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

The EASY-RES approach for aggregation and disaggregation of Inertia and PFR

Álvaro Rodríguez del Nozal // Block 7.B

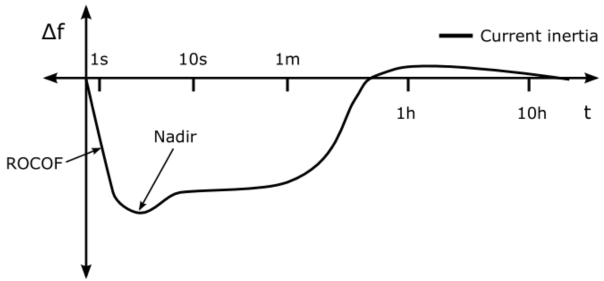
This project has received funding from the European Union´s Horizon 2020 Programme for research and innovation under Grant Agreement no 764090.

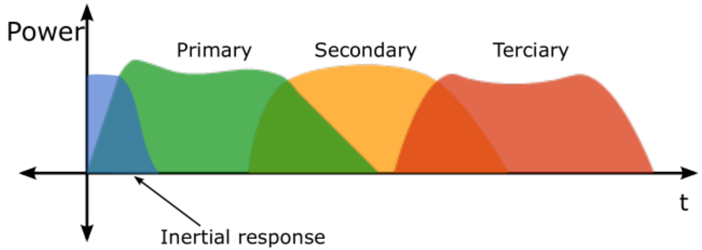
Agenda

- Introduction
- Provision of inertial response
    - Evaluation of the maximum inertial capability
    - Optimal inertia allocation
    - Discussion and conclusions
- Provision of primary frequency response
    - Evaluation of the maximum PFR capability
    - Optimal PFR allocation
    - Discussion and conclusions
- References

Introduction

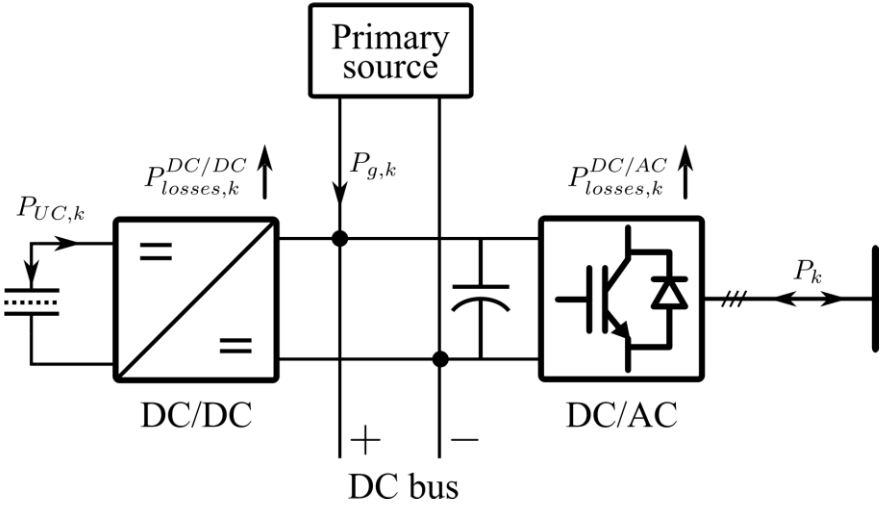
- The integration of DRESs in the electric power system has two main issues that are currently studied:
    - The architecture of the electric power system is being altered moving towards a distributed architecture in which generation units can be placed close to loads.
        - Losses reduction.
        - Associated network stability problems.
    - Most of the DRESs are interconnected to the grid through power converters.
        - New control strategies to provide ancillary services such as inertial response or PFR.





Inertial response

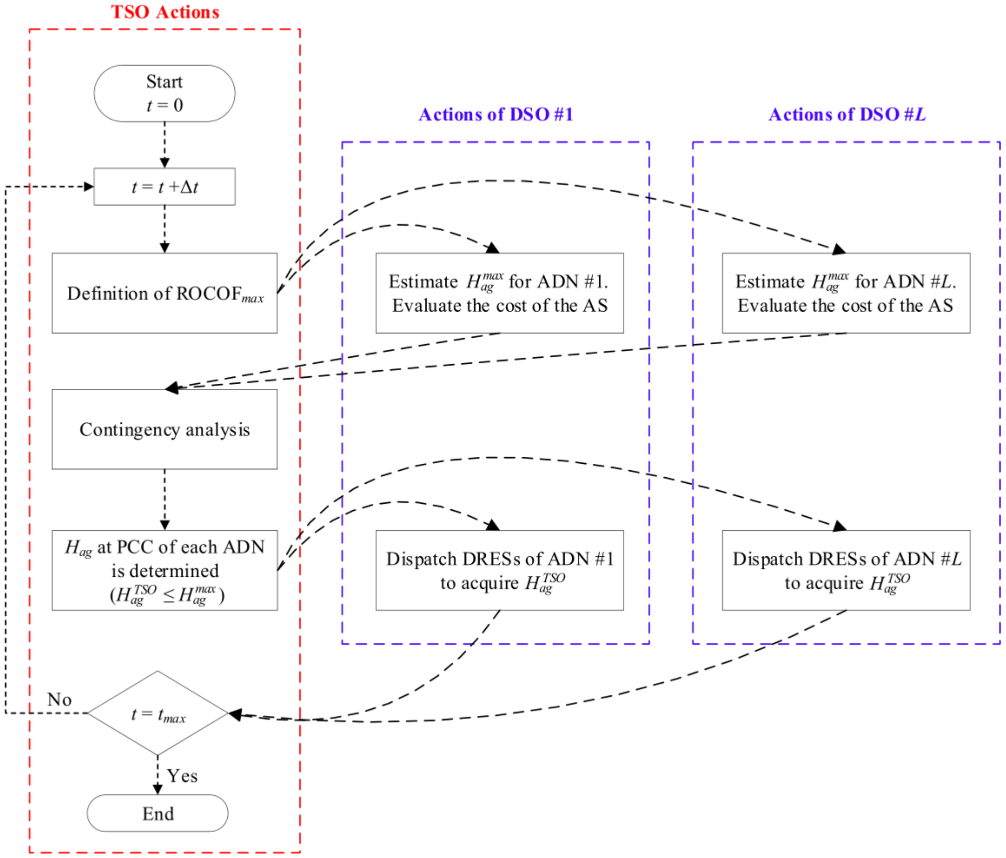
- The inertial response of the DRESs is given by the energy stored in **UCs**.
- The power provided by the UC is first converted to a different DC level by using a DC/DC converter and, after that, it is converted to AC form through the DC/AC converter of the DRES.
  - How can a DRES be assigned an equivalent inertia value?
  - What factors of the structure of the DRES as well as of the topology of the ADN must be considered?
  - How can we provide a specific inertia at the ADN point of interconnection by coordinating several DRESs?



Inertial response

Proposed solution

- The proposed solution is based on the continuous interaction between TSO and DSOs.
- The problem can be divided into two main phases:
  - Evaluation of the inertial capability of the ADN.
  - Determination of DRESs inertia to provide a specific inertia at the point of interconnection with the transmission system.



Inertial response

Operational constraints

- Malfunctioning of protection means:
  - Voltage limits. $V^{\min} \leq |\mathcal{U}_i| \leq V^{\max}$
  - Line Congestions. $|\mathcal{I}_{i,j}| \leq I_{i,j}^{\max}$
- Ultracapacitor limitations:
  - Maximum output power.
  - Maximum energy available.
- Power converter limitations:
  - Maximum temperature of operation.

$$T_{igbt} \leq T^{\max}, \quad T_d \leq T^{\max}$$

$$P_k(pu) = \frac{2H_k}{f_n}\frac{df}{dt} + P_k^{ss}(pu)$$

$$P_{UC,k}(pu) = 2\tilde{H}_k \frac{df}{dt}\frac{1}{f_n}$$

$$P_{UC,k} \leq P_{UC,k}^{max}$$

$$P_{UC,k} \leq \frac{3600 E_{UC,k}^{\max} SoC_{UC,k}}{\tilde{H}_k}$$

Example

$E_{UC,k}^{max} = 8\ Wh$

$SoC_{UC,k} = 30\ \%$

$P_{UC,k}^{max} = 2\ kW$

Available energy:

$$E_{UC,k} = 2{,}4\ Wh\ \frac{3600\ s}{1\ h} = 8640\ Ws$$

$$\tilde{H}_k = 6\ s \rightarrow P^{max} = 1{,}44\ kW$$

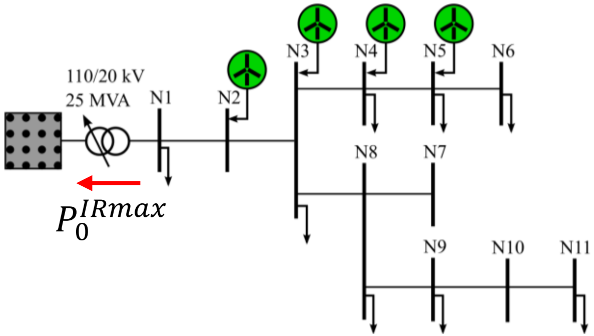
Inertial response

Stage 1: Evaluation of the maximum inertial capability

- Given the maximum ROCOF that the DRESs shall at least be capable of withstanding by the TSO, the DSOs must compute the maximum value of the equivalent inertia that can provide at the point of interconnection with the transmission system.

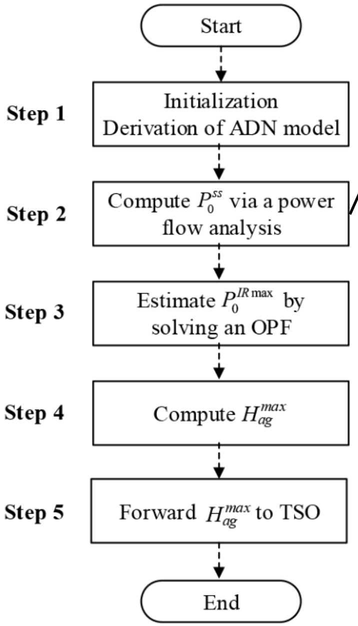
$$H_{ag}^{max} = \frac{f_n}{2} \frac{P_0^{IRmax}(pu) - P_0^{ss}(pu)}{ROCOF_{max}}$$

- Thus, the problem is reduced to find the maximum active power injection at the point of interconnection: P_0^{IRmax}.
  - Network constraints.
  - Power converter limitations.
  - Ultracapacitor characteristics.



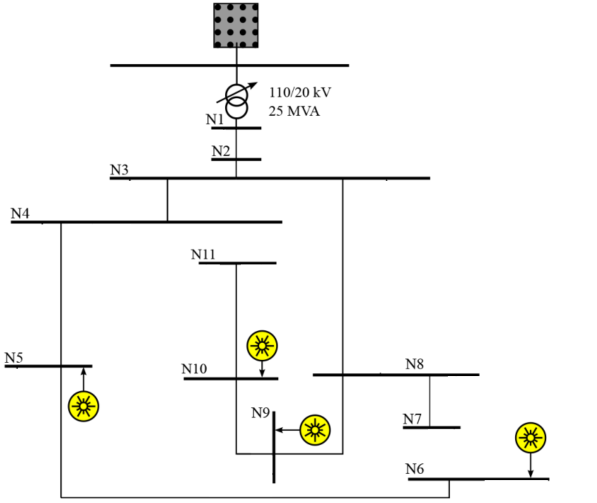
Inertial response

Stage 1: Evaluation of the maximum inertial capability



$$P_0^{ss} = P_{g,5} + P_{g,6} + P_{g,9} + P_{g,10} - P_{loss}$$

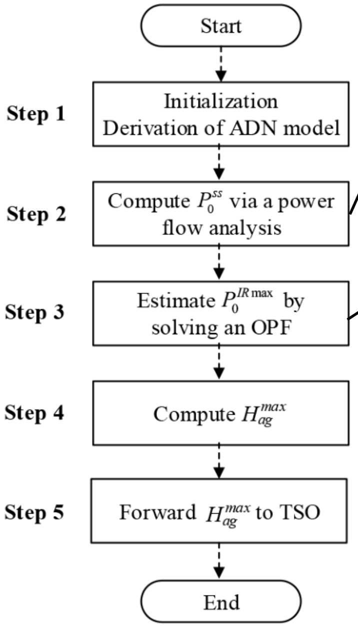
$$P_0^{ss} = 1.045\ kW - P_{loss} = 1.037{,}33\ kW$$



Reference	Bus	$S_{n,k}$ kVA	$P_{g,k}$ kW	$P_{UC,k}^{max}$ kW	$E_{UC,k}^{max}$ kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

Inertial response

Stage 1: Evaluation of the maximum inertial capability



$$P_0^{ss} = P_{g,5} + P_{g,6} + P_{g,9} + P_{g,10} - P_{loss}$$

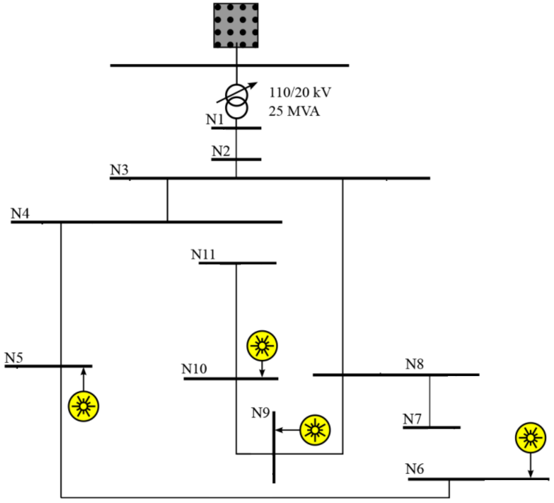
$$P_0^{ss} = 1.045\ kW - P_{loss} = 1.037,33\ kW$$

DRES	G5	G6	G9	G10
$P_{UC,k}$	60.00	40.18	221.01	330.00

DRES	G5	G6	G9	G10
T_{IGBT}^{ss}	49.22	151.20	151.20	134.69
T_{IGBT}^{IR}	74.66	174.77	174.77	166.87

$$P_0^{IRmax} = P_0^{ss} + \sum_k P_{UC,k} - P_{loss}^{UC}$$

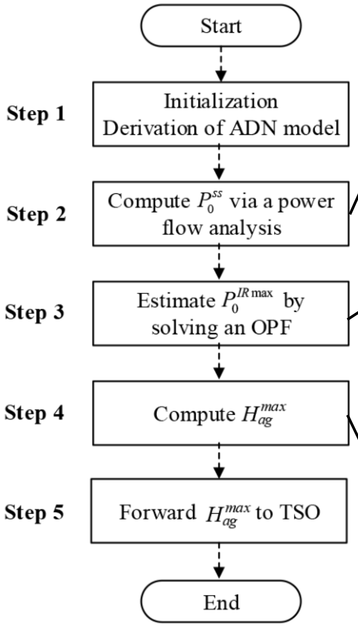
$$P_0^{IRmax} = 1.676,20\ kW$$



Reference	Bus	$S_{n,k}$ kVA	$P_{g,k}$ kW	$P_{UC,k}^{max}$ kW	$E_{UC,k}^{max}$ kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

Inertial response

Stage 1: Evaluation of the maximum inertial capability



$$P_0^{ss} = P_{g,5} + P_{g,6} + P_{g,9} + P_{g,10} - P_{loss}$$

$$P_0^{ss} = 1.045\ kW - P_{loss} = 1.037,33\ kW$$

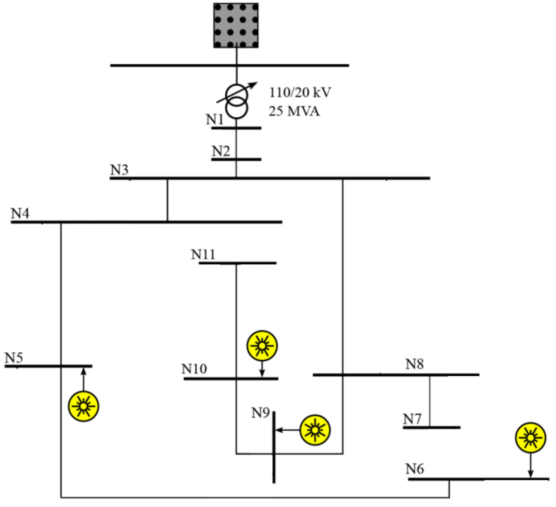
DRES	G5	G6	G9	G10
$P_{UC,k}$	60.00	40.18	221.01	330.00

DRES	G5	G6	G9	G10
T_{IGBT}^{ss}	49.22	151.20	151.20	134.69
T_{IGBT}^{IR}	74.66	174.77	174.77	166.87

$$P_0^{IRmax} = P_0^{ss} + \sum_k P_{UC,k} - P_{loss}^{UC}$$

$$P_0^{IRmax} = 1.676,20\ kW$$

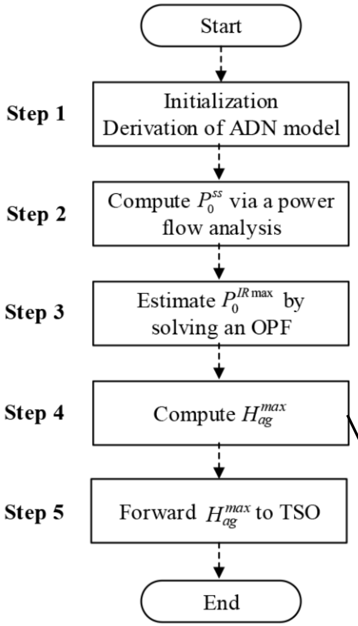
$$H_{ag}^{max} = \frac{f_n}{2} \frac{P_0^{IRmax}(pu) - P_0^{ss}(pu)}{ROCOF_{max}}$$

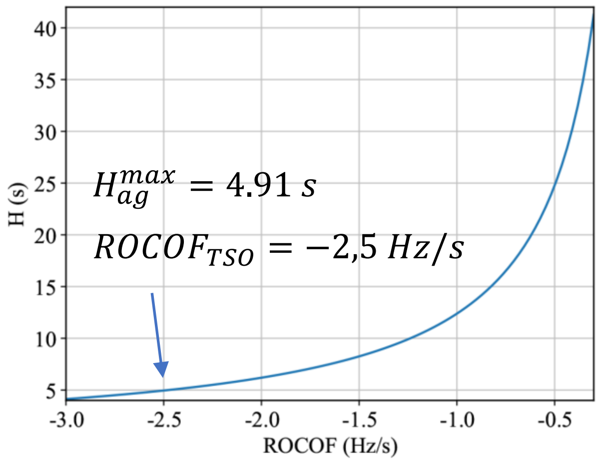


Reference	Bus	$S_{n,k}$	$P_{g,k}$	$P_{UC,k}^{max}$	$E_{UC,k}^{max}$
		kVA	kW	kW	kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

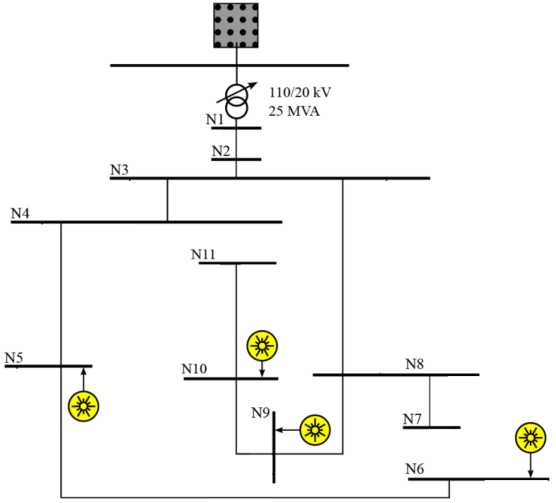
Inertial response

Stage 1: Evaluation of the maximum inertial capability





$$H_{ag}^{max} = \frac{f_n}{2} \frac{P_0^{IRmax}(pu) - P_0^{ss}(pu)}{ROCOF_{max}}$$



Reference	Bus	$S_{n,k}$ kVA	$P_{g,k}$ kW	$P_{UC,k}^{max}$ kW	$E_{UC,k}^{max}$ kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

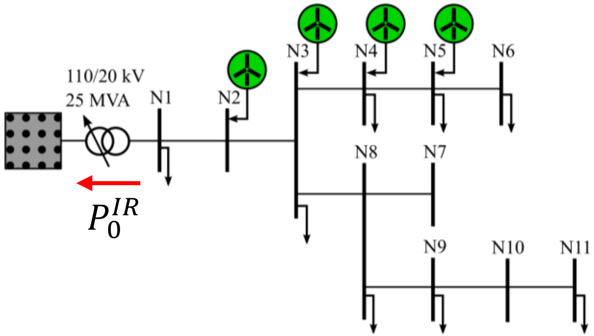
Inertial response

Stage 2: Optimal allocation of inertia

- The DSO must determine the inertia constants for all the DRESs within the ICA in order to provide a specific, TSO-defined, inertia constant at the point of interconnection with the transmission system.

$$P_0^{\mathrm{IR}}\,(\mathrm{pu}) = 2H_{\mathrm{ag}}^{\mathrm{TSO}} \frac{1}{f_{\mathrm{n}}} \mathrm{ROCOF}_{\max} + P_0^{\mathrm{ss}}\,(\mathrm{pu})$$

- Thus, the problem is reduced to optimally find the power provided by the UCs of each DRES to meet P_0^{IR} at the point of interconnection.
  - Network constraints.
  - Power converter limitations.
  - Ultracapacitor characteristics.



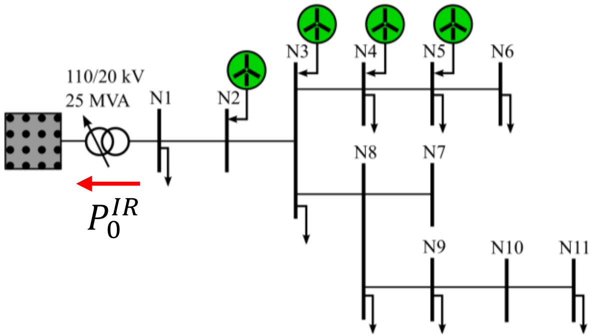
Inertial response

Stage 2: Optimal allocation of inertia

- There are multiple combinations to provide P_0^{IR} at the point of interconnection with the transmission system.
  - Minimize the cost of providing the ancillary service

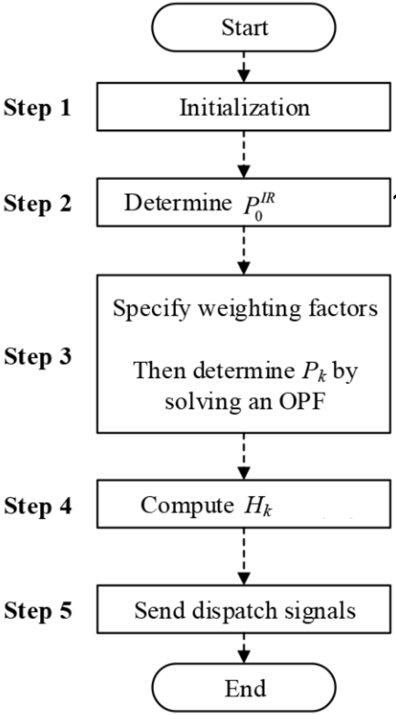
$$C = C_{\text{losses}}^{\text{lines}} + C_{\text{losses}}^{\text{DC/DC}} + C_{\text{losses}}^{\text{DC/AC}}$$

- Extra power losses in the lines.
- Power losses in the DC/DC converter.
  - Not used when service is not provided.
- Extra power losses in the AC/DC converter.
  - Power converters that operate closer to their rated power experience greater losses than those that operate further from that point.



Inertial response

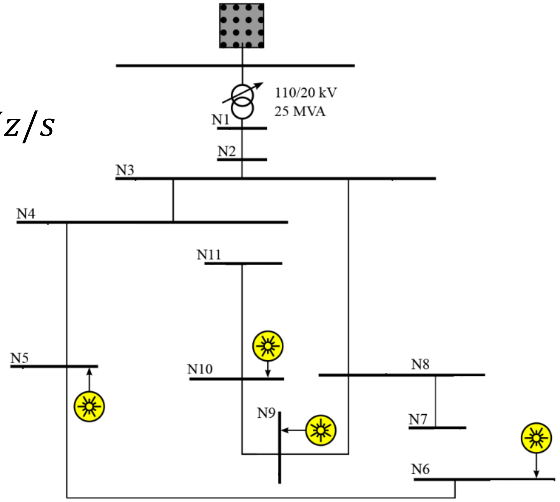
Stage 2: Optimal allocation of inertia



$$P_0^{\mathrm{IR}}\,(\mathrm{pu}) = 2H_{\mathrm{ag}}^{\mathrm{TSO}}\frac{1}{f_{\mathrm{n}}}\mathrm{ROCOF}_{\max} + P_0^{\mathrm{ss}}\,(\mathrm{pu})$$

$$H_{ag}^{TSO} = 4{,}5\ s \quad ROCOF_{TSO} = -2{,}5\ Hz/s$$

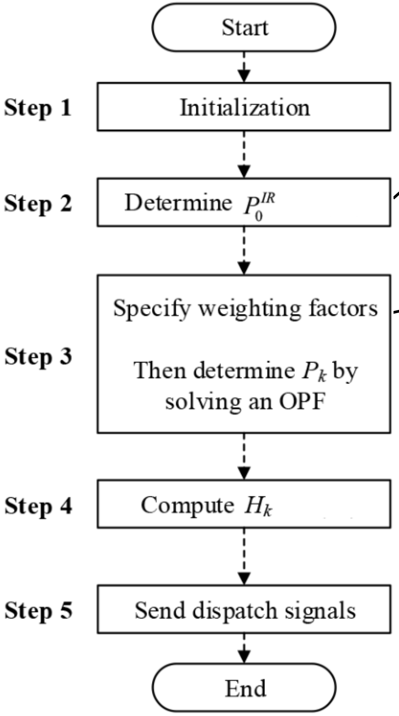
$$P_0^{IR} = 577{,}33\ kW$$



Reference	Bus	$S_{n,k}$ kVA	$P_{g,k}$ kW	$P_{UC,k}^{max}$ kW	$E_{UC,k}^{max}$ kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

Inertial response

Stage 2: Optimal allocation of inertia

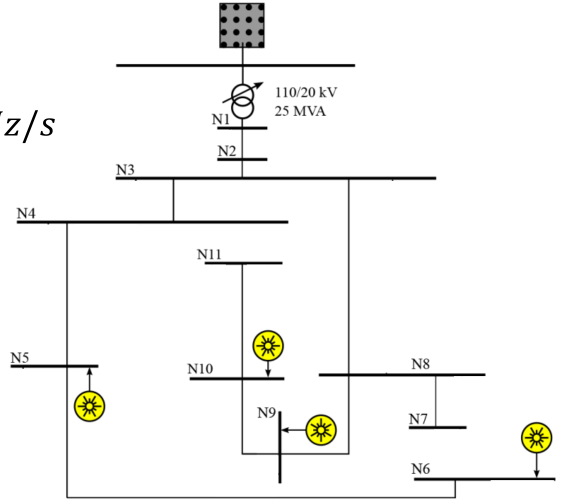


$$P_0^{IR}\,(\mathrm{pu}) = 2H_{ag}^{TSO}\frac{1}{f_n}\mathrm{ROCOF}_{max} + P_0^{ss}\,(\mathrm{pu})$$

$$H_{ag}^{TSO} = 4{,}5\ s \qquad ROCOF_{TSO} = -2{,}5\ Hz/s$$

$$P_0^{IR} = 577{,}33\ kW$$

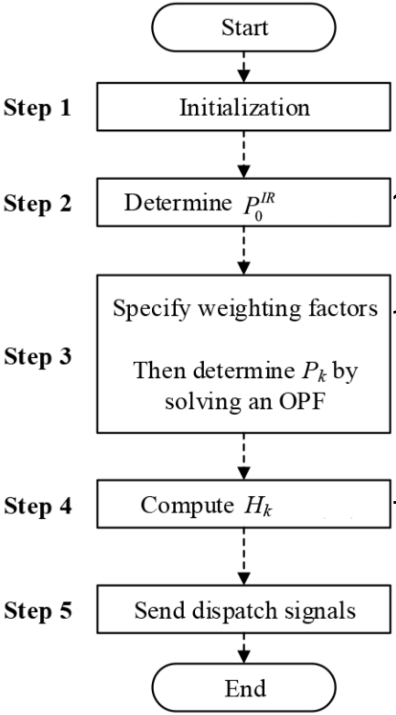
$$C = C_{losses}^{lines} + C_{losses}^{DC/DC} + C_{losses}^{DC/AC}$$



Reference	Bus	$S_{n,k}$ kVA	$P_{g,k}$ kW	$P_{UC,k}^{max}$ kW	$E_{UC,k}^{max}$ kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

Inertial response

Stage 2: Optimal allocation of inertia



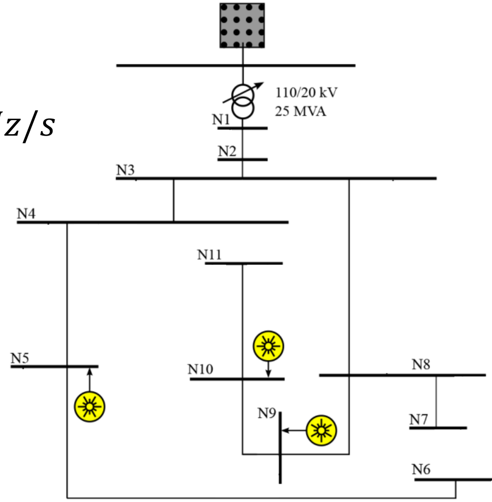
$$P_0^{\mathrm{IR}}\,(\mathrm{pu}) = 2H_{\mathrm{ag}}^{\mathrm{TSO}} \frac{1}{f_{\mathrm{n}}} \mathrm{ROCOF}_{\max} + P_0^{\mathrm{ss}}\,(\mathrm{pu})$$

$$H_{ag}^{TSO} = 4{,}5\ s \qquad ROCOF_{TSO} = -2{,}5\ Hz/s$$

$$P_0^{IR} = 577{,}33\ kW$$

$$C = C_{\mathrm{losses}}^{\mathrm{lines}} + C_{\mathrm{losses}}^{\mathrm{DC/DC}} + C_{\mathrm{losses}}^{\mathrm{DC/AC}}$$

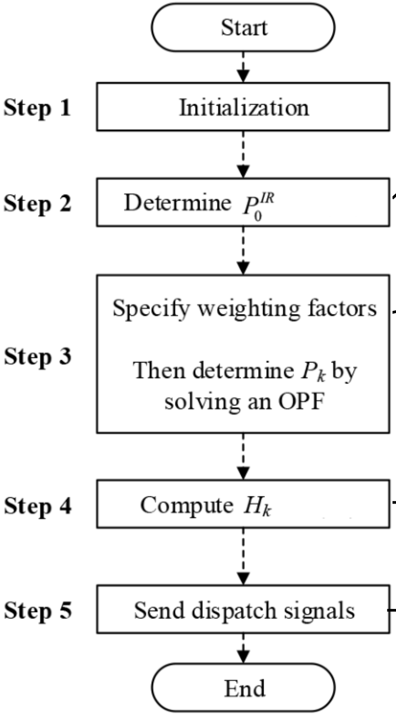
$$H_k = \frac{f_{\mathrm{n}}(P_k^{\mathrm{IR}}\,(pu) - P_k^{\mathrm{ss}}\,(\mathrm{pu}))}{2 \times \mathrm{ROCOF}_{\max}}$$



Reference	Bus	$S_{n,k}$ kVA	$P_{g,k}$ kW	$P_{UC,k}^{\max}$ kW	$E_{UC,k}^{\max}$ kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

Inertial response

Stage 2: Optimal allocation of inertia



$$P_0^{\mathrm{IR}}(\mathrm{pu}) = 2H_{\mathrm{ag}}^{\mathrm{TSO}}\frac{1}{f_{\mathrm{n}}}\mathrm{ROCOF}_{\max} + P_0^{\mathrm{ss}}(\mathrm{pu})$$

$$H_{ag}^{TSO} = 4{,}5\ s \quad ROCOF_{TSO} = -2{,}5\ Hz/s$$

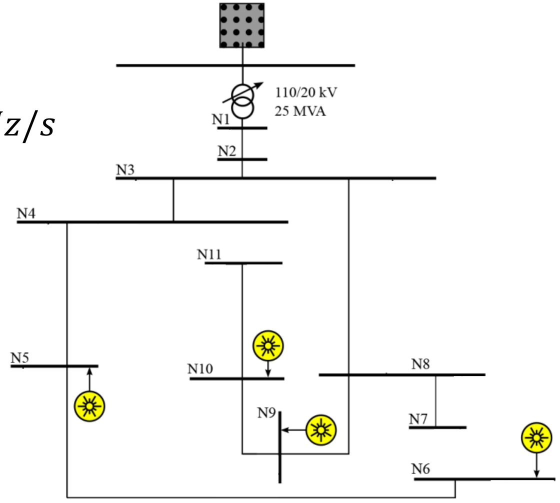
$$P_0^{IR} = 577{,}33\ kW$$

$$C = C_{\mathrm{losses}}^{\mathrm{lines}} + C_{\mathrm{losses}}^{\mathrm{DC/DC}} + C_{\mathrm{losses}}^{\mathrm{DC/AC}}$$

$$H_k = \frac{f_{\mathrm{n}}(P_k^{\mathrm{IR}}(pu) - P_k^{\mathrm{ss}}(\mathrm{pu}))}{2 \times \mathrm{ROCOF}_{\max}}$$

DRESs determine their power injections as

$$P_k(pu) = \frac{2H_k}{f_{\mathrm{n}}}\mathrm{ROCOF}_{\mathrm{meas}} + P_k^{\mathrm{ss}}(\mathrm{pu})$$

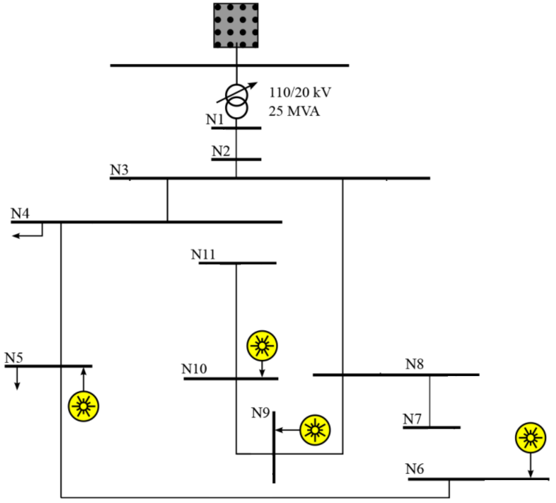


Reference	Bus	$S_{n,k}$ kVA	$P_{g,k}$ kW	$P_{UC,k}^{\max}$ kW	$E_{UC,k}^{\max}$ kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

Inertial response

Stage 2: Optimal allocation of inertia

Objective	DRES	G5	G6	G9	G10	$\sum P_{UC,k}$
Power losses	$P_{UC,k}$	59,88 kW	40,01 kW	220,67 kW	275,33 kW	595,89 kW
	H_k	5,99 s	4,00 s	4,01 s	5,01 s	
Converter losses	$P_{UC,k}$	59,56 kW	38,77 kW	210,15 kW	287,55 kW	596,03 kW
	H_k	5,96 s	3,88 s	3,82 s	5,22 s	

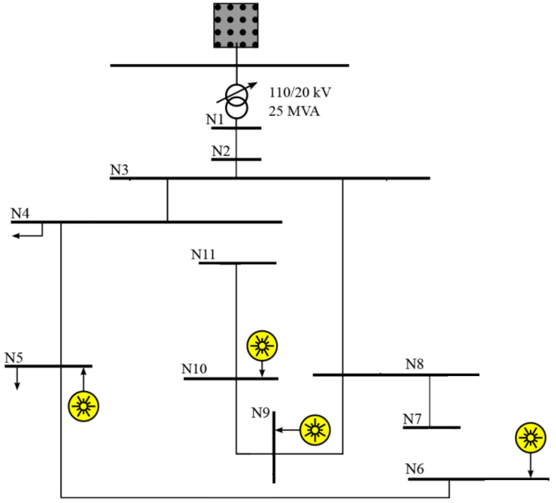


Reference	Bus	$S_{n,k}$ kVA	$P_{g,k}$ kW	$P^{max}_{UC,k}$ kW	$E^{max}_{UC,k}$ kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

Inertial response

Stage 2: Optimal allocation of inertia

Objective	DRES	G5	G6	G9	G10	$\sum P_{UC,k}$
Power losses	$P_{UC,k}$	59,88 kW	40,01 kW	220,67 kW	275,33 kW	595,89 kW
	H_k	5,99 s	4,00 s	4,01 s	5,01 s	
Converter losses	$P_{UC,k}$	59,56 kW	38,77 kW	210,15 kW	287,55 kW	596,03 kW
	H_k	5,96 s	3,88 s	3,82 s	5,22 s	

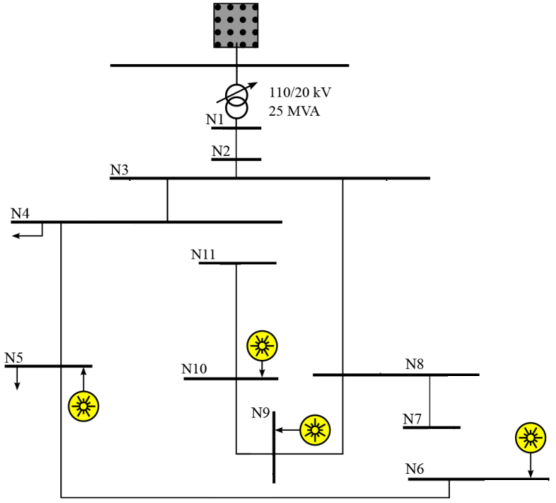


Reference	Bus	$S_{n,k}$ kVA	$P_{g,k}$ kW	$P^{max}_{UC,k}$ kW	$E^{max}_{UC,k}$ kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

Inertial response

Stage 2: Optimal allocation of inertia

Objective	DRES	G5	G6	G9	G10	$\sum P_{UC,k}$
Power losses	$P_{UC,k}$	59,88 kW	40,01 kW	220,67 kW	275,33 kW	595,89 kW
	H_k	5,99 s	4,00 s	4,01 s	5,01 s	
Converter losses	$P_{UC,k}$	59,56 kW	38,77 kW	210,15 kW	287,55 kW	596,03 kW
	H_k	5,96 s	3,88 s	3,82 s	5,22 s	

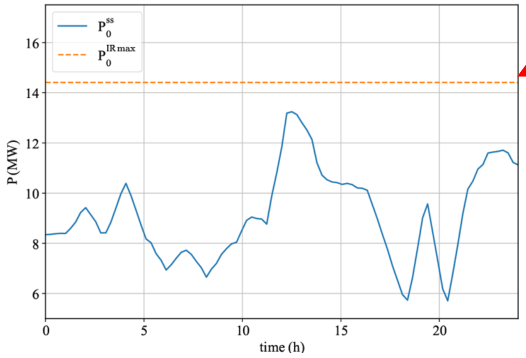


Reference	Bus	$S_{n,k}$ kVA	$P_{g,k}$ kW	$P_{UC,k}^{max}$ kW	$E_{UC,k}^{max}$ kWh
G5	5	100	10	60	0.1
G6	6	100	90	60	0.1
G9	9	550	495	330	0.55
G10	10	550	450	330	0.55

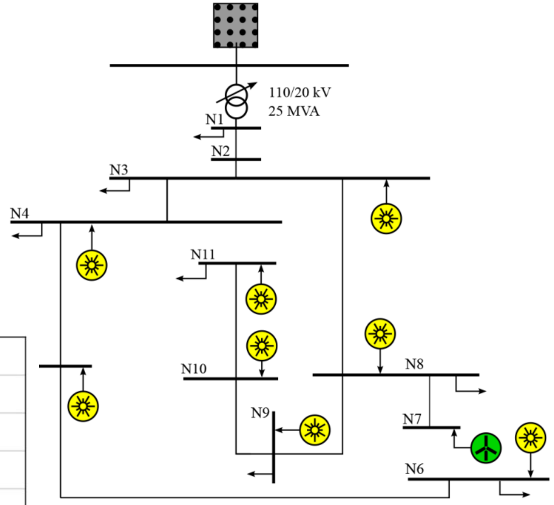
Inertial response

Some simulation results

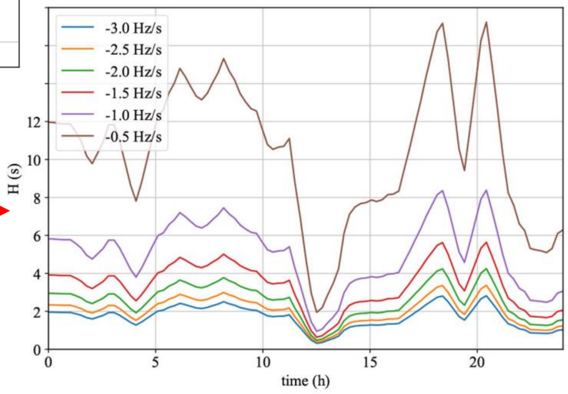
- Evaluation of the maximum inertial capability



Ampacity of the power line at the header of the ADN



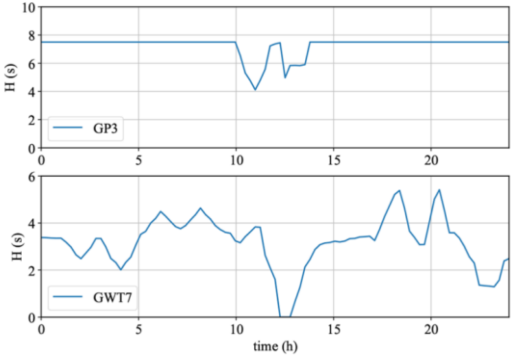
There is a bottleneck around 12 o'clock due to network restrictions



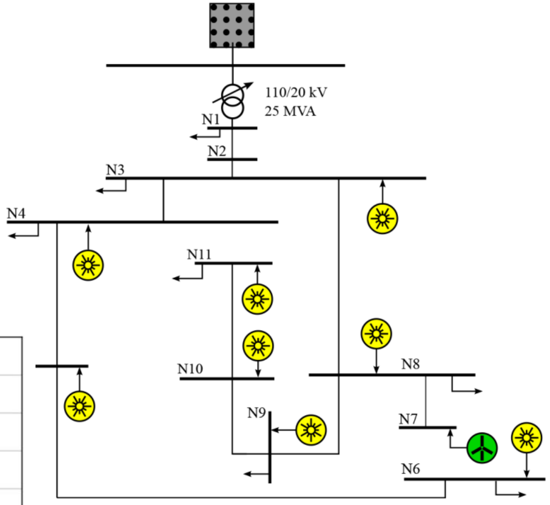
Inertial response

Some simulation results

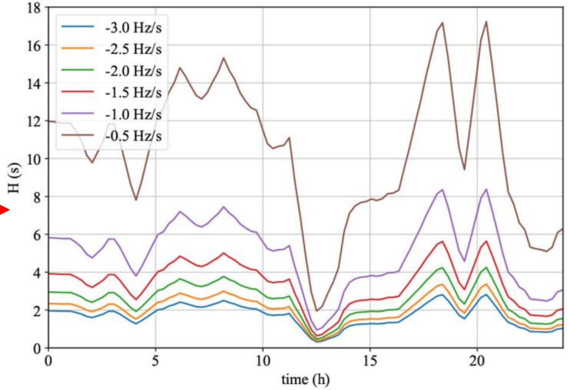
- Optimal allocation of inertia



The wind turbine does not participate in the provision of inertia during the bottleneck



There is a bottleneck around 12 o'clock due to network restrictions



Inertial response

Discussion and conclusions

- Two methodologies have been presented in order to evaluate and provide inertia from AND to the transmission system.
  - The first one aims to determine the maximum aggregated inertial capability of ADNs.
  - The second one aims to optimally dispatch DRESs in order to provide specific, TSO-defined inertial response with the minimum cost .
- Both methodologies are developed based on OPF formulations and take into account all technical and operational limitations of ADNs.
- Future work lines will consider cost functions to allocate inertia within the ICA derived from business models of providing these kind of ancillary services.

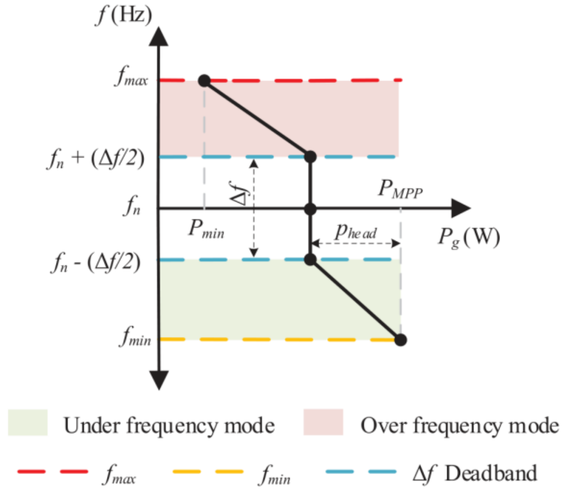
Primary frequency response

- In the framework of the EASY-RES project, the primary frequency response is given by deloading the DRESs, i.e., operating with a headroom under their maximum available power.

- DRESs are controlled with $P(f)$ droop curves to adjust their active power injections based on frequency signals.

  - How can all the DRESs within the ADN be coordinated to provide a specific $P(f)$ droop at the point of interconnection with the transmission system?

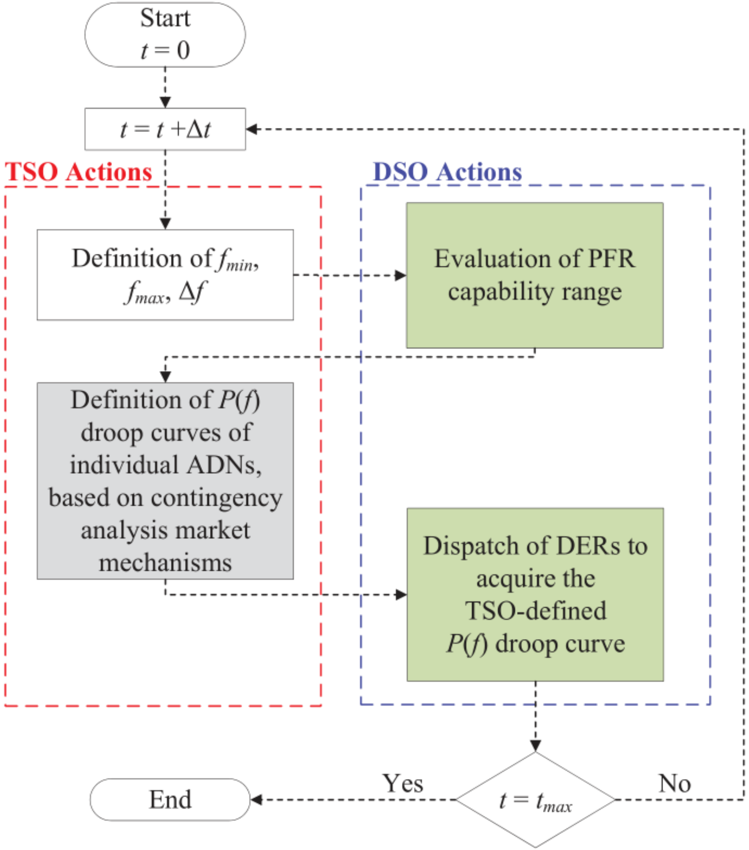
  - Can the ancillary service be provided by only some of the DRESs?



Primary frequency response

Proposed solution

- The proposed solution is based on the continuous interaction between TSO and DSOs.
- The problem, again, can be divided into two main phases:
  - Evaluation of PFR capability range.
  - Determination of DRESs $P(f)$ droop to provide a specific $P(f)$ droop at the point of interconnection with the transmission system.



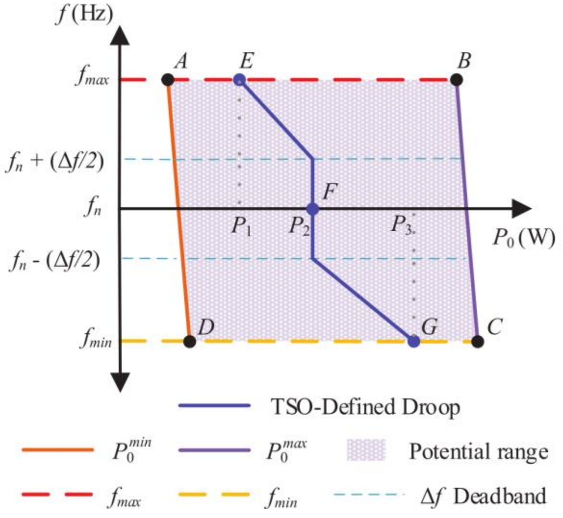
Primary frequency response

Stage 1: Evaluation of the PFR capability

- DSOs should evaluate the range of the aggregated response of all the DRESs within the ADN, i.e., equivalent $P(f)$ droop curves that can be provided at the point of interconnection with the transmission system.
- The maximum and minimum active power that the ADN can deliver at the point of interconnection is computed for several grid frequencies.

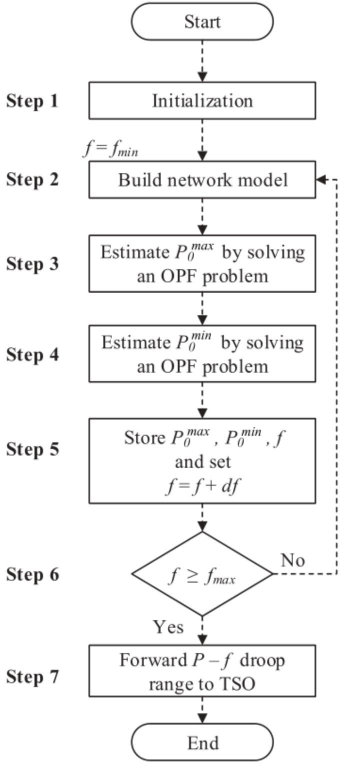
Reactance: $X_L = 2\pi f L$

- Consideration of network constraints.
- It is assumed that the AC/DC power converter of the DRES has been properly sized to handle the possible power coming from the primary source



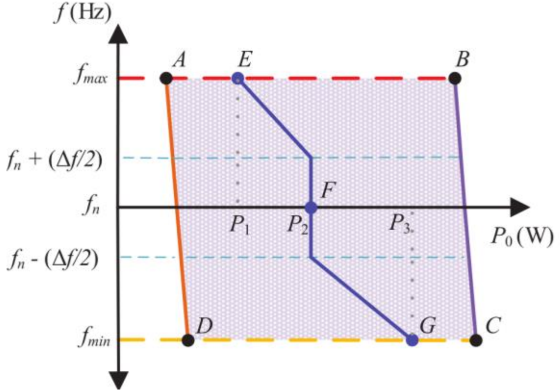
Primary frequency response

Stage 1: Evaluation of the PFR capability



$A: 1{,}694\ MW, 52\ Hz$

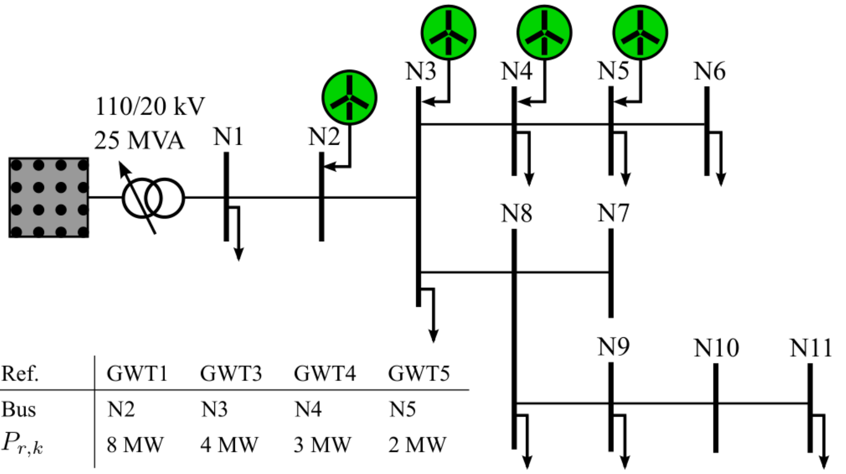
$B: 14{,}398\ MW, 52\ Hz$



$C: 14{,}400\ MW, 46\ Hz$

$D: 1{,}694\ MW, 46\ Hz$

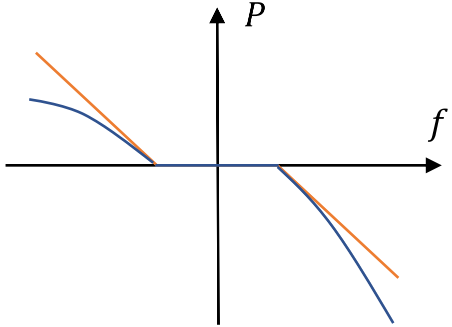
Bus	N1	N3	N4	N5	N9	N6	N8	N11
P_i^L	300 kW	200 kW	150 kW	200 kW	350 kW	250 kW	275 kW	100 kW



Ref.	GWT1	GWT3	GWT4	GWT5
Bus	N2	N3	N4	N5
$P_{r,k}$	8 MW	4 MW	3 MW	2 MW

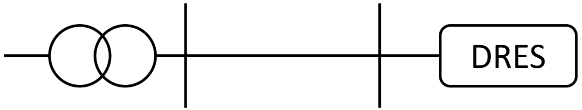
Stage 2: Optimal PFR distribution

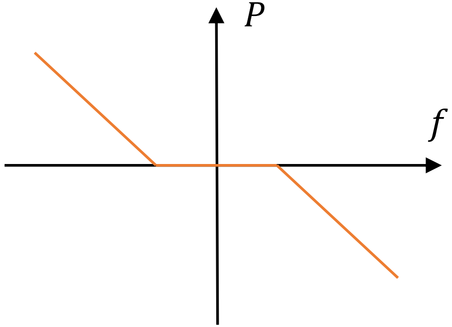
- TSO determines, based on contingency analysis and market mechanisms, the $P(f)$ droop curve that the ADN shall provide at the point of interconnection with the transmission system.
- DSOs must coordinate the PFR droop curves of all the DRESs within the ICA (taking into account the topology of the network) in order to provide the specific $P(f)$ droop at the point of interconnection.



$$P_{DRES} = V \cdot I_{DRES}$$

$$P_0 = P_{DRES} - R \cdot I_{DRES}^2$$





Primary frequency response

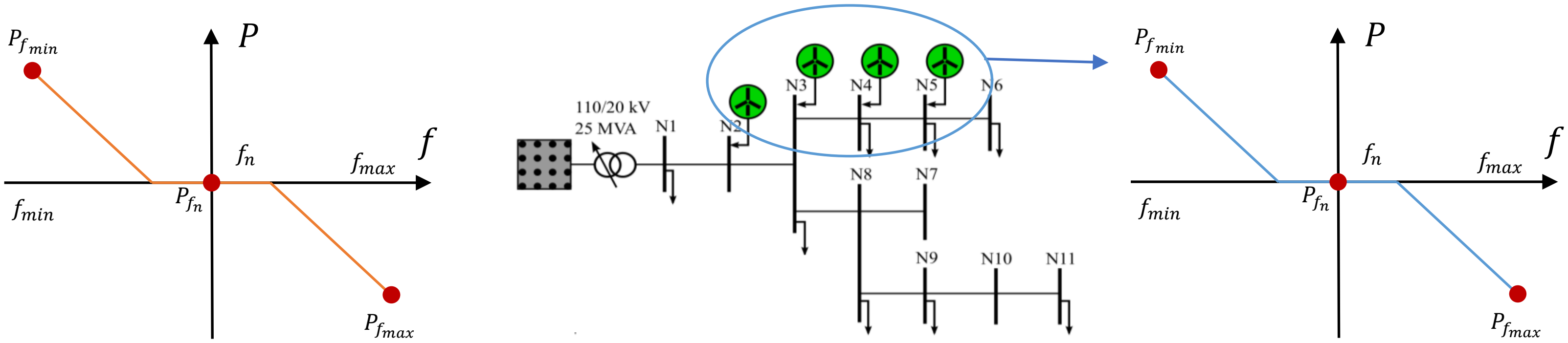
Stage 2: Optimal PFR distribution

- Power injections of each DRES, P_k, are computed using OPF calculations for different grid frequencies to ensure that in each frequency the aggregated contribution of all DRESs provides the TSO-defined P(f) droop curve.

- In the simplest case, P_k should be determined at least for f_{min}, f_n and f_{max}.
  - The optimizer aims to minimize power losses in the lines and headroom power

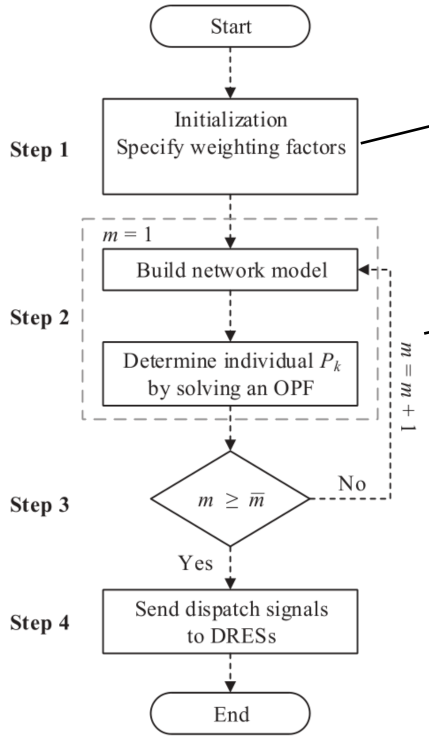
$$C^d = \sum_{k \in \mathcal{D}_i, i \in \mathcal{V}} w_k^d (P_{MPP,k} - P_k)$$

$$C_{loss}^{line} = w_{loss}^{line} \sum_{(i,j) \in \mathcal{E}} R_{i,j} \left(\mathcal{I}_{i,j}\right)^2$$



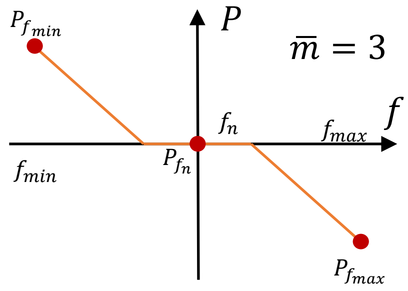
Primary frequency response

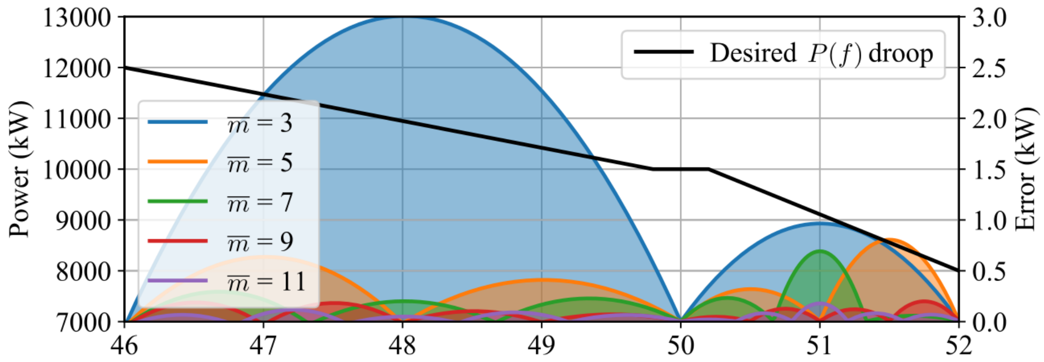
Stage 2: Optimal allocation of inertia



$$C^d = \sum_{k \in \mathcal{D}_i, i \in \mathcal{V}} w_k^d (P_{MPP,k} - P_k)$$

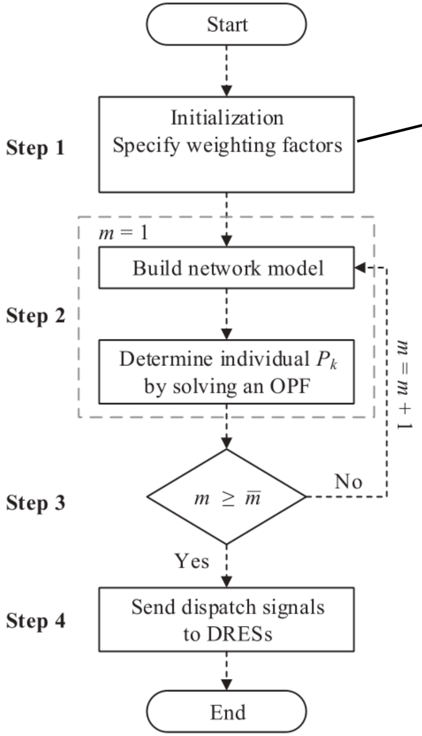
$$C_{loss}^{line} = w_{loss}^{line} \sum_{(i,j) \in \mathcal{E}} R_{i,j} \left(\mathcal{I}_{i,j}\right)^2$$





Primary frequency response

Stage 2: Optimal allocation of inertia

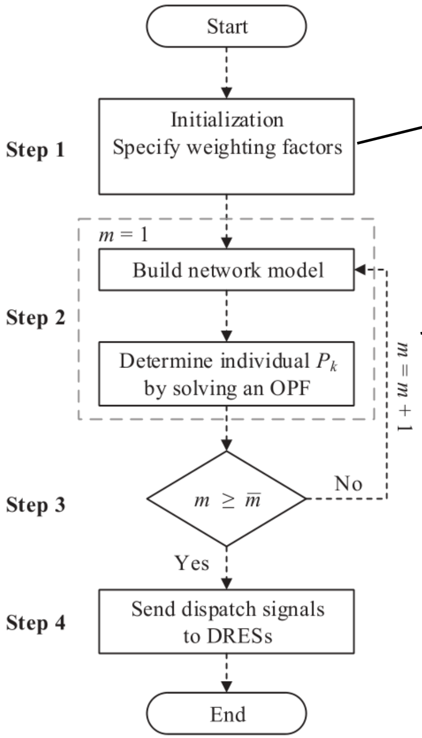


$$C^d = \sum_{k \in \mathcal{D}_i, i \in \mathcal{V}} w_k^d (P_{MPP,k} - P_k)$$

$$C_{loss}^{line} = w_{loss}^{line} \sum_{(i,j) \in \mathcal{E}} R_{i,j} \left(\mathcal{I}_{i,j}\right)^2$$

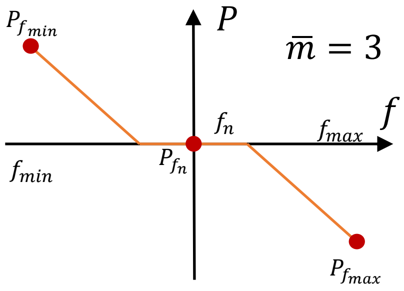
Primary frequency response

Stage 2: Optimal allocation of inertia



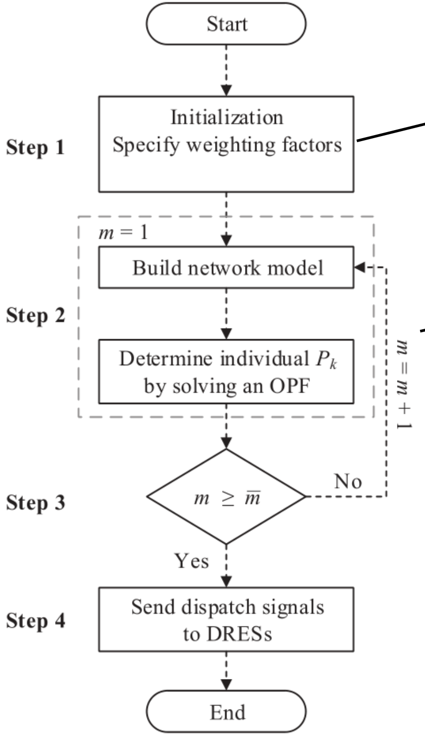
$$C^d = \sum_{k \in \mathcal{D}_i, i \in \mathcal{V}} w_k^d (P_{MPP,k} - P_k)$$

$$C_{loss}^{line} = w_{loss}^{line} \sum_{(i,j) \in \mathcal{E}} R_{i,j} \left(\mathcal{I}_{i,j}\right)^2$$



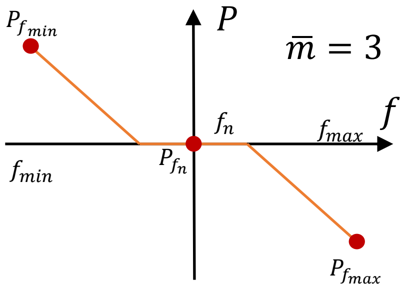
Primary frequency response

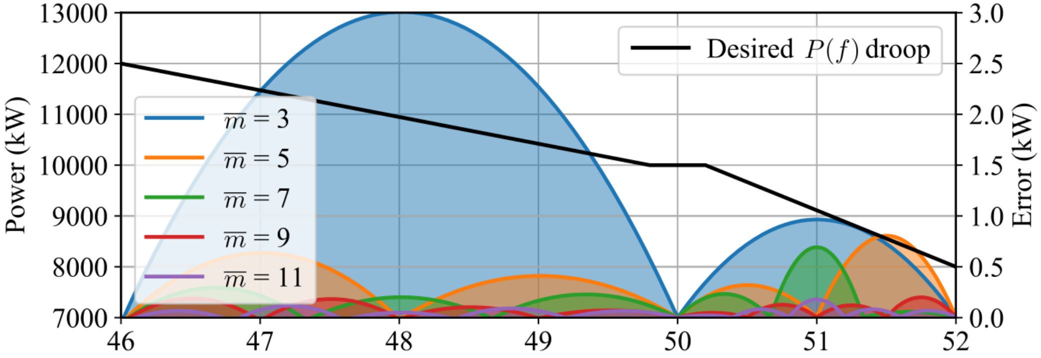
Stage 2: Optimal allocation of inertia



$$C^d = \sum_{k \in \mathcal{D}_i, i \in \mathcal{V}} w_k^d (P_{MPP,k} - P_k)$$

$$C_{loss}^{line} = w_{loss}^{line} \sum_{(i,j) \in \mathcal{E}} R_{i,j} \left(\mathcal{I}_{i,j}\right)^2$$





Primary frequency response

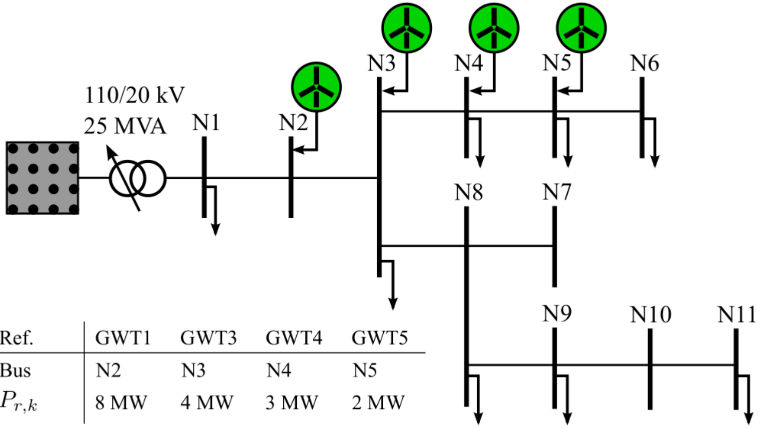
Stage 2: Optimal allocation of inertia

- S1: All WTs participate in PFR.
- S2: WT4 does not participate in PFR

Scenario	f (Hz)	P_{loss}^{line*}	P_{WT2}^{d**}	P_{WT3}^{d**}	P_{WT4}^{d**}	P_{WT5}^{d**}
S1	46	154.06	0	1.533	2.057	1.257
	50	79.29	0.569	2.036	2.56	1.756
	52	38.91	1.502	1.033	0.304	0.203
S2	46	180.89	0.473	2.759	0	1.588
	50	115.84	1.484	3.600	0	1.800
	52	101.81	3.499	3.600	0	1.800

$*P_{loss}^{line}$ are given in kW.
$** \ P^{d}$, i.e., power that de-loaded, is given in MW.

Bus	N1	N3	N4	N5	N9	N6	N8	N11
P_i^L	300 kW	200 kW	150 kW	200 kW	350 kW	250 kW	275 kW	100 kW

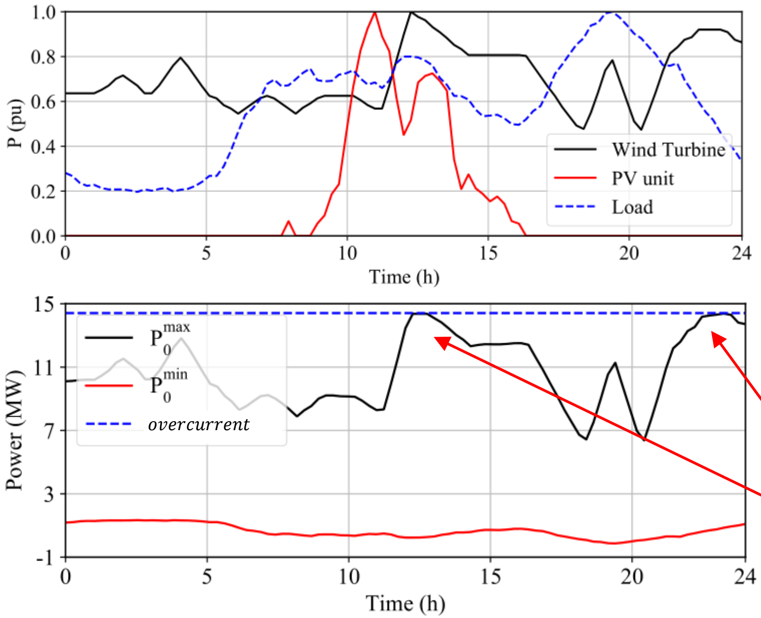


Ref.	GWT1	GWT3	GWT4	GWT5
Bus	N2	N3	N4	N5
$P_{r,k}$	8 MW	4 MW	3 MW	2 MW

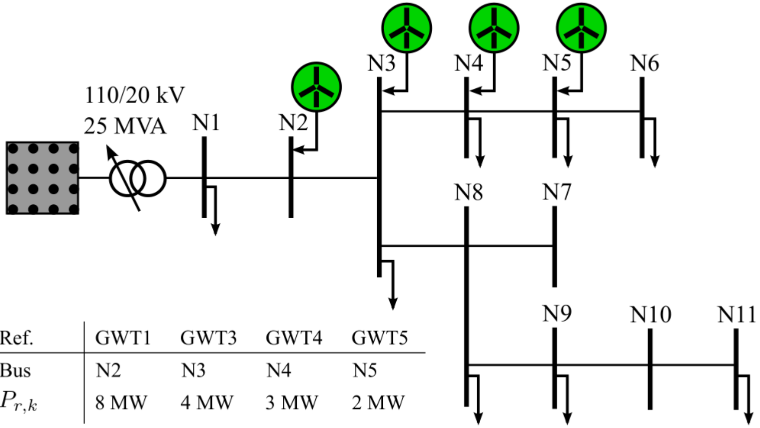
Primary frequency response

Some simulation results

- Evaluation of the maximum PFR capability



Bus	N1	N3	N4	N5	N9	N6	N8	N11
P_i^L	300 kW	200 kW	150 kW	200 kW	350 kW	250 kW	275 kW	100 kW



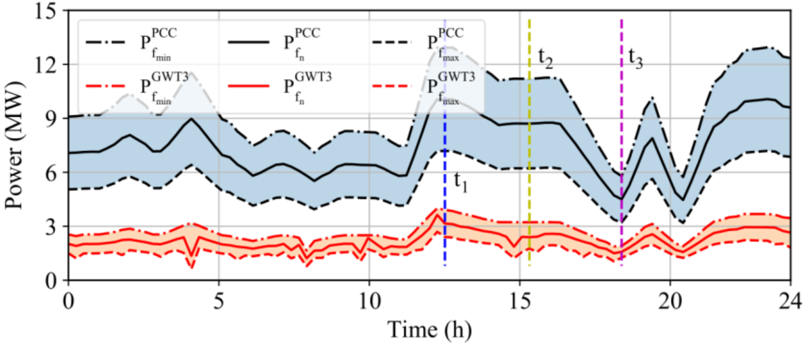
Ref.	GWT1	GWT3	GWT4	GWT5
Bus	N2	N3	N4	N5
$P_{r,k}$	8 MW	4 MW	3 MW	2 MW

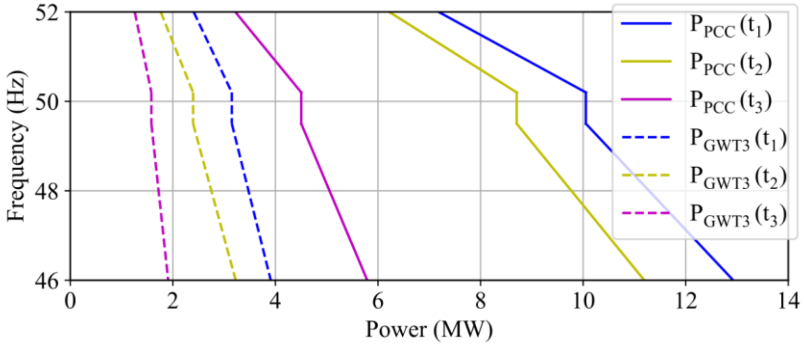
Power injection is limited by the maximum current admissible at the header

Primary frequency response

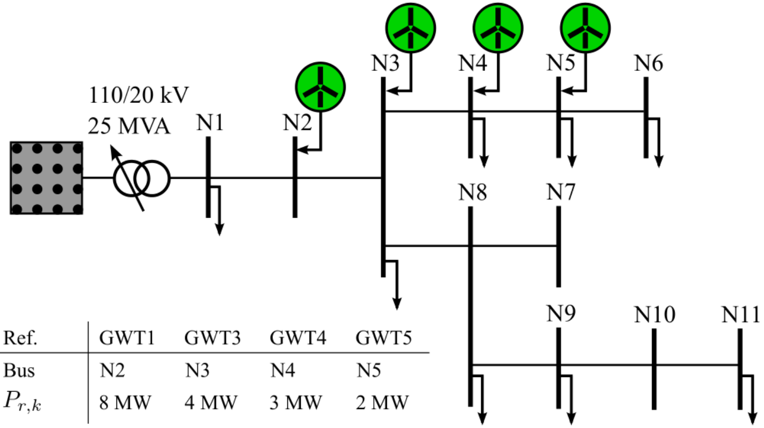
Some simulation results

- Evaluation of the maximum PFR capability





Bus	N1	N3	N4	N5	N9	N6	N8	N11
P_i^L	300 kW	200 kW	150 kW	200 kW	350 kW	250 kW	275 kW	100 kW



Ref.	GWT1	GWT3	GWT4	GWT5
Bus	N2	N3	N4	N5
$P_{r,k}$	8 MW	4 MW	3 MW	2 MW

Primary frequency response

Discussion and conclusions

- Two methodologies have been presented aiming to facilitate the provision of PFR from AND to the transmission system.
  - The first methodology targets to quantify the PFR capability range of the AND.
  - The second one is used to optimally dispatch DERs of the ADN in order to ensure specific frequency regulation characteristics at the point of interconnection.
- Both methodologies are developed based on OPF formulations and take into account all technical and operational limitations of ADNs.
- Future work lines will consider cost functions to allocate PFR within the ICA derived from business models of providing these kind of ancillary services.

References

Publications

- The work presented in these slides summarizes the results of two publications:
  - Rodríguez del Nozal, A., Kontis, E. O., Mauricio, J. M., & Demoulias, C. S. (2020). Provision of inertial response as ancillary service from active distribution networks to the transmission system. IET Generation, Transmission & Distribution, 14(22), 5123-5134.
  - Kontis, E. O., Rodríguez del Nozal, A. , Mauricio, J. M., & Demoulias, C. S. (2021). Provision of Primary Frequency Response as Ancillary Service from Active Distribution Networks to the Transmission System. IEEE Transactions on Smart Grid.
- More information is accessible in Deliverable 2.4 of the EASY-RES project:
  - Rodríguez del Nozal, A., Kontis, E. O., Mauricio, J. M., & Demoulias, C. S. 1st release of Software and its documentation implementing the optimization algorithm for ICA. Deliverable D2,4 of EU H2020 project EASY-RES – Enable Ancillary Services by Renewable Energy Sources, 2020.

Item 4: The EASY-RES Consortium

The Consortium

ARISTOTLE UNIVERSITY OF THESSALONIKI

UNIVERSIDAD DE SEVILLA

UNIVERSITÄT PASSAU

Lancaster University

TU Delft

ΑΔΜΗΕ
ΑΝΕΞΑΡΤΗΤΟΣ ΔΙΑΧΕΙΡΙΣΤΗΣ ΜΕΤΑΦΟΡΑΣ ΗΛΕΚΤΡΙΚΗΣ ΕΝΕΡΓΕΙΑΣ

elektro gorenjska

Stadtwerke LANDAU a.d.ISAR

stadtwerk haßfurt

fenecon ENERGY ENGINEERING

ZD.B ZENTRUM DIGITALISIERUNG. BAYERN

This project has received funding from the European Union´s Horizon 2020 Programme for research and innovation under Grant Agreement no 764090.

Thank you!

Álvaro Rodríguez del Nozal

Affiliation: EASY-RES
Phone: +39
E-Mail: arnozal@us.es
EASY-RES website: http://www.easyres-project.eu/