Power system cost related to the reduction of inertia

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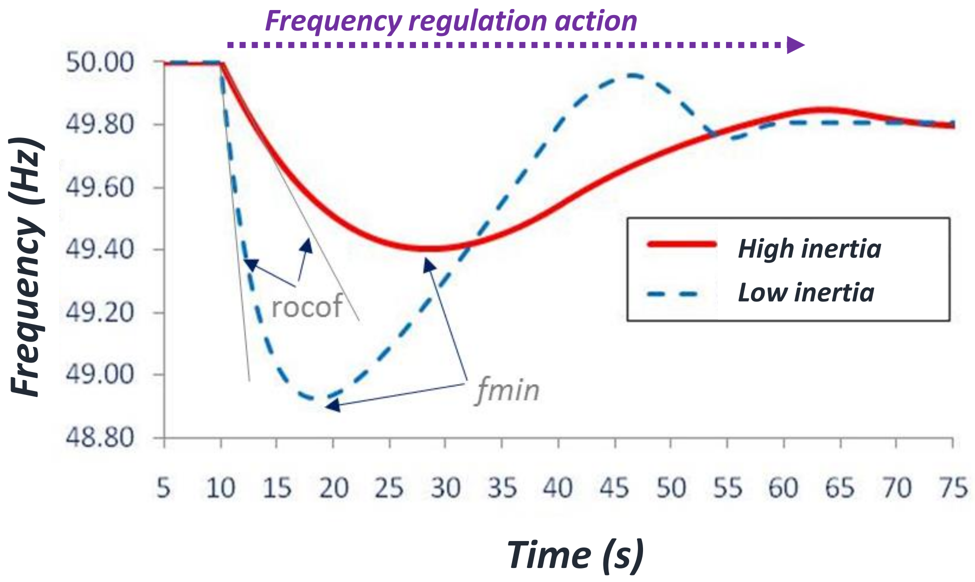
Introduction

Goal of the presentation :

1. Recalling briefly the issue of inertia
2. Making an inventory of the different technical solutions to keep up with the upcoming decrease of inertia
3. **Giving some first methodological elements to assess the cost of these solutions**

Frequency dynamic is affected by the level of inertia

- **Inertia has an influence on the dynamic behavior of the frequency** after any Generation – Consumption unbalance. After a sudden generator loss, in case of low inertia :
  - The frequency drops faster → ROCOF (Rate of Change of Frequency) is higher
  - The frequency minimum (NADIR) is lower



Case 1 : rocof = 0.2Hz/s, nadir = 49.4 Hz

Case 2 : rocof = 1 Hz/s, nadir = 48.9Hz

- **Impacts for the system security :**
  - Low NADIR : load shedding plans could trigger
  - High ROCOF : some generators protection relays could be activated → risk of system frequency collapse

- **Inertia is supplied by conventional fleet : kinetic inertia (KE) of their rotating masses**

- **Variable RES developments → system inertia decreases**

Solutions exist

	SOLUTIONS	EFFICIENCY TO CONTROL		TECHNICAL MATURITY
		ROCOF	NADIR	
go	1 - Must Run Generation (MRG)	Yes	Yes, indirectly	Commercialized
go	2 - Synchronous Condenser (SC)			
go	3 - Fast Frequency Response (FFR)	No	Yes with inertia	
go	4 - Grid Forming	Yes	Yes, indirectly	R&D

A technical tradeoff seems to appear :
1 – As a first step: mitigating the effect of inertia reduction by resorting to FFR
2 – As a second step: maintaining a minimum required level of KE to limit ROCOF

Go to cost of inertia

Solution 1 – Imposing Must-Run Generation (MRG)

Curtailing inverter-based generation and imposing must-run synchronous generators :

- Pros : “basic” solution & no investment cost
- Cons : high variable costs → zero cost variable generation replaced by more expensive fossil-based generation

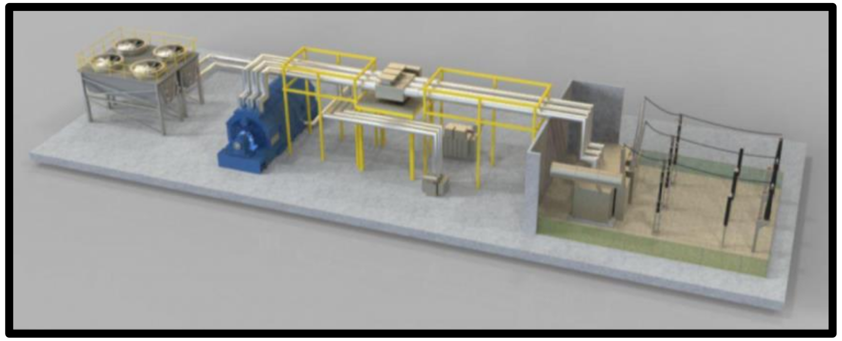
➔ Relevant for small amount of curtailment but unsustainable to integrate large share of VRES

Go back

Solution 2 – Installing synchronous condenser (SC)

Synchronous condenser : synchronous motor running without any mechanical load and spinning freely

- Used so far for voltage regulation, bring also kinetic energy for the system (rotating mass)



- SC's kinetic energy : 2-4 times lower than that of conventional plants
- Possibility to couple with a flying wheel to increase KE
- Possibility to build SC by converting decommissioned power plants

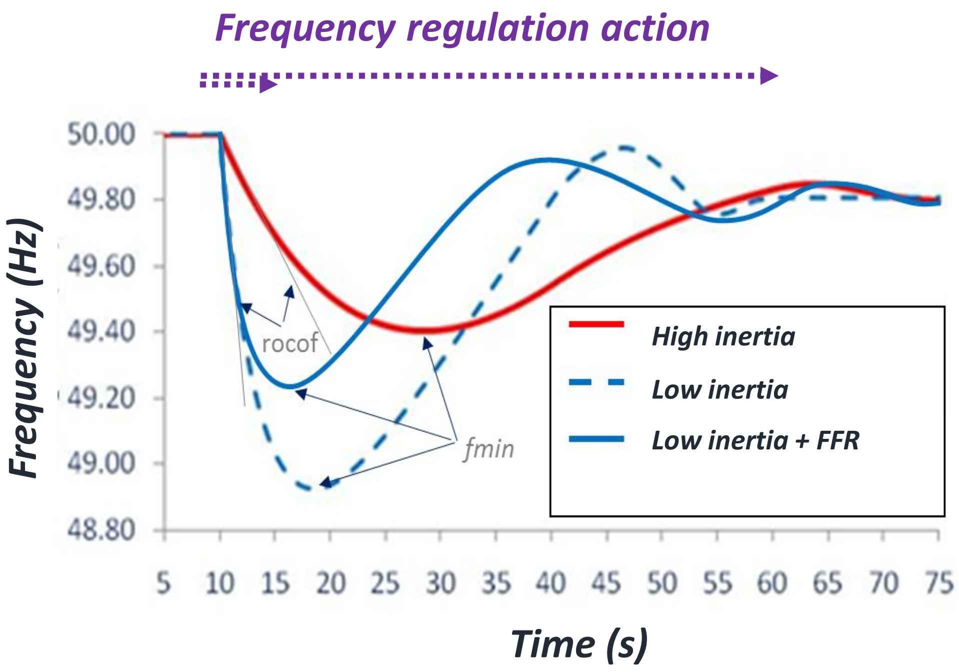
Solution already operational

Go back

Solution 3 – Mitigating the low inertia effects with Fast Frequency Response (FFR)

Concept : very fast injection or withdrawal of power according to frequency changes (hundreds of ms ~ 1s)

- Recent innovative solution based on the high responsiveness of inverters and their control loops.
- Mostly based on storage use; possible exploitation of wind KE.



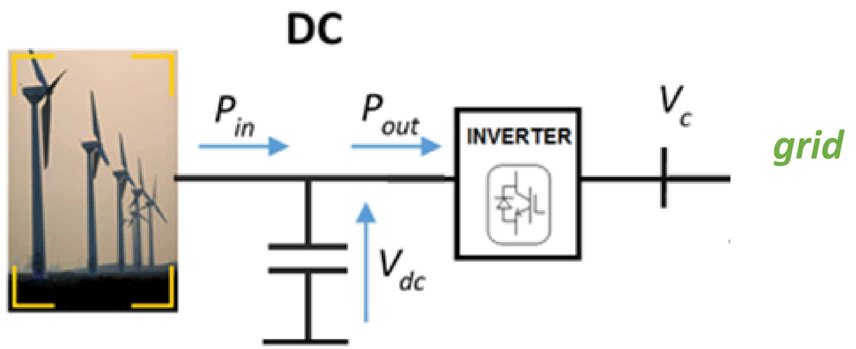
- **Technically robust**
- **Economically viable**
- **However, inefficient to control the ROCOF**
- **→ Can be used to ensure frequency stability until a certain extent of RES integration (not applicable at 100% of RES penetration)**

Go back

- Solution set up by National Grid in 2016 → 200 MW of EFR (Enhanced Frequency Response)

Solution 4 – Exploiting another form of « inertia »

Enhanced control of inverters could create an "inertial response" through power electronics→ the term « Grid Forming » can be found in the literature.



TSOs have shown great interests on this solution.

These controls are already operational in small systems (micro grids), where few negative interactions between inverters of different type and conventional generators can occur.

There are still uncertainties on the applicability as well as on the real "contribution" of this solution at a large system scale .

Go back

Very interesting R&D solution but not considered herein: costs of maintaining necessary KE (Kinetic Energy) would have been overestimated.

Glimpse on the general approach

SIZING

Implementing FFR

Goal : respect minimal Nadir (e.g. 49 Hz) in case of the largest infeed loss (e.g. 1 or 2 GW).

Volume of required FFR :
- Should be assessed based on dynamic simulations;
- Overestimated requirement = largest infeed loss.

Maintaining a minimal level of KE

Goal : respect maximal ROCOF (e.g. 0.5 or 1 Hz/s) in case of largest infeed loss.

Volume of required KE :
→ Based on the next formula (Newton's law)

$$KE_{demand} = \frac{f_0 . \Delta P}{2. ROCOFmax}$$

COST

FFR cost assessment : relevant feedbacks from the 2016 National Grid tenders for the set-up of the EFR (Enhanced Frequency Response) :

→ Price range : 8€/h.MW to 14€/h.MW*

KE cost assessment : tradeoff to be studied between installing CS and using MRG.

Simple methodology developed → see next slides

* https://www.nationalgrideso.com/sites/eso/files/documents/EFR%20Market%20Information%20Report%20v1.pdf

EK cost assessment

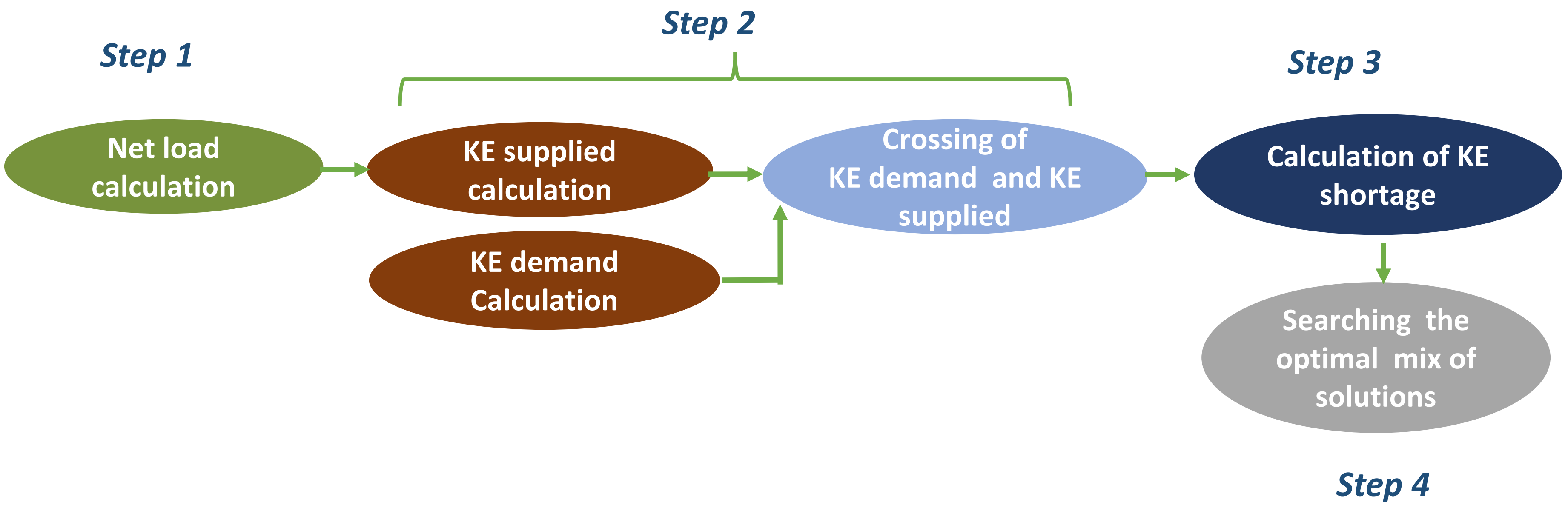
0 - Introduction

1 – Reminder about the inertia of an electrical system

2 - Solutions to compensate inertia decrease

3 – First approach to estimate the cost of inertia decrease

4 steps approach :

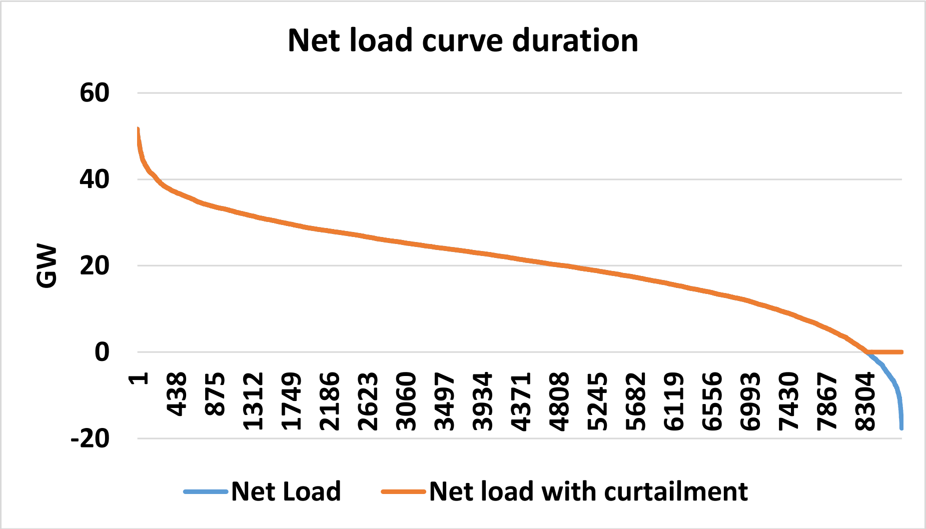


STEP 1 – Net load calculation

Assumptions

Consumption
Load factors of solar&wind
Solar&wind installed capacities
Other RES generation

Net load calculation



- Curtailment car happen (excess of RES generation)

Go back

Steps 2 & 3 – Bringing to light KE shortage

0 - Introduction

1 – Reminder about the inertia of an electrical system

2 - Solutions to compensate inertia decrease

3 – First approach to estimate the cost of inertia decrease

Assumptions

Max ROCOF
Largest infeed loss

KE demand Calculation

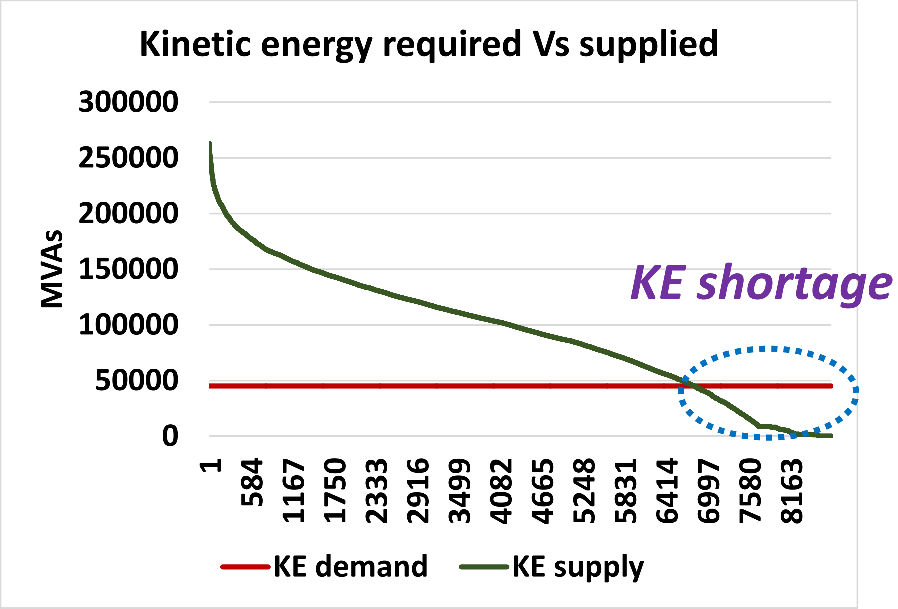
Net load calculation

Assumptions

H of conventional and must-run plants

KE supplied calculation

Crossing of
KE demand en EK supplied



Go back

Step 4 – Optimal solutions to supply the required kinetic energy

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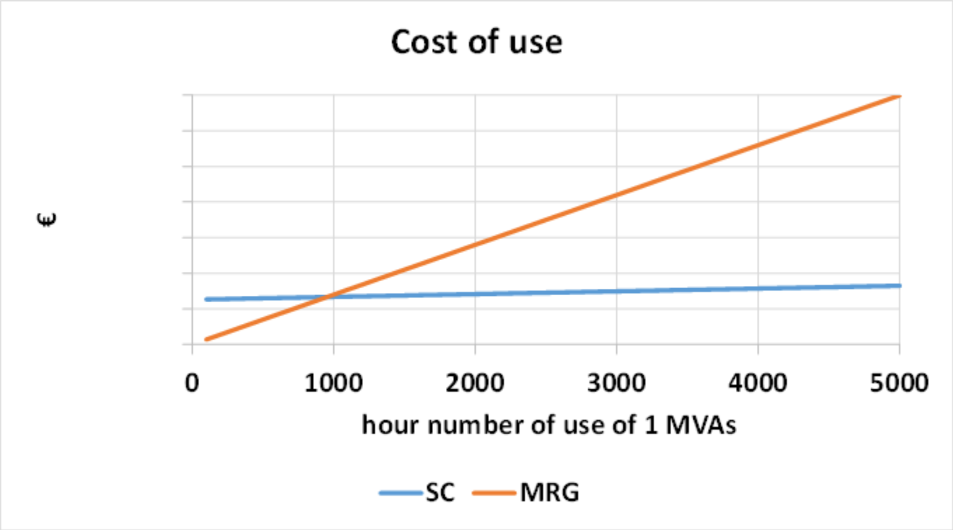
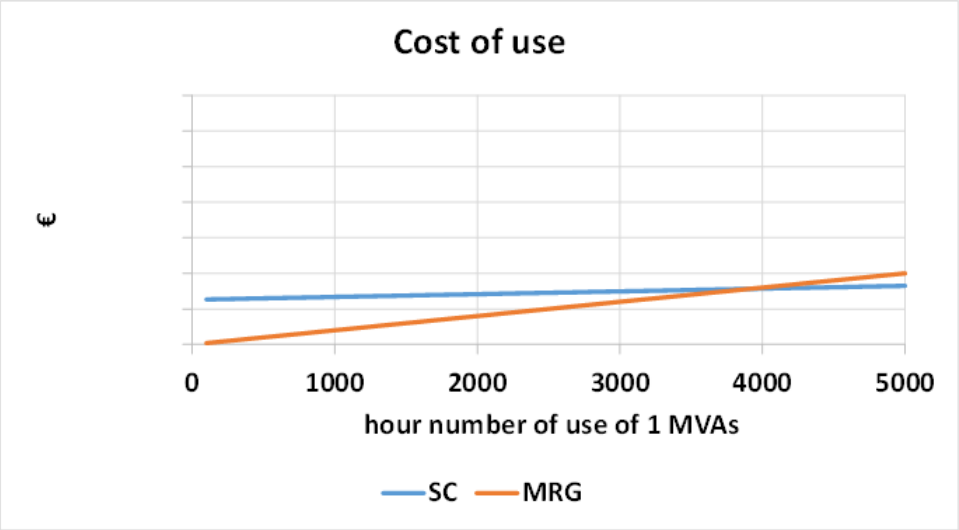
Two possibilities : MRG & SC, with different cost structure :

Solutions	MRG	SC
Fix costs	very low	high
Variable costs	high	very low

Sizing of the SC capacity depends on the electrical mix :

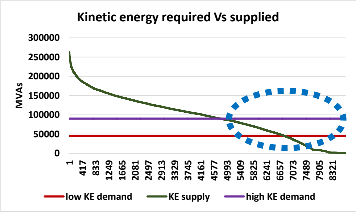


High variable cost of conventional generation → equilibrium = 1000 h/year



Low variable cost of conventional generation→ equilibrium > 5000 h/year

Step 4 – Alternatives to bring kinetic energy



KE shortage

LOW KE NEED

HIGH KE NEED

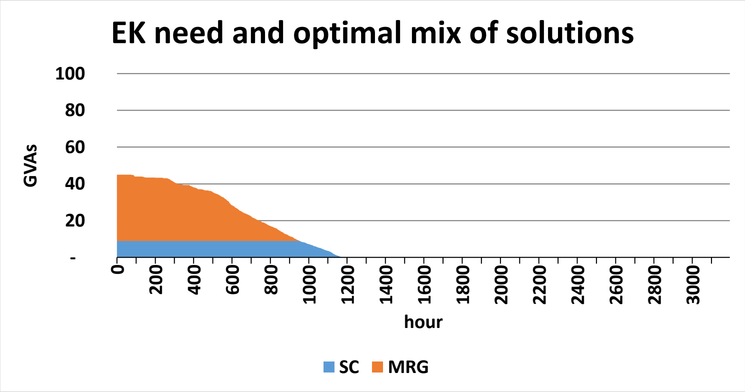
0 - Introduction

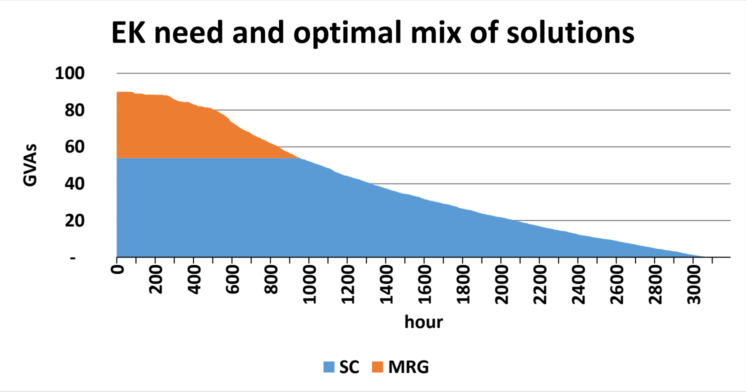
1 - Qu’est ce que l’inertie d’un système électrique ?

2 - Solutions de compensation à la baisse de l’inertie

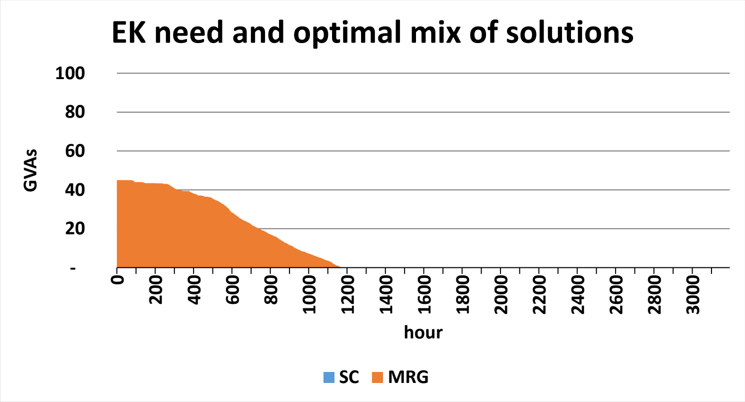
3 – Premières évaluations du coût de ces solutions

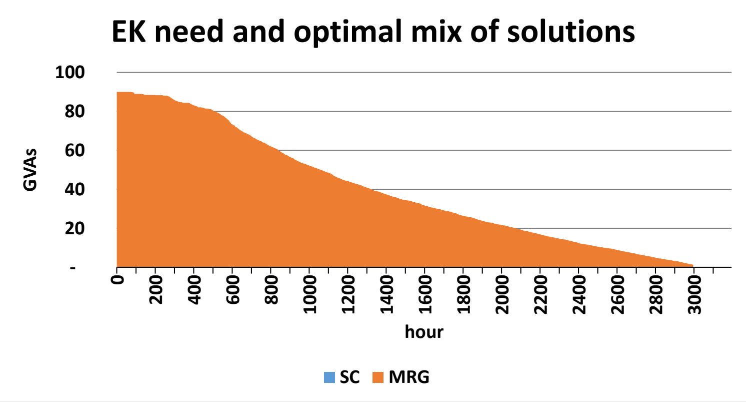
MRG HIGH COST





MRG LOW COST





Depending on the case, it is optimal to install from 0 to 54 GVAs of SC (30 GVA of SC)

Cost of the inertia decrease in the GB context

MRG HIGH COST

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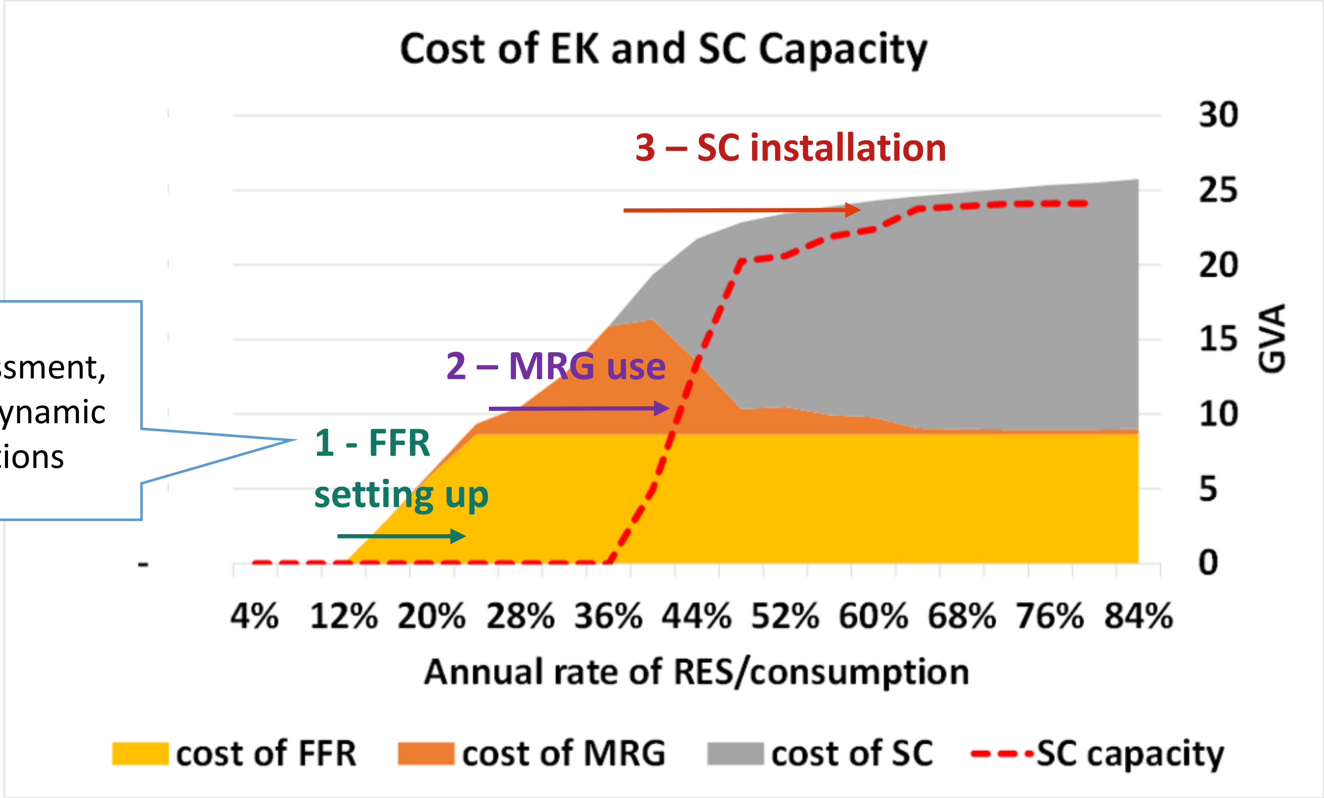
First assessment, without dynamic simulations



2030 GB Context :

- VRES coverage : 40% (+ sensitivities)

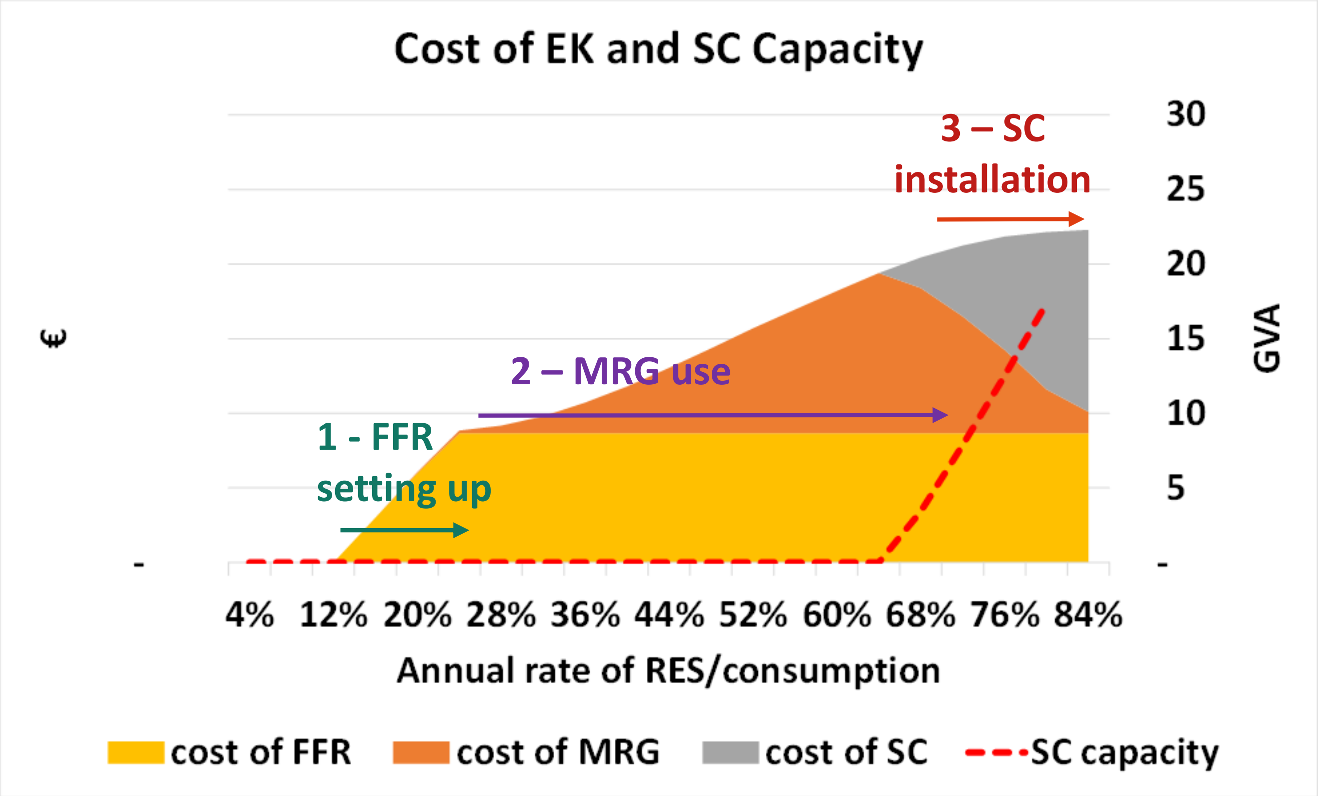
- Largest infeed loss : 1.8 GW

- *Maximal RoCoF : 1Hz/s*
- *Fmin : 49 Hz*

- The 3 solutions are used successively while developing inverters-based RES
- SC installation enables to limit the KE costs

Cost of the inertia decrease in the GB context

MRG LOW COST



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__2030 GB Context :__
- VRES coverage : 40% (+ sensitivities)
- Largest infeed loss : 1.8 GW
- Maximal RoCoF : 1Hz/s
- Fmin : 49 Hz

- In the “Low Cost MRG” case, KE costs increase more slowly and SC installation happen later

Main findings

- Commercial solutions exist to secure an electrical system facing kinetic energy (KE) decreases and to facilitate the RES inverter-based generation's development.
- According to the first studies, in order to minimize global system costs, the suggested application order seems to be :
    1. Implementing FFR (Fast Frequency Response) :

       As a recent technical breakthrough, FFR enables the system to stand much lower kinetic energy level than in the past. FFR is however not efficient enough to ensure the frequency stability in case of very low level of inertia.
    2. Imposing MRG (Must-Run Generation) :

       Relevant and cost-effective while RES curtailment remains low.
    3. Installing SC (Synchronous Condensers):

       Viable solution at higher levels of RES integration.
- The total cost of these solutions depends highly on :
    - The maximal acceptable ROCOF / frequency nadir defined by the TSOs.
    - The cost of MRG (low/high variable cost)
- Voltage and rotor angle stabilities → another good reason for MRG and SC utilization?
- Grid forming control of inverters could also be part of the solution in the future.


Thank you!