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Assumptions and methodology for a probabilistic FCR dimensioning in the Continental Europe synchronous area in accordance with Article 153(2) of the Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation

Date: 15 January 2025

Contents

Whereas

(1) Article 153(2) of the Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (hereafter referred to as “System Operation Guideline” or “SO GL”) contains criteria that the Transmission System Operators (hereafter referred to as “TSOs”) of each synchronous area shall follow when specifying the dimensioning rules for Frequency Containment Reserve (hereafter referred to as “FCR”).

(2) According to Article 6(3)(d)(ii) of the SO GL, the dimensioning rules for FCR are subject to approval by all regulatory authorities of the concerned region. Once approved these rules are included in the synchronous area operational agreement. For the Continental Europe synchronous area this agreement is part of the wider Synchronous Area Framework Agreement (hereinafter referred to as “SAFA”) stipulated by the TSOs.

(3) The TSOs of the Continental Europe synchronous area have historically adopted a deterministic criterion for the dimensioning of FCR. Such criterion considersconsider that the FCR shall be able to contain a frequency deviation due to the worst expected outages combination in the system, reflected by the ‘reference incident’ being equal to 3000 MW in both positive and negative direction, pursuant to Article 153(2)(b) of the System Operation Guideline.

(4) For the Continental Europe synchronous area, Article 153(2)(c) of the SO GL states that the TSOs of the Continental Europe synchronous area have the right to define a probabilistic dimensioning approach for FCR, taking into account the pattern of load, generation and inertia, including synthetic inertia as well as the available means to deploy minimum inertia in real-time in accordance with the methodology referred to in Article 39 of the SO GL, with the aim of reducing the probability of insufficient FCR to below or equal to once in 20 years.

(5) The probabilistic FCR dimensioning generally contributes to the achievement of the objectives of Article 4(1) of the SO GL. Specifically, the probabilistic FCR dimensioning provides the TSOs of the Continental Europe synchronous area with a methodology to evaluate the needs of FCR considering all the relevant contributing factors. Such methodology contributes to the determination of common operational security requirements and principles as set in Article 4(1)(a) of the SO GL. It furthermore contributes to ensuring the conditions for maintaining operational security throughout the Union as set in Article 4(1)(d) of the SO GL. Finally it contributes to ensuring the conditions for maintaining a frequency quality level of all synchronous areas throughout the Union as set in Article 4(1)(e) of the SO GL. The probabilistic FCR dimensioning does not impact on the other objectives listed in Article 4(1) of the SO GL.

(6) The probabilistic methodology for FCR dimensioning contributes to pursuing the general objectives of the SO GL of safeguarding operational security by defining the proper FCR dimensioning needs.

Article 1
Subject matter and scope

1. The assumptions and methodology for the probabilistic FCR dimensioning represent the dimensioning rules for FCR for Continental Europe synchronous area in accordance with Article 153(2) of the SO GL.

Article 2
Definitions and interpretation

2. For the purposes of the probabilistic FCR dimensioning, terms used in this document shall have the meaning of the definitions included in Article 3 of the SO GL.

3. Further, in theprobabilistic FCR dimensioning, unless the context requires otherwise, the following definitions shall apply:
   a) Critical Condition' is a serie of minutes meeting one or more of the citeria for not acceptable minute and spaced each other not more than a parametrical number of minute.
   b) 'Deterministic frequency deviation' or 'DFD' means regular deviations of the grid frequency that occur around the hourly or sub-hourly intervals.
   c) 'Equivalent reservoir energy capacity' means the energy requirement for LER associated to the Time Period and shall amount to twice the energy provided by the full activation of LER for the Time Period.
   d) 'FAT' means 'automatic FRR Full Activation Time' as defined in Article 3 (101) of SO GL.
   e) 'frequency nadir' is the minimum instantaneous frequency reached during an underfrequency transient.
   f) 'frequency zenith' is the maximum instantaneous frequency reached during an overfrequency transient.
   g) 'Initial RoCoF', is the RoCoF calculated at the time in which a disturbance happens.
   h) 'LER' means 'FCR providing units or groups with limited energy reservoirs': FCR providing units or FCR providing groups are deemed as with limited energy reservoirs in case a full continuous activation for a period of 2 hours in either positive or negative direction might, without consideration of the effect of an active energy reservoir management, lead to a limitation of its capability to provide the full FCR activation.
   i) 'LER Share' means the amount of LER in MW.
   j) 'Long lasting frequency deviation' or 'LLFD' means an 'event with an average steady state frequency deviation larger than the long-lasting frequency threshold over a period longer than the time to restore frequency.
   k) 'Long-lasting frequency threshold' means a parameter used to identify Long lasting frequency deviation.
   l) 'Market induced imbalances' means the 'generation-load imbalance caused by the change in generation set points according to the results of the market scheduling'.
   m) 'Maximum Transient Frequency Deviation' is the difference in absolute value between the frequency at the time in which the disturbance happens and the frequency nadir for under-frequency or the frequency zenith for over-frequency phenomena. It represents the maximum frequency excursion before frequency starts to recover.
   n) 'Maximum Initial RoCoF' is maximum RoCoF acceptable during a transient.
   o) 'RoCoF', means Rate of Change of Frequency, is the derivative of the frequency.
   p) 'System droop' means 'the ratio between frequency deviation and steady state power response provided by FCP'.
   q) 'Time Period', means 'the time for which each FCR provider shall ensure that its FCR providing units or groups with limited energy reservoirs are able to fully activate FCR continuously, as of triggering the alert state and during the alert state' as determined according to Article 156(9) of the System Operation Guideline.

4. In this document, unless the context requires otherwise:
    a) the singular indicates the plural and vice versa;
    b) references to an "Article" are, unless otherwise stated, references to an Article of this document;
    c) the table of contents and headings are inserted for convenience only and do not affect the interpretation of the probabilistic FCR dimensioning; and
    d) any reference to legislation, regulation, directive, order, instrument, code or any other enactment shall include any modification, extension or re-enactment of it then in force.

Article 3
Outcome of the probabilistic FCR dimensioning

1. The outcomes of the probabilistic FCR dimensioning is a symmetrical value in MW for FCR for the entire Continental Europe synchronous area in accordance with Article 153 of the System Operation Guideline, computed according to the process described in Article 4.

Article 4
FCR dimensioning criteria and process

1. The symmetrical value for FCR for the entire Continental Europe synchronous area represents the minimum amount of FCR needed in accordance with Article 153 of the SO GL, taking into account the pattern of load, generation and inertia, including synthetic inertia as well as the available means to deploy minimum inertia in real-time in accordance with the methodology referred to in Article 39 of the SO GL, with the aim of reducing the probability of insufficient FCR to below or equal to once in 20 years.

2. The symmetrical value for FCR for the entire Continental Europe synchronous area is computed by the mean of an iterative procedure as follows:
    a) the process starts by setting a FCR value equal to the reference incident;
    b) the FCR value is tested by the mean of the Probabilistic Simulation Model referred to in Article 5;
    c) if the FCR is deemed sufficient according to the criteria in Article 7, the procedure stops, otherwise the FCR value is increased by 100 MW and a new iteration is run;
    d) the process continues until a sufficient FCR value is detected.

Article 5
Probabilistic Simulation Model

1. The Probabilistic Simulation Model simulates the behaviour of the whole Continental Europe synchronous area in terms of frequency trends, testing the efficiency of the value of FCR in ensuring a proper frequency quality according to the frequency acceptance criteria in Article 6. .

2. The Probabilistic Simulation Model shall implement a function to calculate the dynamic frequency response consequent to a disturbance. Such function shall consider the variation in power imbalance between two following calculation steps and calculate the key parameters of the frequency transient: (frequency nadir, frequency zenith and RoCoF), along with the steady state frequency deviation considering the system droop. The models parameters are tuned to provide the best equivalent behaviour of the power system.

3. The Probabilistic Simulation Model uses a Probabilistic Simulation Process in order to simulate several years of operation conditions of the synchronous area by means of random draws of power imbalances associated to DFDs, LLFDs, and outages of relevant grid elements. For each simulated year a power imbalance trend is determined and the corresponding frequency deviation and relevant parameters are computed according to the function described in paragraph 2.
   The operation period to be simulated shall be estimated to generate statistically significant results and to provide the best compromise among the desired level of accuracy and computational time efforts; in any case at least 200 years shall be simulated.
   The time discretization adopted by the Probabilistic Simulation Process shall be 1 minute. Each variable shall thus be calculated on a 1-minute basis.

4. Input power imbalances deriving from DFDs and LLFDs are computed by the mean of an algebraic relation simulating the steady state behaviour of the system.

5. Power imbalances associated to outages of relevant grid elements are determined simulating the FRP with a single FRP controller without FRR limitations. The single FRP controller shall use a FAT calculated as an average of the FAT of all the LFC areas belonging to the synchronous area weighted by the FRR K-factors, until the FAT will be harmonized.

6. The annual review of FRR K-factors can be neglected as long as the review does not affect signicantly the average FAT as defined in paragraph 5.

7. The Probabilistic Simulation Process can neglect the entire Cross-Border Load-Frequency Control Process.

8. The Probabilistic Simulation Process shall be able to simulate the depletion of LER and its effects on the frequency deviation, taking into account the LER Share and the Time Period. If an alert state is detected, as of triggering the alert state and during the alert state, the depletion of the LER is simulated considering that the energy content in the reservoir as of triggering the alert state allow the LER to fully activate FCR continuously for a period equal to the Time Period.

9. More details about the Probabilistic Simulation Model are reported in the Annex.

Article 6
Sources of power imbalances

1. As detailed in the Annex and mentioned in Article 5(3), the Probabilistic Simulation Model shall take into account:
   a) Outages of relevant grid elements,
   b) Deterministic frequency deviations (DFDs),
   c) Long lasting frequency deviations (LLFDs).

2. For DFDs and LLFDs, the TSOs shall consider the market induced imbalances and analyse frequency historical trends of the synchronous area over a number of years, as defined by the Continental Europe TSOs according to Article 9.

3. For outages of relevant grid elements the TSOs shall define a list of all the grid elements whose outages lead to relevant power imbalances and indeed to relevant FCR activation.

Article 7
Frequency acceptance criteria

1. At each iteration, all Critical Conditions occurring in each simulated year are identified by checking whether a serie of minutes, spaced each other not more than a parametrical number of minutes meets one or more of the following criteria:
   a) The Steady State Frequency Deviation exceeds the steady state maximum frequency deviation.
   b) The frequency nadir or frequency zenith during a frequency transient exceeds the admissible thresholds, as defined by the Continental Europe TSOs according to Article 9.
   c) The absolute value of RoCoF exceeds the Maximum Initial RoCoF, as defined by the Continental Europe TSOs according to Article 9.

2. The FCR considered is deemed sufficient when the number of identified Critical Conditions is less than or equal to 1/20 of the number of simulated years. Such condition shall be fulfilled by the final dimensioned FCR

Article 8
Simulation scenarios

1. The symmetrical value for FCR for the entire Continental Europe synchronous area is determined every two years considering the best estimations of the input data regarding the evolution of sources of frequency disturbances (taking into account the frequency management procedures implemented in the meantime by the Continental Europe TSOs), the expected LER shares, their respective Time Period and any other factor impacting the calculation and dimensioning of FCR.

2. In case there are significant changes in the input datasets, the TSOs may, on their own initiative, redetermine the symmetrical value for FCR for the entire Continental Europe synchronous area even before the two years period foreseen in paragraph 1.

3. The national regulatory authorities of the Continental Europe synchronous area have the right to send the TSOs a coordinated request for the redetermination of the The symmetrical value for FCR for the entire Continental Europe synchronous area.

Article 9
Reporting

1. Before each run of the FCR dimensioning process pursuant to Article 4, the TSOs shall provide the national regulatory authorities of the Continental Europe synchronous area with the values, and justifications for each value, of all the relevant thresholds adopted to assess the frequency acceptance criteria of Article 7, and all the parameters described in the Annex.

2. The TSOs shall send to the national regulatory authorities of the Continental Europe synchronous area at the end of each run of the FCR dimensioning process pursuant to Article 4 a report listing:
   i. the mitigation measures considered in the LLFDs dataset and how they were taken into account;

ii. the main parameters adopted to assess the frequency acceptance criteria and the reasons behind their choice;
iii. the symmetrical value for FCR;
iv. the reasonings behind the choice to redetermine the symmetrical value for FCR in case such redetermination occurs on initiative of the TSOs according to Article 8(2);

Article 10
Publication and implementation of the probabilistic FCR dimensioning

1. Each Continental Europe TSO shall publish the probabilistic FCR dimensioning without undue delay after all the national regulatory authorities of the Continental Europe synchronous area have approved the document, in accordance with Article 8 of the SO GL.

2. The Continental Europe TSOs shall have implemented the probabilistic FCR dimensioning within 12 months after the national regulatory authorities of the Continental Europe synchronous area have approved the document.

3. Within 1 month from the approval of the FCR dimensioning by the national regulatory authorities of the Continental Europe synchronous area, the Continental Europe TSOs shall organize a series of meeting with the above mentioned regulatory authorities in order to keep discussing how the FCR obligation may be identified in order to allocate more responsibilities to the LFC blocks causing the most significant LLFDs.

Article 11
Language

1. The reference language for this methodology shall be English. For the avoidance of doubt, where TSOs need to translate this methodology into their national language(s), in the event of inconsistencies between the English version published by TSOs in accordance with Article 8(1) of the SO GL and any version in another language, the relevant TSOs shall, in accordance with national legislation, provide the relevant national regulatory authorities with an updated translation of the methodology.

Technical Annex of the methodology for performing the probabilistic dimensioning of FCR in CE synchronous area according to Article 153(2) of Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation

Date: 15 January 2025

Contents

1 Acronyms and references

ACE	Area Control Error
CE	Continental Europe
LER	FCR providing units or groups with limited energy reservoir
FCR	Frequency Containment Reserve
FCP	Frequency Containment Process
FRR	Frequency Restoration Reserve
FRP	Frequency Restoration Process
FSM	Frequency Sensitive Mode
Non-LER	FCR providing units or groups without limited energy reservoir
NP RES	Non Programmable Renewable Energy Sources
RES	Renewable Energy Sources
SO GL	System Operation Guideline
SA	Synchronous Area
$T_{min\ LER}$	As of triggering the alert state and during the alert state, time for which each FCR provider shall ensure that its FCR providing units with limited energy reservoirs are able to fully activate FCR continuously.
FAT	Full Activation Time of FRR
ROCOF	Rate of Change of Frequency

[1] COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation.

[2] ENTSO-E, SPD, “Frequency Stability Evaluation Criteria for the Synchronous Zone of Continental Europe”, 2016.

[3] ENTSO-E, SPD – Inertia TF, “Inertia and Rate of Change of Frequency (RoCoF)”, 2020.

[4] ENTSO-E, “ENTSO-E HVDC Utilization and Unavailability Statistics 2021”, 2022.

2 Methodology for probabilistic approach for FCR dimensioning

2.1 Overview and description of the methodology

The methodology to perform the FCR probabilistic dimensioning required in the Continental Europe Synchronous Area is based on a probabilistic model which randomly combines the most important source of power imbalance in the system and simulate the resulting frequency deviation.

The model works on a large set of simulated years, in order to reach probabilistic significant results.

According to Article 153(2)(c) of SO GL, the probabilistic approach to FCR dimensioning shall be aimed at reducing the probability of insufficient FCR to below or equal to once in 20 years.

Namely, whenever a power imbalance exceeds the available FCR, the FCR is considered insufficient. In terms of frequency deviation, such condition results in a steady state frequency deviation larger than the Maximum Steady State Frequency Deviation (at which FCR shall be fully deployed).

Moreover, since the available FCR impacts also the frequency transient following a sudden change in power imbalance. “insufficient FCR” conditions are also those conditions where the frequency dynamic performances are severely degraded. , i.e. those conditions whenthe frequency exceeds specific thresolds in terms of Δf peak or ROCOF.

The purpose of the model is thus to determine the minimum amount of FCR which allows to ensure that the insufficient FCR conditions (i.e., a Critical Conditions) occur not more often than once in 20 years.

A Critical Condition is a serie of minutes spaced each other not more than a parametrical number of minutes and meeting one or more of following criteria:

a. The absolute value of Steady State Frequency Deviation (SSΔf) as simulated by the Probabilistic Simulation Model exceeds the steady state maximum frequency deviation (200 mHz fro CE)
b. The absolute value of frequency peak reached during a transient exceeds the admissible tresholds .
c. The absolute value of ROCOF exceeds the Maximum Initial ROCOF.

Maximum Transient Frequency Deviation and Maximum Initial ROCOF are parameters defined by TSOs and made publicly available before the execution of the methodology.

The model starts with the current deterministic FCR. The model then iterates increasing step by step the FCR until the number of Critical Conditions in the simulated frequency deviation is such that they occur not more often than once in 20 years.

The model takes into account the potential presence of LER (Limited Energy Reservoir FCR providers) in the calculation of the results.

- The Probabilistic Simulation Model shall take into account:Outages on generation plants and HVDC connections. Details on how the power imbalance is calculated are provided in Section 2.4.
- Power imbalance associated with Deterministic Frequency Deviations (DFDs). Details on how the DFDs are calculated are provided in Section 2.2.
- Power imbalance associated with Long-Lasting Frequency Deviations (LLFDs). Details on how the LLFDs are calculated are provided in Section 2.3.

DFDs and LLFDs are calculated starting from historical data of frequency deviations while the power imbalances due to outages are derived from outages statistics.

An overall power imbalance is randomly generated from these three different sources of disturbance. Such power disturbance is used to calculate simulated frequency deviation trends which are then analysed to verify whether they fulfill the minimum acceptance criteria.

The whole model operates with a time granularity of one minute. Hence the power input power imbalance as well as the simulated frequency deviations are trends with 525600 minutes a year (leap-year presence is neglected).

The overview of the process is shown in the following Figure 1.

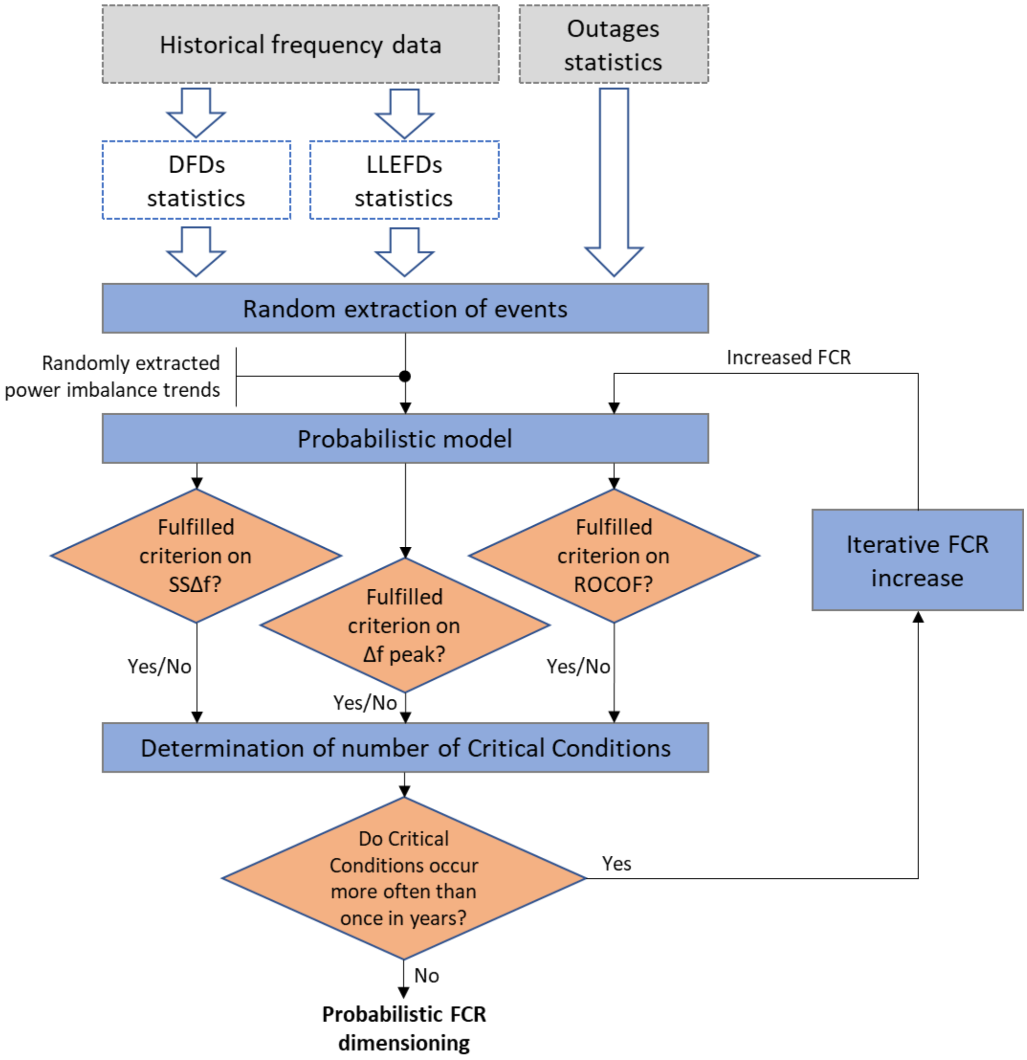

Figure 1: General overview of the model adopted for the probabilistic approach for FCR dimensioning

Figure 2 provides a more detailed depiction of how the input statistics (frequency, outages) are exploited.

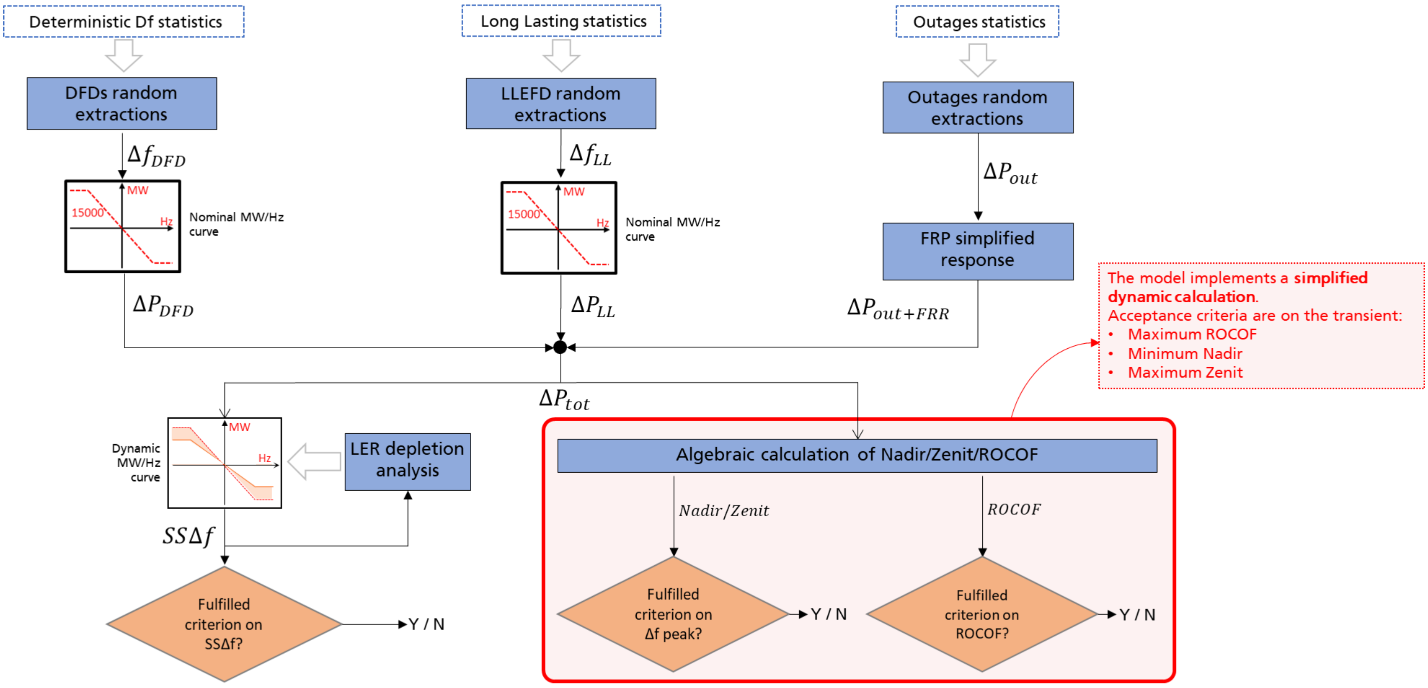

Figure 2: Detailed overview of the model adopted for the probabilistic approach for FCR dimensioning

2.2 Functionality for DFDs statistics and DFDs random extractions

DFDs are market-induced frequency deviations which regularly occur around the change of the market time unit (usually the change of hour).

In the model, the statistic of DFDs are directly calculated from the historical frequency trends with 1-minute granularity. The model extracts the frequency around the change of hour: are considered as DFDs all the frequency samples in a minutes range around the minute 0 (DFD interval).

For each simulated year, this functionality is aimed at calculating a trend of the frequency deviation due to DFDs.
This trend is equal to 0 for all the minutes m which do not belong to the DFD interval. The minutes m belonging to the DFD interval are taken from the input historical frequency trends.

DFDs are randomly selected for the input of the model, looking at homologous days in past years. For example the DFDs to be assigned to 1st January of a simulated year are directly taken from the DFDs which actually occurred in the system during the 1st January of a randomly selected past year (e.g. 2018). This mechanism allows to keep the daily pattern of occurrence for DFDs: for example, the DFDs occurring around 6 am are taken from the same hour in the same day of another year.

The random choice of the year is biased towards most recent years. The probability of the past year y is indeed calculated with the following formula:

$$p_y = \frac{1}{N_{years}} e^{-\frac{y-y_{last}}{N_{years}}}$$

Where:
y_{last} is the most recent year for which data are available;
N_{years} is the number of years for which historical trends are available.

The functionality results in a frequency trends composed by randomly extracted DFDs.

2.3 Functionality for LLFDs statistics and LLFDs random extractions

For the purpose of FCR dimensioning, the definition of long-lasting frequency deviations (LLFDs) is a “condition with an average steady state frequency deviation larger than a share of the Standard Frequency Range over a period longer than the Time To Restore Frequency”.

The tool scans the frequency trends acquired as input to detect all such conditions.
The scan operates following these rules:

- A moving average (with a width equal to Time to Restore Frequency) scans the data of a whole year.
- If the moving average frequency deviation exceeds a threshold equal to a share of the Standard Frequency Range, a LLFD is detected.
- The LLFD length is calculated looking at its average frequency. The LLFD lasts as long as its average frequency exceeds a share of the Standard Frequency Range. This average is calculated from the beginning of the LLFD).

A list of all the detected LLFDs is created. Each LLFD is associated with the following information:

- Year of occurrence;
- Minutes in which it started;
- Duration;
- Frequency trend (vector of df characterizing the event)

These statistics are than exploited to generate a random extraction of LLFDs to be used as input by the model.

The procedure iterates on all the minutes of the year, asfollows:

1. It decides whether or not a LLFD starts at minute m.
   This choice depends on the probability that a LLFD starts at the generic minute m of a day (e.g., at 02.15 PM). The latter probability is equal to the ratio between the number of LLFD starting in the minute m (in the whole frequency dataset) and the number of days in the frequency dataset ($365 * N_{years}$).
   If no LLFD occurrence is extracted, the procedure proceeds analysing the following minute (m+1).
   If a LLFD occurrence is extracted, the procedure proceeds at the step 2.
2. The year y from which to select a LLFD starting at minute m is randomly extracted. For this the following probability is used:
   $$p_{m,y} = \frac{1}{N_{m,years}} e^{-\frac{y-y_{last}}{N_{m,years}}}$$
   Where $N_{m,years}$ is the number of years for which at least one LLFD starting at minute m has been detected and y_{last} is the most recent year for which data are available;
3. The specific LLFD to be used is then chosen from the set of all LLFDs started at minute m and occurred in the year y (chosen in the step 2). The random choice of the specific LLFD to be used is based on an uniform distribution: all LLFDs in the set have the same probability to be chosen.
4. The selected LLFD is assigned to the trend. If the LLFD lasts for k minutes, the LLFD frequency trend is assigned to the interval between minute m and minute m+k-1.
5. The procedure returns to step 1 for minute m+k.

The functionality results in a frequency trends composed by randomly extracted LLFDs.

2.4 Functionality of outages random extractions and calculation of associated power imbalances

The outages are provided as input already in a statistical form: each potential event is associated with its:

- power loss: power change as of the event occurs;
- probability of occurrence: average number of events in a year.

The random extraction of outages uses as input the list of possible events

The extraction operates cycling on all the minutes of the year. For each minute m, all the possible events are tested to verify whether they occur or not.
For each possible event v, a random value in [0, 1] is generated and it's compared with the probability that the event occurs in the minute ($p_{v,m}$):

$$p_{v,m} = 1 - e^{-\frac{FR}{365*24*60}}$$

Where FR: $Failure\ Rate$ is the average number of occurrence in a year for a specific outage.

If the random generated value is below $p_{v,m}$ the outage occurs. It means that the system must cope with the power imbalance associated with the event.

The total amount of power imbalance in each minute is equal to the sum of the power imbalances of all the events which are extracted in that minute.

The result of the calculation is a yearly power imbalance trend due to extracted outages.

FRR effects are applied to such calculated power imbalance yearly trend. The FRR is modelled as a simplified 1st order dynamic system. The power imbalances are brought to zero by FRR with a time constant equal to 1/3 of the FRR FAT.
After roughly 3 time constants the transient is ended, this condition simulates the restoring effects of FRR in balancing the power imbalance due to outages within FRR FAT.
The following Figure 3 shows an example of the FRR effects on the power imbalances due to outages.

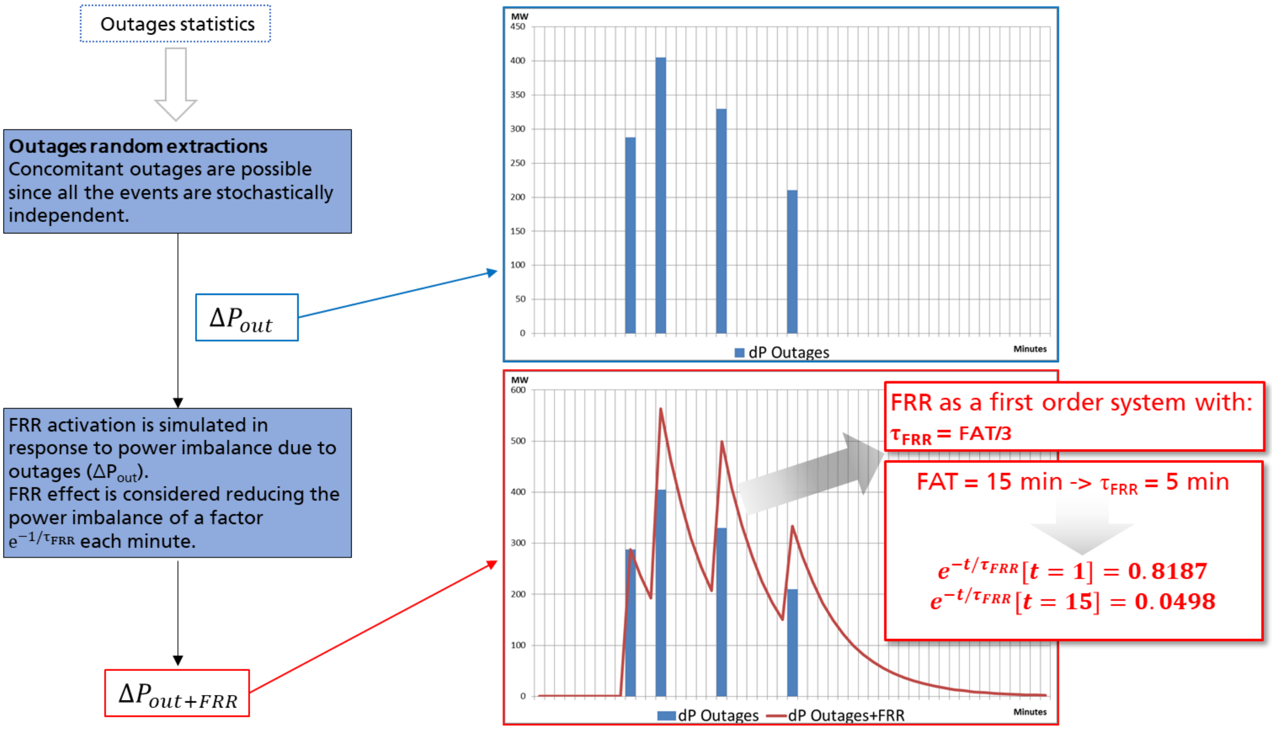

Figure 3: Example of FRR effects on power imbalance due to outages (15 min FAT is merely illustrative)

The functionality results thus in power imbalance trends due to outages and consequenct FRR activation.

2.5 Functionality of combination of extracted DFDs, LLFDs and outages to generate global power imbalance trends

The combination of the input due to different sources takes place in terms of power imbalance: the power imbalance due to outages is combined with the power imbalance corresponding to DFDs and LLFDs.

In order to convert the frequency deviation trends into equivalent yearly power imbalance trends, a converting module is used. The module operates the conversion using a MW/Hz curve (given as input). In other words, the frequency deviations due to DFDs and LLFDs are converted into power imbalances assuming the conversion factor which was in place at the moment of their real occurrence. Such converting factor is the MW/Hz dependency with a FCR equal to the value present in the year the data are referred to (e.g., 3000 MW for years up to 2024).. Such MW/Hz dependency doesn’t change during the iteration since it is related to historical data trends.

The global power imbalance is obtained by summing the three power imbalances (due to LLFDs, DFDs, and outages).

To avoid overlaps between DFDs and LLFDs the priority is given to LLFDs. LLFDs and DFDs are not summed each other, but - on each minute - the presence of a LLFD overrides the presence of a DFDs.

2.6 Model to calculate the steady state frequency deviation in every minute.

This functionality progressively simulates system operation (in terms of frequency control) over the 525600 minutes of a year.

For each minute m it calculates the stady state simulated frequency deviation ($SS\Delta f_m$) considering as input:

- The global power imbalance: ΔP_m
- current regulating energy: $reg.en._m$

The regulating energy depends on the FCR amount in the current interation and on the possible exhaustion of LER present in the FCR provision.

The output of the functionality is the simulated steady state frequency deviation trend ($SS\Delta f$).

Such variable is modelled through a MW/Hz curve as shown in the example of Figure 4.

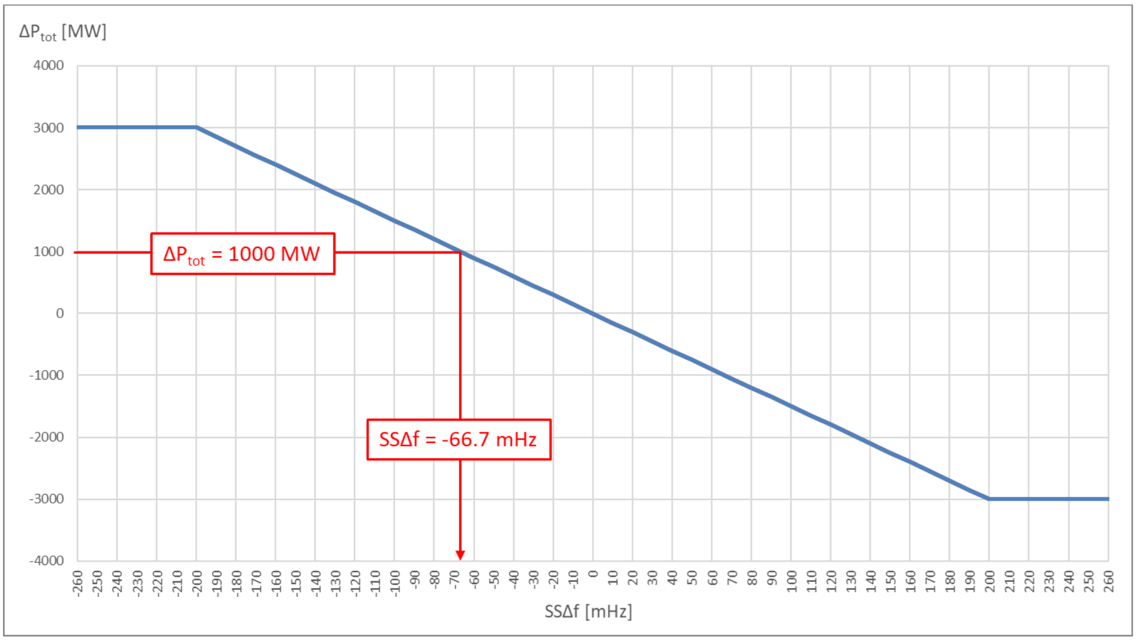

Figure 4: Example of using a MW/Hz curve of 3000 MW/Hz to calculate SSΔf from ΔP_{tot}

A change in the regulating energy ($reg.en._m$) leads to a different frequency deviation, starting from the same power imbalance.

The standard regulating energy depends on the procured FCR. For instance, if in the current iteration a condition with FCR = 3000 MW is considered, the standard regulating energy ($reg.en_{standard}$) is equal to 15000 MW/Hz (i.e., 3000 MW of FCR with full activation at 0.2 Hz).

Should a LER depletion be detected, the regulating energy ($reg.en._m$) decreases and the modelled curve has to be rescaled.

When LER reservoirs are depleted, their FCR contribution is indeed considered as instantaneously lost (they cannot provide anymore upward/downward regulation power).
Only the non-LER providers are still available to regulate the system. Given an input power imbalance, the resulting frequency deviation is thus greater than in the situation with all the LER available.

This condition is modelled with a reduction of regulating energy (i.e., a rescale of the MW/Hz curve) equal to the proportion of FCR lost due to the LER depletion. This proportion is the LER share.

For instance, if the LER share is 50%, once the LER are depleted the regulating energy is reduced by a factor 2 (the MW/Hz is rescaled by a factor 2). It means that the frequency deviation associated with a power imbalance is doubled if compared to the standard condition.
The following Figure 5 shows the reduction in such example.

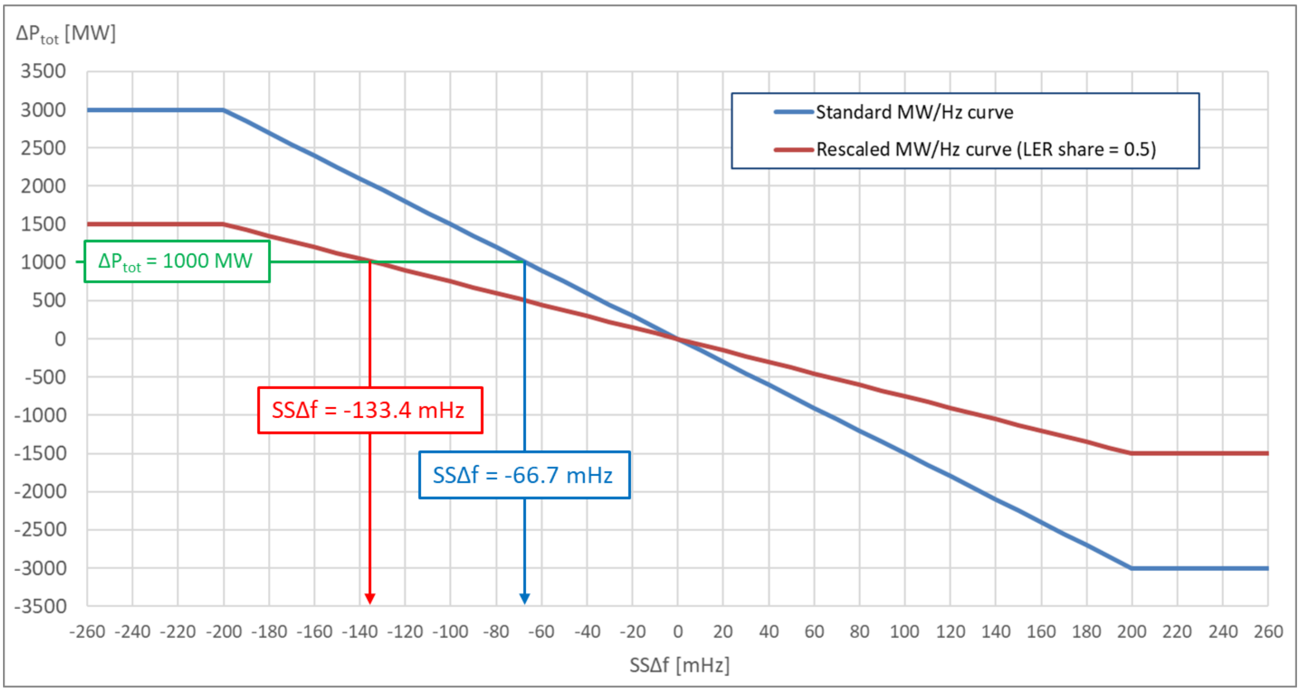

Figure 5: Example of rescale of MW/Hz curve by a factor 2

The model update at each minute m the current regulating energy ($reg.en._m$). The formula is:

$$reg.en._m = \begin{cases} reg.en_{standard} \cdot (1 - LER\ share), & if\ LER\ are\ depleted \\ reg.en._{standard}\,, & if\ LER\ are\ not\ depleted \end{cases} \qquad (1)$$

To check whether the LER are depleted or not, the energy content of LER reservoir is calculated in each minute.
The Figure 6 schematically shows the process by which the regulating energy is rescaled as a consequence of the a LER depletion.

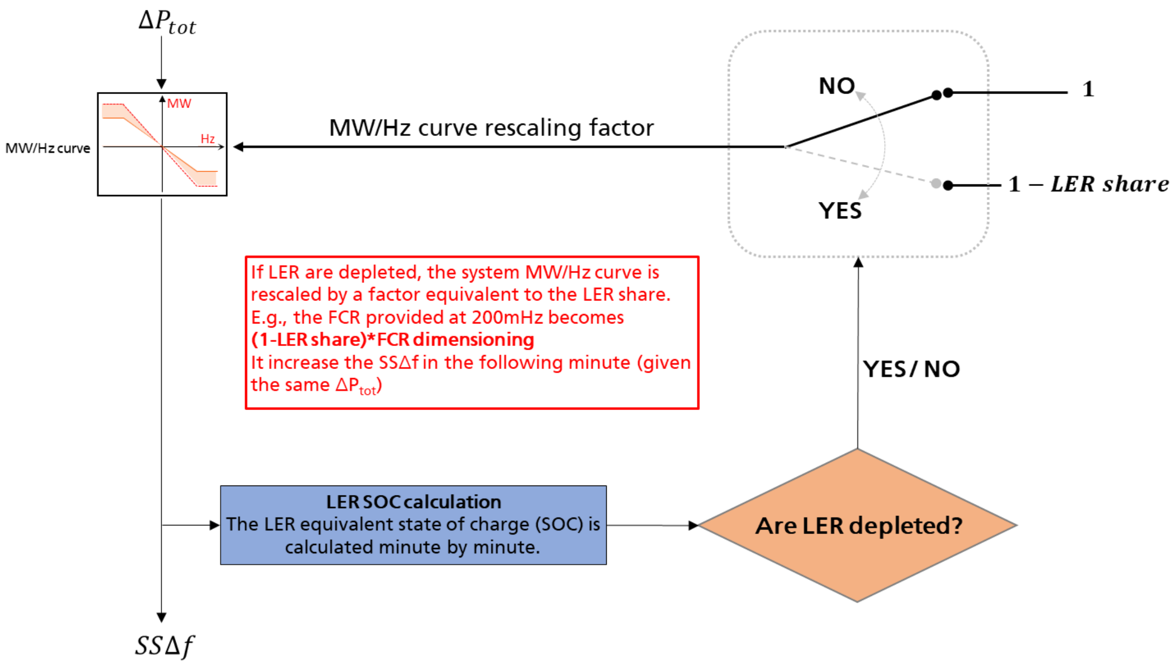

Figure 6: Schematic procedure for rescaling MW/Hz curve as a result of LER depletion

The combined effects of the recharging strategy and of the simulated frequency deviation can lead the LER to recover from a depletion condition. As this occurs, the regulating energy returns to its standard condition (e.g., 15000 MW/Hz if FCR = 3000 MW).

The LER are considered without energy limitations while frequency remains inside the Standard Frequency Range.

If a continuous exceeding of the Standard Frequency Range includes the triggering of an alert state[1], the activated energy and the residual energy in the reservoir is calculated from the triggering of the alert state..

LER deplete as their reservoir reaches the maximum or minimum energy level. The capacity of the reservoir depends on the minimum activation time period the LER are subject to.

2.7 Model to calculate the dynamics of the frequency deviation in each minute.

The characteristics of the frequency during a transient - such as the frequency peak (nadir or zenit) and the ROCOF – need to be considered for the FCR dimensioning process (Figure 8).

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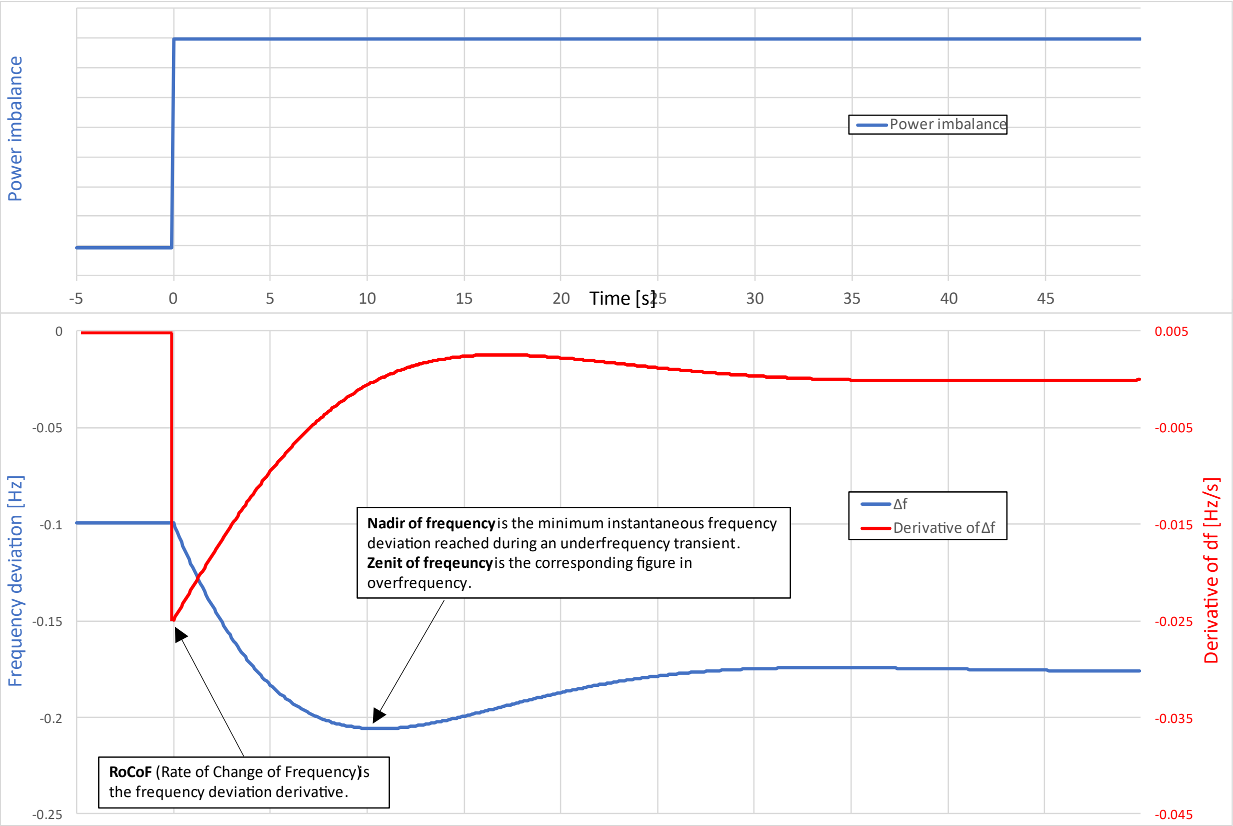
[1] An alert state is triggered if at least one of the following conditions occurs:

- The absolute value of simulated steady state frequency deviation exceeds for 5 consecutive minutes half of the Maximum Steady State Frequency Deviation.
- The absolute value of simulated steady state frequency deviation exceeds for 15 consecutive minutes the Standard Frequency Range.



Nadir of frequency is the minimum instantaneous frequency deviation reached during an underfrequency transient. **Zenit of freqeuncy** is the corresponding figure in overfrequency.

RoCoF (Rate of Change of Frequency) is the frequency deviation derivative.

Figure 7: Example of frequency transient characteristics and main performance indicators: zenit, nadir and RoCoF

Given the wide number of transient to be calculated for the dimensioning exercise, it is unfeasible to perform an actual dynamic simulation in each single minute. There is therefore the need to adopt an algebraic calculation of zenit/nadir and ROCOF starting from the aggregated single-busbar model depicted in Figure 8, based on considerations from [2].

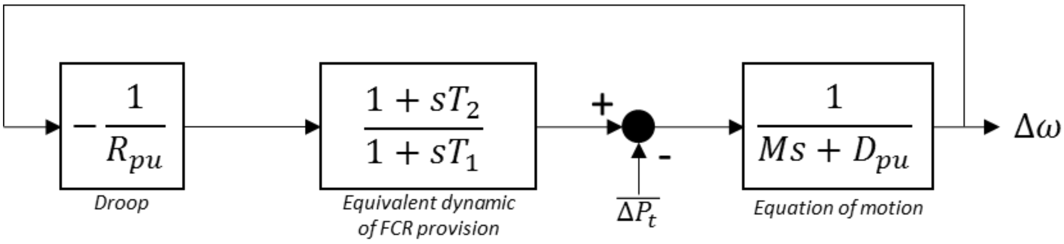


Figure 8: Simplified single-busbar dynamic model of the CE power system

Where:

- **Equation of motion**: represents the response of the power systems in terms of inertia and self regulation of load;
- **Droop**: represents the static response of the FCR (see Figure 4);
- **Equivalent dynamic of FCR provision**: represents the average combined effects of the dynamic responses provided by all FCR providers.

The parameters presented in Figure 8 are thus:

$R_{pu} = \frac{1}{En.Reg.} \cdot \frac{P_n}{f_n} \ [pu_P/pu_{\Delta f}]$	Droop in pu ($En.\ Reg.$ is associated with a certain MW/Hz curve and it's expressed in [MW/Hz])
$T_1\ [s]$	Pole time constant of average FCR dynamics
$T_2\ [s]$	Zero time constant of average FCR dynamics
$D_{pu} = \frac{D}{f_n}[pu_P/pu_{\Delta f}]$	Self-regulation of load (D is expressed in [pu/Hz])
$M = 2 \cdot H\ [s]$	System equivalent angular momentum (2*Inertia)
$P_n\ [MW]$	Load at SA level
f_n	Nominal frequency (50 Hz)

The output of the diagram ($\Delta\omega$) is the frequency deviation in pu.

Considering the actual and complex dynamics of the SA, with this model significant approximations are introduced, since each provider (and each technology) has its own peculiarities when it comes to the FCR deployment dynamic. Such variety of responses is simplified with a single 2nd order dynamic model in order to derive the algebraic formulas for Zenit/Nadir and ROCOF. The ROCOF is evaluated as the initial ROCOF.

Such formulas are derived assuming that a stepwise disturbance is applied on the model presented in Figure 8.

In this way an algebraic relationship between the disturbance and the system parameters can be used within the iterative probabilistic model.

The calculation of dynamic performances of frequency deviations are based on the same 1-minute granularity adopted for the steady state calculations. It means that all the variables (e.g., power imbalance and steady-state frequency deviation) continue to change minute-by-minute.
Both the transient frequency peak (zenit/nadir) and the ROCOF are therefore calculated on a 1-minute basis.

The input of such calculation is the difference of power imbalance between two following minutes.

2.8 Assessment of the acceptability criteria on the resulting simulated frequency deviation

A FCR dimensioning shall be considered acceptable if ensures that the FCR is insufficient not more often than once every 20 years.

The first step is to assess whether a specific minute is considered an acceptable minute. A minute is considered an acceptable minute if it fulfills all the following three criteria:

- The absolute value of the simulated steady state frequency deviation does not exceed the steady state maximum frequency deviation;

- The absolute value of the maximum/minimum instantaneous frequency deviation during transients doesn’t exceed the thresholds defined by the TSOs;
- The absolute value of the ROCOF does not exceed the Maximum Initial ROCOF as defined by the TSOs?

A minute is considered a not acceptable minute if at least one criterion is not fulfilled.

To interpret the «once in 20 years» criterion, the concept of “Critical Condition” is then introduced: a Critical Condition is a series of not acceptable minutes spaced each other not more than a parametrical number of minutes (e.g., 15 minutes).
A single Critical Condition could then be made by several following minutes with one or more criteria not fulfilled.

The choice of such approach is related to the fact that the combination of disturbances causing a condition where one or more criterion (SSΔf / zenit/nadir / ROCOF) are not fulfilled could persists for several minutes.

The «once in 20 years» criterion is applied on the number of Critical Conditions rather than on single minutes. The FCR dimensioning is thus aimed at ensuring that the number of detected Critical Conditions is less or equal to 1/20 of the number of simulated years.

E.g., if 200 years are simulated by the model, no more than 10 (200/20) Critical Conditions shall occur.