EASY-RES

SUMMER SCHOOL
"ENABLING DRES TO OFFER ANCILLARY SERVICES"
20th – 24th SEPTEMBER 2021

NEW SUGGESTIONS FOR THE MEASUREMENT AND QUANTIFICATION OF AS

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- Definition of Synchronous Zone
- The role of Inertia in frequency stability
- The role of Frequency Containment Reserves
- The role of Frequency Restoration Reserves and Replacement Reserves
- Examples of major frequency deviations in Continental Europe
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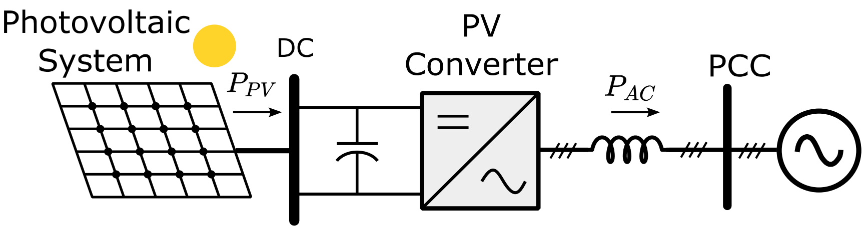
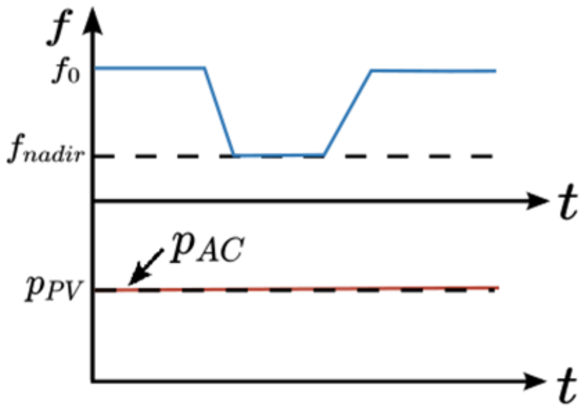
Why do we need measurement and quantification

Challenge: To measure and quantify AS that are deployed in a few seconds.

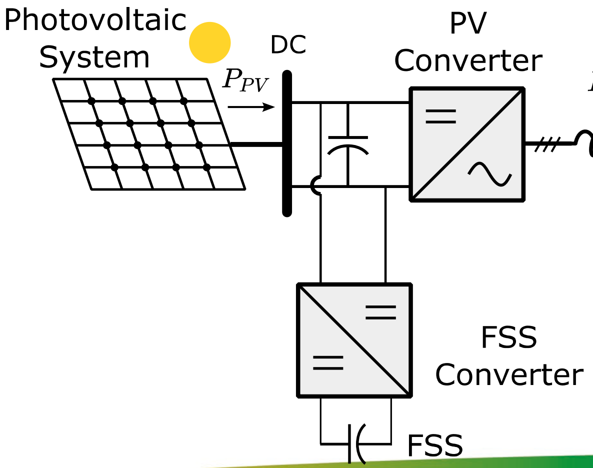
Inertial Response

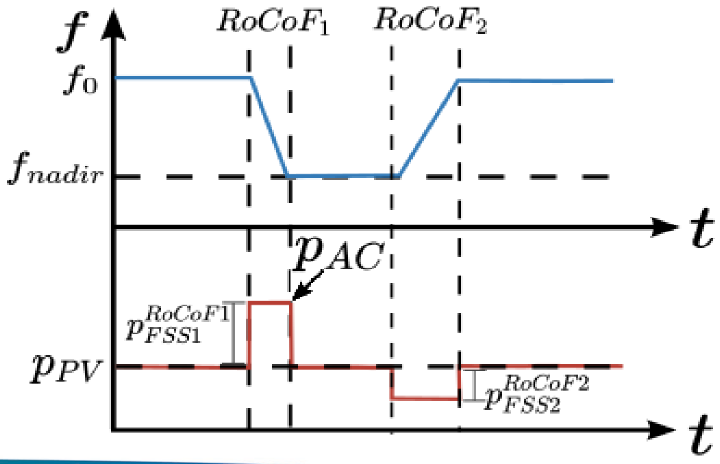
Currently (Grid-feeder)



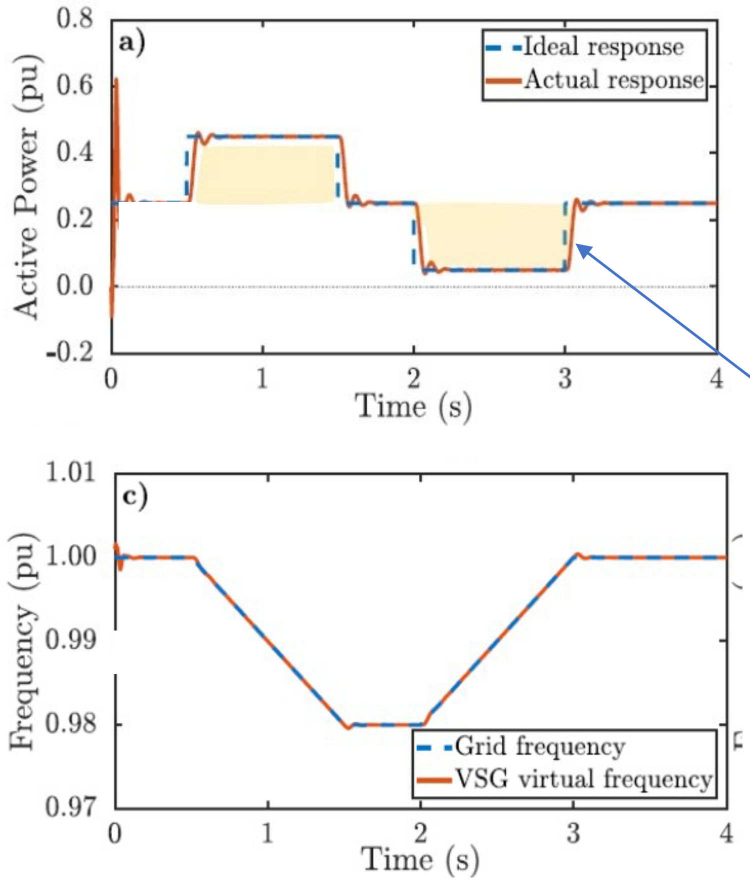


EASY-RES UVSG





High RoCoF



Currently Inertia is not an AS but is treated as a system support function.
Reason: It is inherently provided by the large synchronous generators or condensers.

Inertial provision is “tangible” only under high ROCOFs.

$$2 \cdot H \frac{df^{pu}}{dt} = p_m^{pu} - p_e^{pu}$$

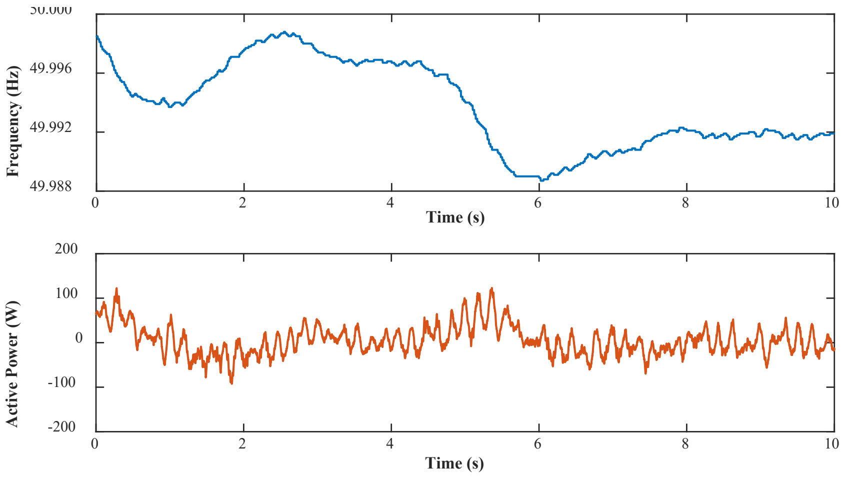
Only then is Δp measurable, thus quantifiable.

In such cases, the inertial response could be quantified as the “inertial energy”

$$E_i = \int_T \Delta p \cdot dt = \int_T |p_m - p_e| \cdot dt = \int_T 2 \cdot H_{set} \frac{df}{dt} \cdot dt$$

Where T is the period for which $\frac{df}{dt} \neq 0$ and
H_{set} is the inertial time constant set in a DRES or whole distribution grid.

However, most of the time, the frequency variation presents very small ROCOFs

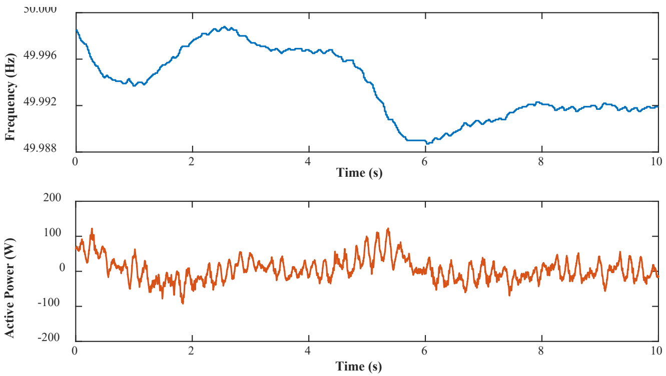


Frequency measured every 20ms!

Inertial power variation of an unloaded 20kVA PV inverter with $H_{set} = 7s$

It is shown that the power varies by $\pm 100\ W$ which is very small to be measured and quantified if the inverter is loaded during the daytime.

However, most of the time, the frequency variation presents very small ROCOFs



Measurement of the frequency and time in a window of 100ms as suggested in the recent IEEE 1547-2018

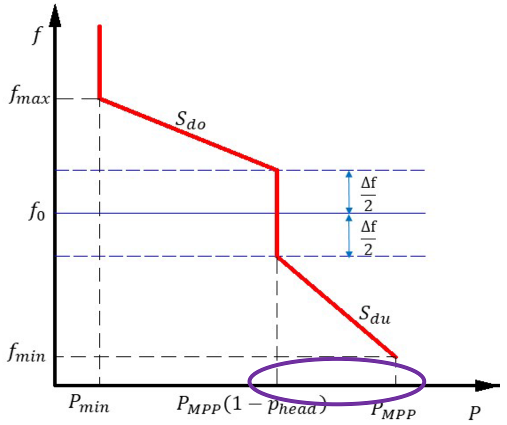
For this reason it is suggested that the inertial response is not continuously measured and quantified but it is financially compensated based on its availability only.
The availability can be proved by tests in certified labs but also (this is another suggestion) during the time periods the DRES is not loaded (e.g. during night for the PV systems and during periods of very low wind velocity).
The verification could be done by calculating the "inertial energy" over a relatively large period (some minutes) with

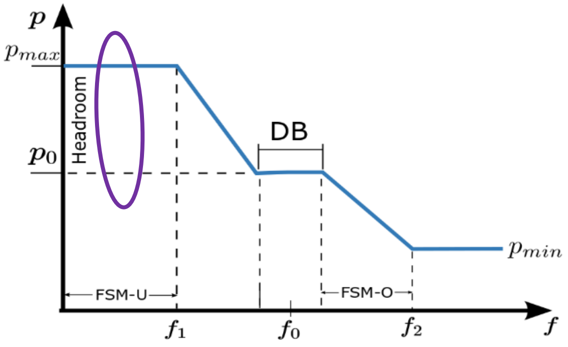
$$E_{i,T} = \sum_{i=1}^{N}\left[2 \cdot H_{set}\frac{\Delta f_i}{\Delta t}\Delta t\right] \cdot S_N = 2 \cdot H_{set} \cdot S_N \sum_{i=1}^{N} \Delta f_i$$

$E_{i,T}$ should be compared with the actual absolute energy measured during the same period T.

with,
$\Delta f_i = |f(t_i) - f(t_i - \Delta t)|$
$T = N \cdot \Delta t$
H_{set} is the inertia time constant set in DRES
S_N is the nominal power of DRES (the reference power for defining H_{set}

Primary Frequency Response (PFR)



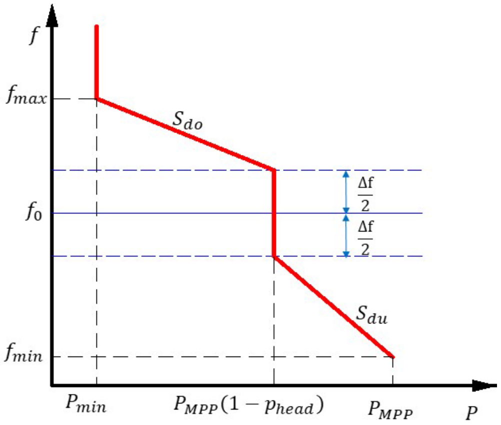


A DRES provides primary frequency response when it operates in FSM.

- In order to act as FCR in underfrequency events too, it has to operate with a headroom below its MPP.
- The headroom, P_{head}, can be a fixed percentage of P_{MPP} , or have a fixed value in kW (MW).
- The slopes of the droop, s_{du} and s_{do} can be set to various values by the DSO or TSO.

$P_{max} = P_{MPP}$ for RES, i.e. it is variable
$P_{min} = 0$ for PV systems
$P_{min} \neq 0$ for wind systems for stability reasons of the wind turbines.

Primary Frequency Response (PFR)



The operation or not in FSM-O and/or FSM-U can be activated/deactivated by enabling/disabling signals sent by the DSO-Aggregator or TSO.

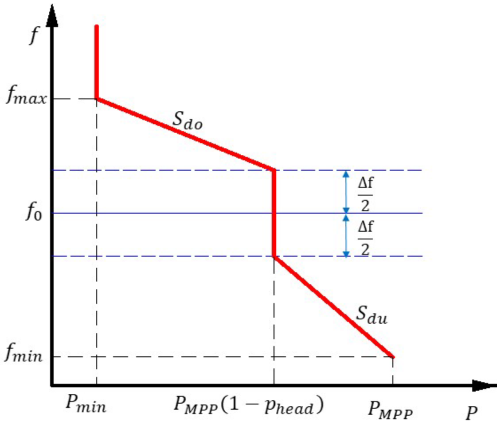
A quantification of the DRES contribution to PFR can be calculated by energy NOT provided to the grid due to this action.

$$E_{PFR}^{T} \quad {}_{t=t_{enable}}^{t_{disable}} \quad P_{MPPT}(t) \quad P(t) \quad dt$$

Measured

Calculated by measuring the MPP of the primary source (P_{m-MPPT}) and taking into account PV converter efficiency, $\eta_{DRES}(P_{m-MPPT})$

Primary Frequency Response (PFR)



$$E_{PFR}^{T} \quad {}_{t=t_{enable}}^{t_{disable}} \quad P_{MPPT}(t) \quad P(t) \quad dt$$

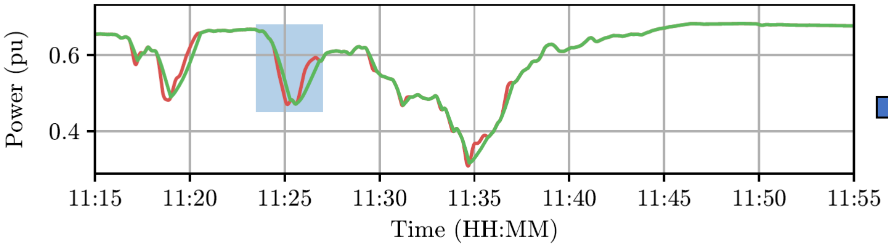
Measured

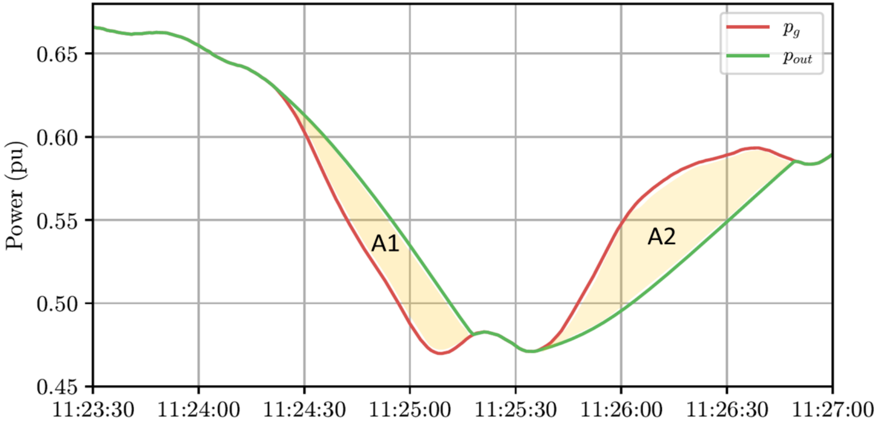
Calculated by measuring the MPP of the primary source (P_{m-MPPT}) and taking into account PV converter efficiency, $\eta_{DRES}(P_{m-MPPT})$

Synchronized measurements of $P_{m-MPPT}(t)$, $P(t)$, $f(t)$ are needed.

P_{m-MPPT}(t), *P*(t): averaged over 1s with accuracy=1% of the nominal DRES power

f(t): 10mHz accuracy over a window of 50 cycles (1s)





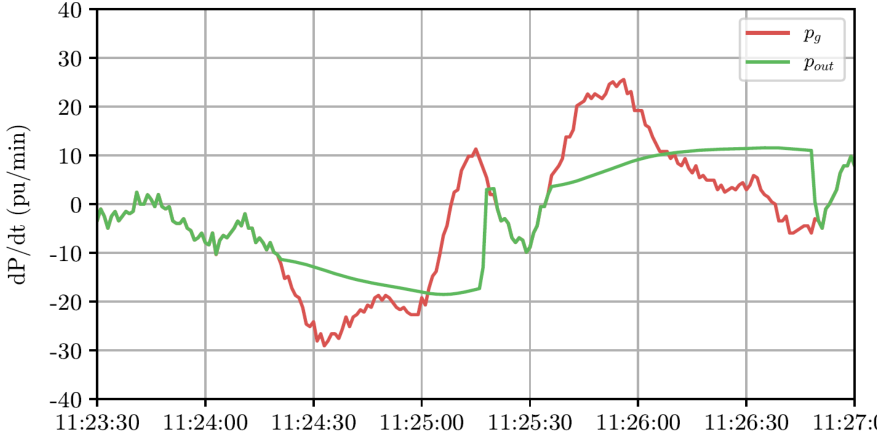
active power ramp rate at the DRES PCC

$$ramp = \frac{\Delta P_{el}(t)}{\Delta t}$$

$$\Delta P_{el}(t) = \frac{P_{el}(t) - P_{el}(t - \Delta t)}{P_{N,DRES}}$$

achieved ramp rate limitation (RRL)

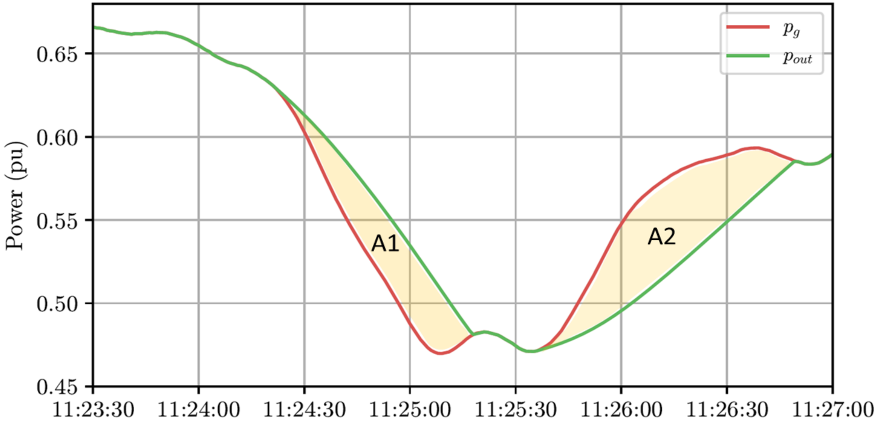
$$RRL = \int_{t_1}^{t_2} \left| P_{el}(t) - P_{MPP}(t) \right| dt$$



P_{MPP} is calculated by measuring the MPP of the primary source (P_{m-MPPT}) and taking into account PV converter efficiency, $P_{MPP} = \eta_{DRES}(P_{m-MPPT})$

$$RRL = \int_{t_1}^{t_2} \left| P_{el}(t) - P_{MPP}(t) \right| dt$$

It is practically the sum of areas A1, A2, … An.



Power smoothing is implemented by the action of the Fast Storage System. In the end of a period (some seconds, minutes, etc) the SoC of the FSS should return to the initial value. This means that

$$\int_{t_1}^{t_2} P_{el}(t) - P_{MPP}(t)\, dt = 0$$

$t_2 - t_1$ is defined by this formula

Quasi-steady-state:

Measuring Window for power

DRES with FSS: average over 200ms (10 cycles)

ESS: average over 1 s (slower ramps → Δt=1-10 min)

Challenges for Quantification of DRES RP in distribution systems:

- distribution systems exhibit larger unbalances
- the voltage and current harmonic pollution is larger
- some DRES may also act as active harmonic filters at the same time.

Suggested Metric 1:

$$E_{RP} \qquad {}_{T}\left|Q_1^{+}(t)\right| \; dt$$

$$Q_1^{+}(t) \qquad \sqrt{3}\; V_1^{+}(t)\;\; I_1^{+}(t)\;\; \sin j\,{}_1^{+}(t)$$

Specifications:

1. <u>accuracy in the measurement</u>

- For voltage and currents should be 1% of their nominal values
- For reactive power 5% of S_N.
- sampling rate of at least 6.4 kHz (128 samples/period).

2. <u>Aggregation intervals at three levels</u>:

- digital value of reactive power is measured with *T* equal to 10 cycles (200 ms).
- Aggregation over a 3-seconds period (15 of 10-cycles values),
- Aggregation over 10min (200 of 3-seconds values)
- Aggregation of 24-h period (144 of 10min values)

Suggested Metric 2:

$$E_{L\text{-}RP} \qquad {}_{T} \qquad P_{loss}(t)\ \ dt$$

$$D\,P_{loss}(t) = P_{out}(t)\ \frac{1}{h(P_{out}, Q_1^{+})} - \frac{1}{h(P_{out}, 0)}$$

Measured or Analytically estimated

Known Value by Datasheet

Some general considerations regarding Reactive Power Exchange by DRES converters

1. Operation down to PF=0.707 requires converter oversizing up to $\sqrt{2}$
2. ΔP_{loss} can increase up to 1.5% with respect to PF=1

Converter-interfaced DRES can act as active harmonic filters:

- Basic constraint: the RMS value of the currents injected should not exceed the thermal limit of the converter switches.
- available even when the primary energy source is not available.
- active harmonic filtering does not require any additional equipment → there is no additional investment cost service , only operational cost similar as reactive power

Measurement:

RMS value of harmonic current

$$I_h^2(i) = \frac{1}{T}\int_0^T i_{h,i}^2(t)dt$$

i^{th} minute

period T=1 minute

instantaneous harmonic current

Suggested Metrics:

$$D_{h,day} \sum_{k=1}^{1440} I_h(k) \quad I_1(k) \; I_h \quad , I_h(k) \quad I_1(k) \; I_h$$

1-min rms value of the fundamental current injected by the converter during the kth minute

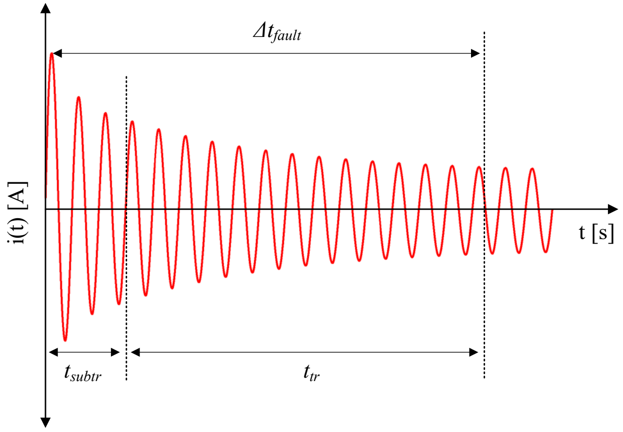
coefficient of the individual harmonic defined in IEEE 1547-2018

$$D_{day} = \sqrt{\sum_{h=2}^{25} D_{h,day}^2}$$

Specifications:

1. Measurement of voltage and current:
   - at the DRES converter terminals
   - according the Class A mentioned in IEC 61000-4-7 and IEC 61000-4-30 Standards
2. Considering that the switching frequencies of the DRES are in the range of 10-20 kHz, it is reasonable to focus on mitigation of harmonics up to the 25th order.

Synchronous Gen.



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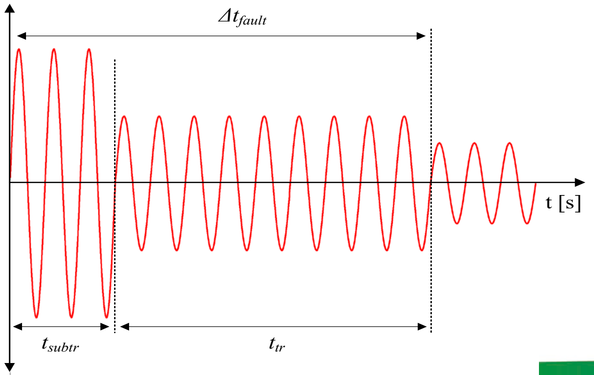
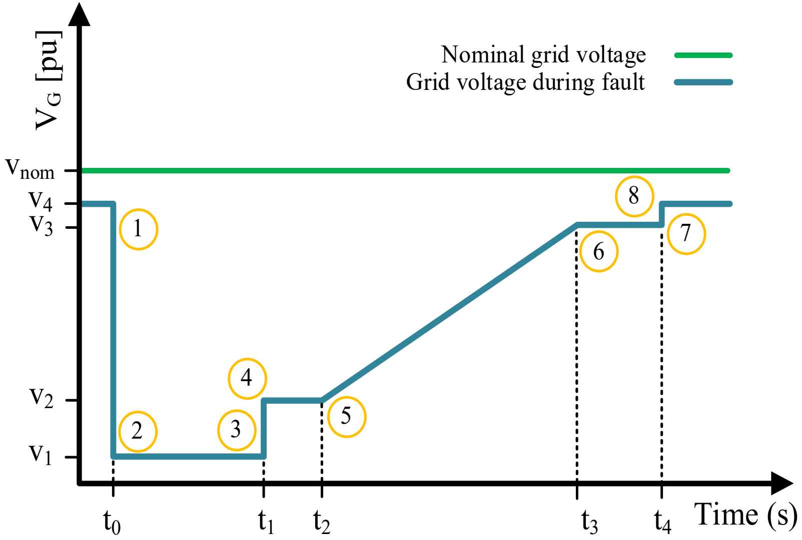


The target is to use conventional overcurrent devices within the distribution grid

- With the proposed methods, the protection selectivity in distribution grids can be preserved with the existing protection means despite the increased DRES penetration.
- This is achieved by either controlling the DRES to inject specific (or zero) currents depending on the relative location of the fault.



The EASY-RES UVSG allows a configurable Fault-ride-through curve.

Additionally, the methodology for evaluating the required Fast Storage System to achieve this FRT capability is developed.

Since the contribution to fault clearing is stochastic and whenever happens lasts only for a couple of seconds, it is suggested that no measurements take place to quantify the contribution to fault clearing.

Instead, it is suggested that the availability of this service is remunerated after being verified in certified labs.

Summary and discussion

Measurement and quantification (M&Q) methods are suggested for existing and new AS offered by DRES.

- For the provision of synthetic inertia the M&Q method aims to prove the availability of this service and not the actual delivery. Thus, the availability should be remunerated.
- For contribution to fault clearing, it is suggested that simply the availability is remunerated rather than the actual contribution due to the stochastic fault occurrence and their short duration. The availability can be certified in proper labs.

All the presented M&Q methods are suggestions of the EASY-RES team. There is no relevant work in the scientific and technical literature.

References

[1] Demoulias, C.S.; Malamaki, K.-N.D.; Gkavanoudis, S.; Mauricio, J.M.; Kryonidis, G.C.; Oureilidis, K.O.; Kontis, E.O.; Martinez Ramos, J.L. *Ancillary Services Offered by Distributed Renewable Energy Sources at the Distribution Grid Level: An Attempt at Proper Definition and Quantification*. Appl. Sci. 2020, 10, 7106. https://doi.org/10.3390/app10207106

The EASY-RES Consortium

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Thank you!

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