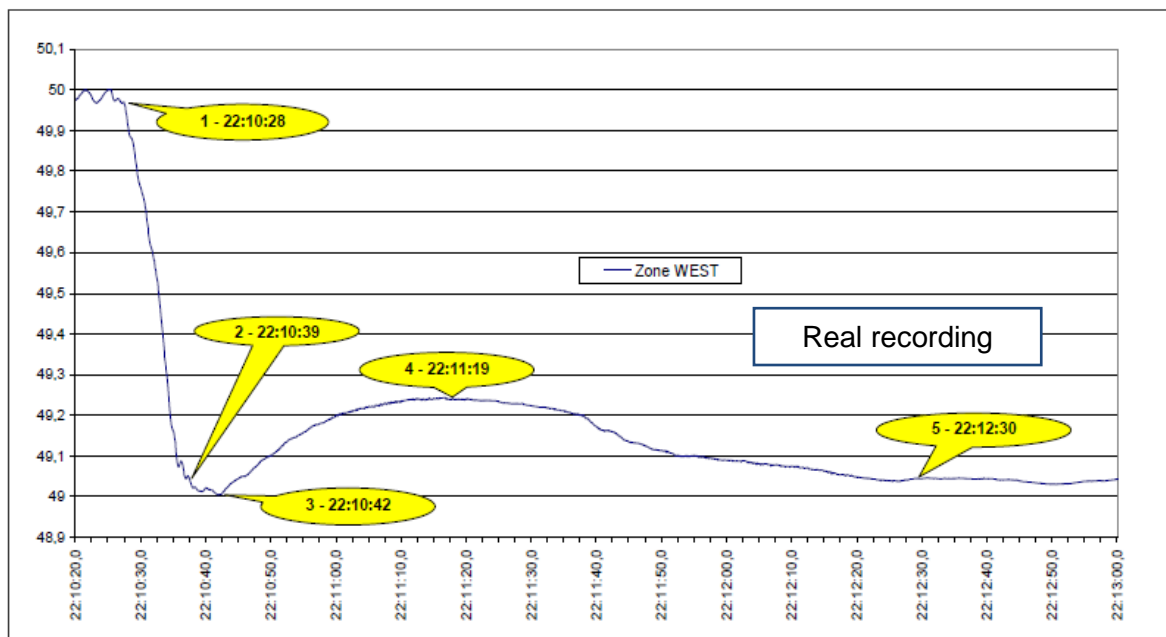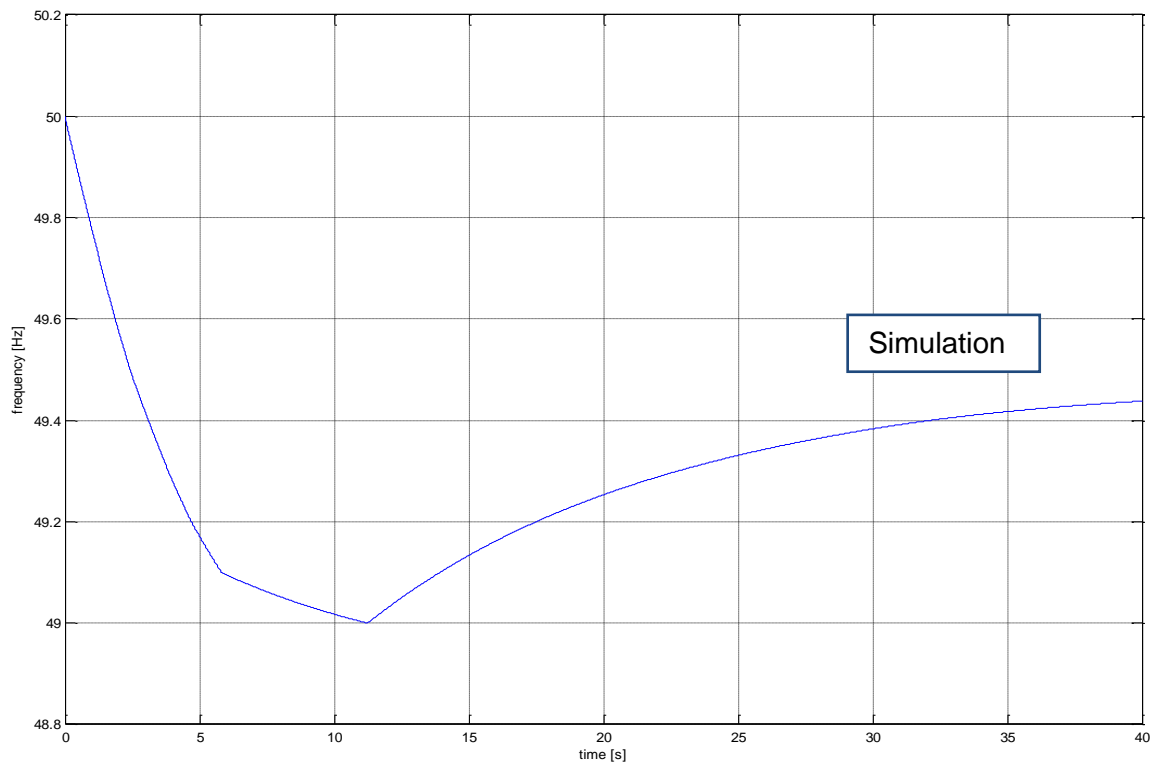
Figure 2: Comparison between 4th November 2006 West area frequency recording and simulation

Scenario	# thresholds	Frequency of activating threshold						
		% of load shed per threshold						
UFLS plan 1	n=6	49.0 Hz	48.8 Hz	48.6 Hz	48.4 Hz	48.2 Hz	48.0 Hz	Total
		2%	4%	6%	8%	10%	10%	40%
UFLS plan 2	n=4	49,0 Hz	48.7 Hz	48.4 Hz	48.2 Hz			
		5%	9%	11%	15%			40%
UFLS plan 3	n=4	49,0 Hz	48.8 Hz	48.6 Hz	48.4 Hz			
		12.5%	12.5%	12.5%	12.5%			50%
UFLS plan 4	n=4	49,0 Hz	48.7 Hz	48.4 Hz	48.2 Hz			
		15%	11%	9%	5%			40%
UFLS plan 5	n=6	49.0 Hz	48.8 Hz	48.6 Hz	48.4 Hz	48.2 Hz	48.0 Hz	
		10%	10%	8%	6%	4%	2%	40%
UFLS plan 6	n=8	49.0 Hz	48.87Hz	48.74Hz	48.61Hz	….	48.1 Hz	
		2.5%	2.5%	2.5%	2.5%	…..	2.5%	20%
UFLS plan 7	n=8	49.0 Hz	48.87Hz	48.74Hz	48.61Hz	….	48.1 Hz	
		3.75%	3.75%	3.75%	3.75%	….	3.75%	30%
UFLS plan 8	n=8	49.0 Hz	48.87Hz	48.74Hz	48.61Hz	….	48.1 Hz	
		5%	5%	5%	5%	…..	5%	40%
UFLS plan 9	n=8	49.0 Hz	48.87Hz	48.74Hz	48.61Hz	….	48.1 Hz	
		6.25%	6.25%	6.25%	6.25%	…..	6.25%	50%
UFLS plan 10	n=8	49.0 Hz	48.87Hz	48.74Hz	48.61Hz	….	48.1 Hz	
		7.5%	7.5%	7.5%	7.5%	…..	7.5%	60%
UFLS plan 11	n=10	49.0 Hz	48.9 Hz	48.8 Hz	48.7 Hz	….	48.1 Hz	
		2%	2%	2%	2%	…..	2%	20%
UFLS plan 12	n=10	49.0 Hz	48.9 Hz	48.8 Hz	48.7 Hz	….	48.1 Hz	
		3%	3%	3%	3%	…..	3%	30%
UFLS plan 13	n=10	49.0 Hz	48.9 Hz	48.8 Hz	48.7 Hz	….	48.1 Hz	
		4%	4%	4%	4%	…..	4%	40%
UFLS plan 14	n=10	49.0 Hz	48.9 Hz	48.8 Hz	48.7 Hz	….	48.1 Hz	
		5%	5%	5%	5%	…..	5%	50%
UFLS plan 15	n=10	49.0 Hz	48.9 Hz	48.8 Hz	48.7 Hz	….	48.1 Hz	
		6%	6%	6%	6%	….	6%	60%

Table 4 - Overview simulated scenarios

Figure 3 resumes from graphical point of view all the simulation results. It is possible do the following considerations:
- the blue lines represent the Policy 5 UCTE prescriptions and delimit an area
- some plans (i.e. 6, 11, …) are completely out of the blue delimited area
- some other plans (i.e. 15) partially are included into the area, but, requiring more (or less) load to be shed, are in the last part, outside
- other plans are within the area (i.e. 9)

In conclusion it is easy to see the "investigation area" of the study, demonstrating also a large comparison range between different strategies.
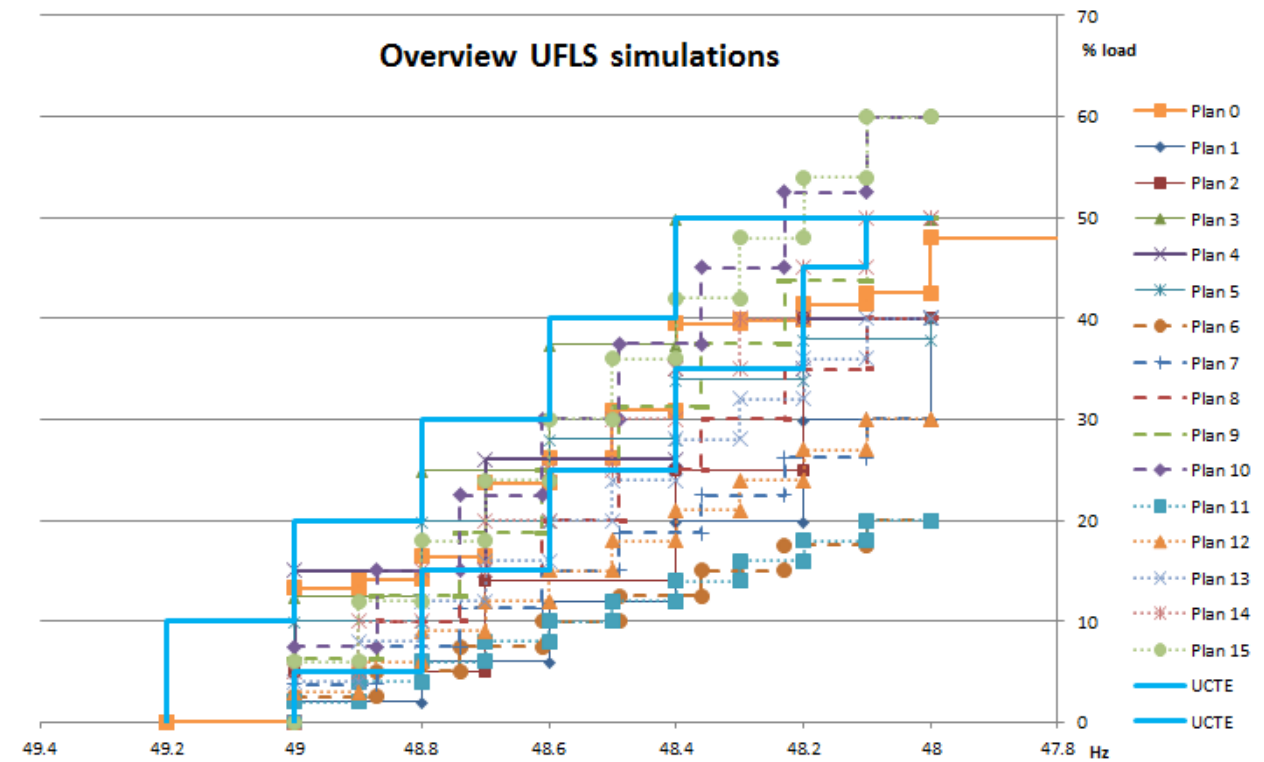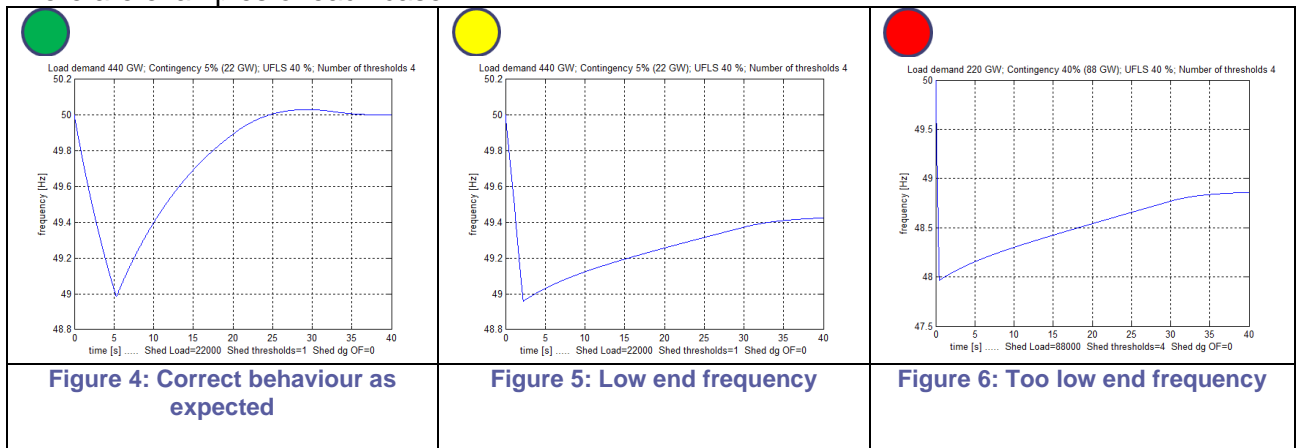

Figure 3: Overview UFLS simulations

6. Discussion on simulations results

Results have been analysed and assessed with the following acceptance criteria:

🟢	Accepted when a) final frequency in the range 49.9 Hz – 50.1 Hz and b) maximum overshoot below 50.2 Hz
🟡	Critical when c) final frequency out of the range 49.9 Hz – 50.1 Hz but within 49.2 Hz – 50.2 Hz, OR d) maximum overshoot reaches 50.2 Hz
🔴	Rejected e) final frequency out of the range 49.2 Hz – 50.2 Hz and f) overshoot reaching 50.2 Hz

Table 5 Evaluation criteria for simulation results. Final frequency is measured at t=40 s.

Here are examples of each case:

Figure 4: Correct behaviour as expected	Figure 5: Low end frequency	Figure 6: Too low end frequency

The green traffic light indicates the ideal load shedding behaviour; the yellow response is acceptable in emergency although it does not always guarantee a full frequency recovery and hence requiring additional load shedding actions or generation increase.

The red cases mark unacceptable load shedding strategies either due to practically absent frequency recovery or frequency overshoots due to overreaction.

The simulation results tabular output can be found in Annex, therein the corresponding criteria for ranking are depicted on this traffic light classification concept.

6.1 Current scenario - UFLS plan 0

This scenario represent the situation "as is". The results show that load shedding plan works, but confirm the need to be optimized in order to comply better the criteria of acceptance previously described.

With the smaller contingencies (1% - 10%), the final frequency is too high, and for the higher contingencies (30% - 40%) the end frequency is not sufficiently recovered.

The renewable infeed has a mixed impact: results are worse for smaller contingencies and better for the high contingencies.

In conclusion it is advisible that even for the current situation of dispersed generation infeed additional load shedding shall be in operation in order to compensate the current undesired disconnection of generation during an automatic under frequency load shedding event.

6.2   Variable thresholds UFLS plans 1 to 5

Plan 1 is an example of an increasing step-size scheme, with a very limited size of load shedding during the first steps (2, 4, 6, 8, 10, 10%).
With the given acceptance criteria, the UFLS Plan 1 gives acceptable results for high values of contingencies (10% or more) at peak load without renewable energy infeed.
On the other hand, "small contingencies" (less than 10% of global load), which are much more probable, the final frequency is never acceptable. If only one threshold is triggered, the frequency does not recover to an acceptable value. For the smaller contingencies, the end frequency becomes too high when the third threshold (with increasing size) is reached.
For the minimum load cases, the results are quite similar (acceptable for bigger contigencies, not acceptable for smaller contingencies).
The impact of infeed of renewable energy is limited on the final results. There is only a weak impact due to the overfrequency disconnection thresholds.

Plan 2 also reflects an increasing step-size situation: the results are less acceptable than in the previous case. Only a few cases at peak load situation are acceptable, all the other situations create an unacceptable end frequency which is too high. Only cases with low contigency (5%) or the biggest contingency (40%) obtain the green status. This is linked with the increasing step-size. With the small contigencies, only 1 threshold is triggered. With the biggest contingency, all thresholds are being activated. The intermediate contingencies provoke the shedding of the second / third threshold, which are too big to avoid the overfrequency at the end.
Due to the overfrequency shedding of dispersed generation, the end frequency is a bit lower, but still unacceptable high.

In plan 3, the end frequency never reaches an acceptable value for all the peak load situations. Due to the big steps (12,5%), too much load is shed with each step, which leads to an overshoot of the end frequency.
The disconnection of renewable energy at the overshoot will lead to a lower end frequency, but still too high to be acceptable.

Plan 4 is an example of a decreasing step-size case. Only the biggest contigencies, where all thresholds are activated, are acceptable. Due to the biggest steps are being used first, the end frequency is too high in the other situations.
The shedding of dispersed generation gives a little lower end frequency, but still unacceptable.
The biggest contingency with activation of the four thresholds is now unable to recover to 50 Hz, due to the limited amount of conventional generation.

Plan 5 is also a decreasing step-size case, but with a smaller first step than the previous case, and with an equal size for the first two steps.

Due to the big (10%) first step, the low contingency situations create an frequency overshoot, even in the cases with dispersed generation being shedded at overfrequency.
Only the mid-range contigencies (10%-20%) are accepted if no dispersed generation is in the grid. With DG, these scenarios also become unacceptable.
The biggest contingencies (30%-40%) lead to an end frequency which is not recovered (more with DG infeed), due insufficient load shedded even with the activation of all the thresholds.

In conclusion it can be stated that non-linear load shedding schemes does not contribute in a positive way to reach a desirable system balance. Therefore, a symmetrical distribution of load over all load shedding stages is the recommended option.

6.3   8 thresholds UFLS plans 6 to 10

The following 5 cases have 8 equally sized steps, but with different amount of total shedded load

In plan 6 only a limited amount of contingency cases are acceptable. Even with the activation of all steps, the end frequency is never fully recovered. The minimum load cases (1%-5%) have a slightly better behaviour, but only a few cases are satisfactory. The impact of renewable infeed is very limited.

In plan 7, due to the increase of the total shedded load (30%), the results are a little bit better than with the previous plan. But still at higher contigencies (above 10%), the frequency is not able to recover to an acceptable level. Like in the previous plan, the impact of renewables is limited.

In plan 8, all results are acceptable without infeed of dispersed generation and for all contingencies the end frequency returns to 50Hz. If the dispersed generation is taken into account, the results become critical in most cases. In the situation with minimum load and large contingencies (30%-40% of load demand), the frequency is not able to fully recover. The overfrequency disconnection has almost no impact on the results. This plan is a good reference candidate in case of complete retrofit program extended to all RGCE TSOs.

In plan 9 the results are less acceptable in terms of quality than in the previous UFLS planWith the increase of the maximum shedded load to 50%, the end frequency becomes too high for the cases without renewable infeed. If the dispersed generation is taken into account, the final frequency tends to improve.

In plan 10 with the further increase up to 60% of load to be shedded with activation of all the thresholds, the results are almost never acceptable, as either the end frequency is too high, or not fully recovered. In general, the minimum load results are better than the maximum load cases.
The impact of renewables infeed is very limited, and does not improve the outcome.

6.4   10 thresholds UFLS plans 11 to 15

The following 5 plans contain 10 equally sized steps evenly distributed between 49 Hz and 48 Hz

In plan 11 without and with renewable infeed, the results are either critital or unacceptable for all the contingencies bigger than 10% of the load demand. The end frequency is never able to recover to 50 Hz, even by activating all steps. The results are slightly better at the minimum load situations, but never satisfactory.

In the plan 12, the final frequency is higher due to the increase of the total volume of load that can be shed (in comparison with previous case), but still not adequate. Only a few case are acceptable for small contigencies if renewable energy is taken into account.

Referring to plan 13, with the increase up to 40%, the results are more correct, especially at mimimum load. Only for the largest contingency (40%) the end frequency is not restored. The infeed of renewable energy has a positive impact for the peak load situations. Also this plan can be judjed a good reference candidate.

In plan 14 all results are correct without dispersed generation and critical (**Error! Reference source not found.**) when taken into account. Overfrequency disconnection of the renewable infeed has no real impact on the results (only very limited amount is lost).

Plan 15 demonstrate that if the total size of the UFLS scheme is further increased until 60%, results are worse than the previous case. Most simulations lead to too high end frequency. This is especially the case for the small contingencies (5%-10% and the big contingency (40%).
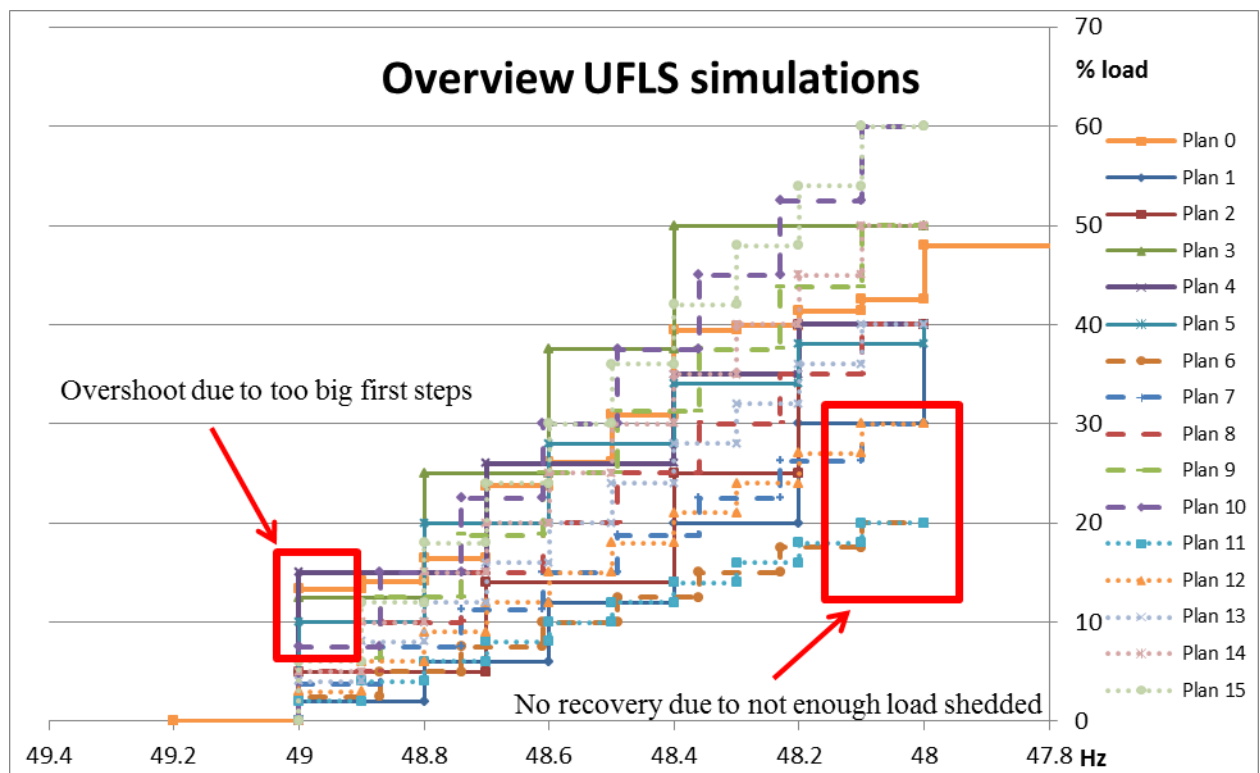The impact of renewable infeed is mixed, but still not acceptable.

Figure 7: Overview results.

Figure 7 underline the "zones" where the choise of total quantity to be shedded has influence; from simulation we conclude that the only acceptable range is between 40% and 50% of total system load.
As can be desumed from figure 8, the more efficient plans are 8, 13, 14; the common factors are:
- number of thresholds (range between 8 and 10)
- maximum acceptable magnitude of a single step: 10%
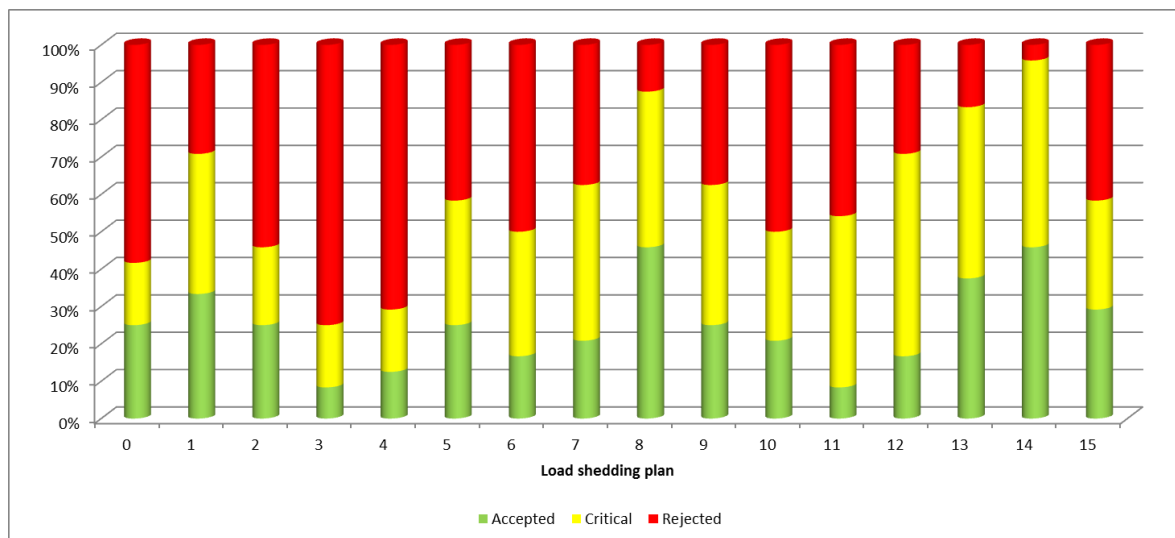- maximum total shedded load (range between 40% and 50%)

Figure 8: Classification of results for the simulations per UFLS plan

In conclusion, these results are used applying a certain "tolerance" in the way to be implemented in all the practical realities of RGCE, taking also into account different sizes of systems and trying to reduce the gap between existing situations and desired load shedding design.

7. Conclusions and Recommendations

7.1 Reference Load Definition

Based on the fact that within the majority of the CE TSOs the current underfrequency load shedding relays are located at the interface between the transmission and distribution system. Therefore, the most appropriate document in order to define the reference load reported [3]; reference load is:

– Yearly average net load consumption, while:
  – In the corresponding summation only those feeder are considered which do not have any dispersed generation infeed or those with only low dispersed generation
  – Mixed feeders with loads and high dispersed generation infeed are not considered in the summation process

This concept of calculating the reference load will have to be considered when each TSO has to implement his load shedding scheme. However it is foreseen that due to the further increase of decentralised infeed the shift of UFLS relays to lower voltage levels will be required and the number of relays will also have to increase correspondingly.

7.2 UFLS plan design recommendations

A general finding from the simulations which all parties should bear in mind is the fact that a load shedding plan is the last resort. This means that in some situations load shedding leads from a less than optimum state of the system to not optimal final state, and in few cases, does not avoid a system black out.

This conclusion is in line with the state-of-the-art experience and it is a consequence of the behaviour under extreme circumstances. Many local problems such as voltage stability, loss of units due to false tripping by protection, grid splitting, can produce unexpected situations within the system. These particular effects can be studied with more detailed models, but experience shows that uncertain information about parameters and real grid configuration at moment of the transient studied can lead to results which are even more inconsistent.

So starting from these considerations, the study was based on a normative model that guarantees an adequate degree of conservative approach without deviating to far from the real system behaviour.

The maximum value of total load that shall be shed per single TSO is 50% of the reference load for the whole system; the minimum value that shall be shed per single TSO is 40% of the reference load; Figure 9 illustrates the "permitted area" where the expected general system behaviour of load shedding plan is shown. Two load shedding plans 8 (blue) and 14 (orange) are shown. The black surve delimits the boundary of maximum load that can be shedded (clearly in whole frequency range must be considered the constraint about maximum step amplitude, equal to 10 %).
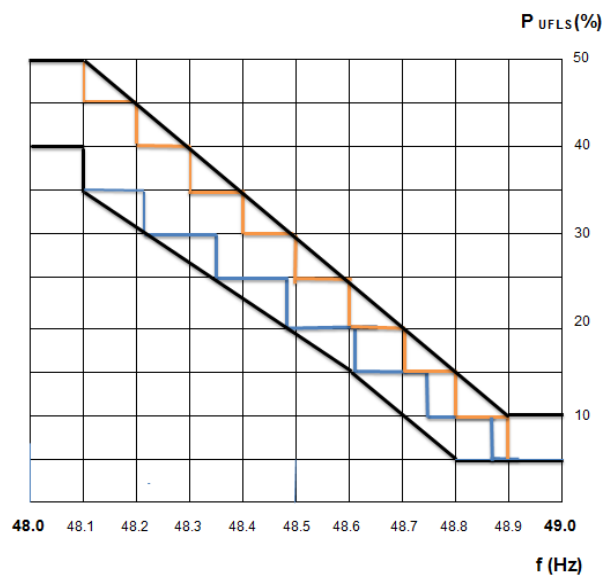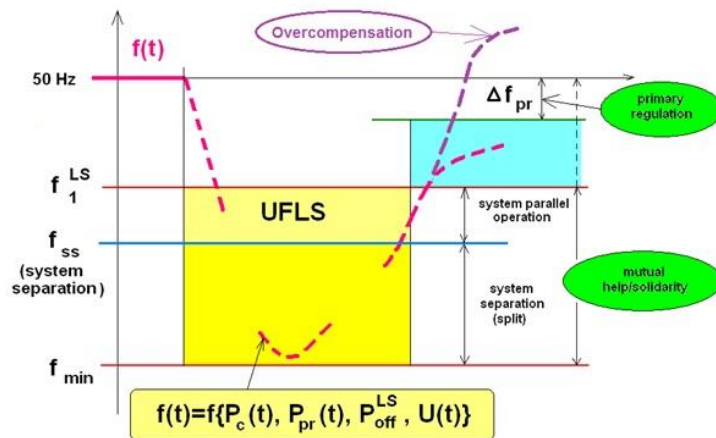

Fig. 9: Practical load shedding boundaries (black). Recommended load shedding plan 8 (blue) and plan 14 (orange) are also displayed.

The number of steps and the value of the total shed load is chosen in order to avoid overcompensation or frequency stagnation at low values. The appropriate ideal frequency to the system after load shedding intervention could be in the band of ± 200 mHz around 50 Hz; but this is not possible or feasible in all studied cases; the Figure 10 illustrates graphically it.

Fig. 10: Underfrequency load shedding principle

The amplitude of each step shall be in the range of 5-10%. The minimum mandatory number of steps for single TSO is 6; this value is a compromise between the equal linear theoretical setting and the optimal practical solution. If the maximum permitted amplitude of single step is exceeded, the TSO must increase the number of steps in order to comply with it. The suggested maximum number of steps is 10 due to UFLS relay tolerances. The qualitative explanation of effect of step selection (varying the size) is showed in following Fig. 11; this can help to better understand simulation results.
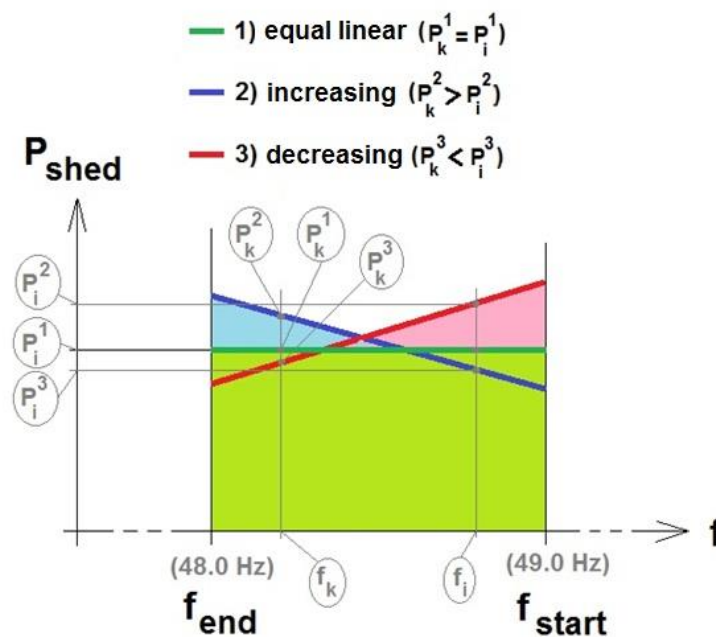

Fig.11: Underfrequency step size variation

Selected operating frequency range of the automatic UFLS is 49.0 - 48.0 Hz. The highest value is determined by the minimal frequency value of the automatic disconnection of pump-storage generating units from pumping mode (e.g. 49.3 Hz) taking into consideration a necessary security margin. The lowest value is determined by the minimal required operating frequency value (47.5 Hz) of the generating units taking into consideration a small frequency band also with necessary security margin for an individual additional load shedding of TSOs if it is needed. This additional load shedding can be important after a network split in case of island operation.

Additional recommendations are:
1. The TSOs should carefully evaluate the expected **total tripping time** of load shedding relays, considering measure and time, trip action of auxiliary circuits and circuit breaker opening time: it is highly recommended to use set the total time to less than or equal to **150 ms** and, in any case, **300 ms** should not be exceeded.
2. The TSOs should, based on the maximum level of accuracy of relays, select **100 mHz - 200 mHz as range** of frequency **between each step**. Current state-of-the art underfrequency relays ensure a measurement accuracy of +/- 30 mHz.

7.3   Special Cases

Based on the inventory of current frequency relays settings, it is clear that some applications in use with single TSOs are at the limit between load shedding plan and Special Protection Schemes; in some cases the TSOs use frequency relays to cut parts of the system or shed load in order to compensate for a loss of generation or for local problems. Some general rules can be reported (out of the scope of the present study simulation, but necessary to avoid confusion of system criteria and parameters).

The shedding of equivalent load by storage devices, pumps or load it is recommended to be applied below 49.8 Hz (optionally via ROCOF use and eventually with intentional delays) only if the TSO documents it to RG CE, demonstrating that this is a "balancing" emergency action that does not disturb the system.

References

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