C4 – Power System Technical Performance

PS 3 / Challenges and Advances is Power System Dynamics

Paper ID : 930

Inertia Need and Cost Related to System Splits for the Future Continental Europe Power System

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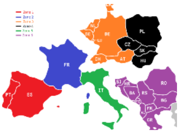
Glossary :
VRES : Variable Renewable Energy source
SC : Synchronous Condenser
KE : Kinetic Energy
RoCoF : Rate of Change of Frequency
UCED : Unit Commitment with Economic Dispatch

Motivation

- Previous paper (2020 CIGRE C4-658): in the long term (with 66% of RES), system splits with more VRES (less inertia) will endanger the European system



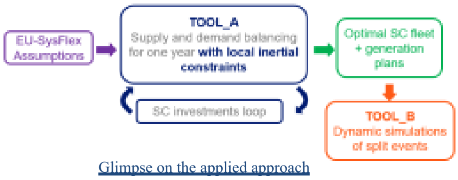
Example of system split : Europe in three

Splitting event	NADIR < 47.5 Hz	ZENITH > 51.5 Hz	|RoCoF| > 1 Hz/s
Iberian Peninsula	~1%	~14%	~72%
Italy	< 1%	~1%	~58%
Europe in 3	0%	0%	~25%

EU-Sysflex previous result : system splits lead to many extreme RoCoF values

- **Addressed question** : how to ensure the system frequency stability in case of system splits in a cost-effective way ?

Approach based on a tools chain



Glimpse on the applied approach

- **Tool A : UCED model with inertial constraints in each zone prone to be separated**. Three action levels : 1) limiting the interconnectors flows, 2) starting up more conventional groups, 3) use Synchronous Condensers (SC)
- **External SC investment loop:** acts iteratively with tool A to fix the optimal amount of SCs in each vulnerable zone (optimal amount = neither over nor under investments)
- **Tool B, models the frequency dynamics in case of split events :** used to validate the robustness of the generation plans delivered by tool A

Main assumptions

- Max acceptable RoCoF = 1 Hz/s (2 Hz/s as sensitivity)
- SCs feature (with flywheel) and investment costs: according to public data from CIGRE 2020
- Long term scenario based on EU-SysFlex assumptions
- Split events' configurations considered by the methodology:

Zone	Annual consumption	Wind Capacity	Solar Capacity	Chosen split events	Max triggered Imbalance
Iberian Peninsula	342 TWh	54 GW	53 GW	1- split from France	12 GW
Italy	394 TWh	26 GW	57 GW	1- split from France & Switzerland	18.5 GW
France	548 TWh	58 GW	45 GW	1- split from Spain 2- split from Italy 3- split from Belgium, Germany and Switzerland	12 GW 5.5 GW 18 GW
Germany + neighbors	1016 TWh	124 GW	112 GW	1- split from France & Italy 2- split from Eastern countries	31 GW 13 GW
Eastern countries	363 TWh	21 GW	5 GW	1- split from Germany & Austria	13 GW

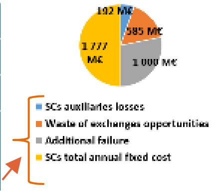
Modeled split scenarios considered

Main results

Zone	1 Hz/s case	
	SCs Capacity	Range of SCs running hours
Iberian Peninsula	39 GVA	2000-5100 h/y
Italy	35 GVA	1500- 3700 h/y
France	14 GVA	700-2500 h/y
Germany + neighbours	12 GVA	2000-2200 h/y
Eastern countries	0 GVA	-

SC investment loop results → mainly in the peninsulas

Max RoCoF = 1 Hz/s - Yearly Indicators Deviation from base case 'no KE constraint'	
Interconnectors flows	-35 TWh/y -6%
Curtailment	+0.36 TWh/y +2%
CO_2 emissions	+1.7 Mt/y +1%
Total Production Cost (including SCs costs)	+1.77 B€/y



Tool A results – system implication

- KE constraint implies a lesser use of the interconnectors → more VRES curtailment and some additional episodes of power inadequacy with failure (mostly in Italy) → more system costs

Splitting event	% RoCoF > 1 Hz/s	
	No KE	KE + SC
Iberian Peninsula	~ 72%	0%
Italy	~ 58%	0%
Europe in 3	~ 25%	< 1%

Tool B result : dynamic validation → KE constrains are effective are securing the system

Conclusion

- Very high RoCoF values are removed
- KE constraint implies a significant deoptimization of the system
- Dedicated inertial assets (such as SCs) are crucial. No investments means much more adverse impacts of the KE constraints (see next slide)

Perspectives

Broader perspective should be considered :

- Other stability aspects must be considered (voltage control, system strength, …) and interests of SCs for multi-services provision
- Other solutions for stability services must be considered (BESS and VRES with Grid Forming capabilities, HVDC behavior during split events)
- Other splits events configurations

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More about Inertial Constraint

RoCoF equation

$$RoCoF = \frac{50\,Hz \cdot |Imbalance|}{2\,KineticEnergy}$$

→

Constraint for each zone prone to face system split :

$$KineticEnergy(t) \geq \frac{50\,Hz \cdot \left| \sum FlowsIn(t) - \sum FlowsOut(t) \right|}{2\,RoCOF\,Max}$$

Possible consequences in the generated generation plans in France, Portugal and Spain :
- Less interconnector flows
- More local inertia with more conventional
- More RES curtailment

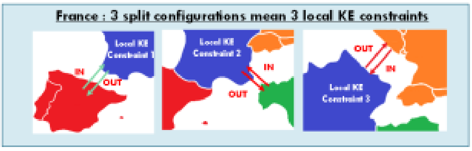


Illustration for the separation of Iberian Peninsula from France

3 possible splits for France

More about SCs investment loop

- At each iteration and for each vulnerable zone, computation of the Gross Margin for a fictive SC

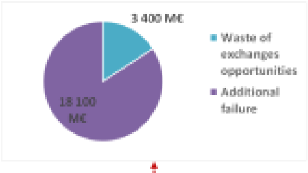
$$GM(SC_z) = \sum_t G(SC_z, t) \left[C(SC)\,MarginalCost(z,t) + \sum_{mz} H(SC)\,KE\,MarginalCost(mz,t) \right]$$

Capacity = 250 MVA; Consumption = 1.2%; Power Marginal Cost (output by Tool_A; Inertia constant = 7s; Inertia Value for KE constraint mz and (output by Tool_A)

- GM(SC_z) is compared to the annual SC fixed costs_sc(z) $NetIncome_{sc}(z) = GM_{sc}(z) - AnnualFixedCost_{sc}$
- SC is invested in the most profitable zone (higher value of NetIncome_sc)

What if no SCs investment is made ?

Yearly Indicators	Focus on case 1 Hz/s With SCs	Focus on case 1 Hz/s Without SCs
Interconnectors flows	-35 TWh/y	-111 TWh/y
	-6%	-18%
Curtailment	+0.36 TWh /y	+ 35 TWh/y
	+2%	+146%
CO_2 emissions	+1.7 Mt /y	+10.9 Mt/y
	+ 1%	+6%
Total Production Cost (including SCs fixed costs)	+1.77 B€/y	+21.5 B€/y



- Interconnectors' flows are drastically reduced
- Part of VRES generation cannot be fully exported when necessary and must be curtailed (especially in peninsulas), CO2 emissions surge
- Total production cost increase drastically for two reasons :
- Curtailed VRES is compensated by conventional with higher fuel costs
- Power adequacy is not ensured anymore and supply shortage skyrockets in Italy (+1.6 TWh)

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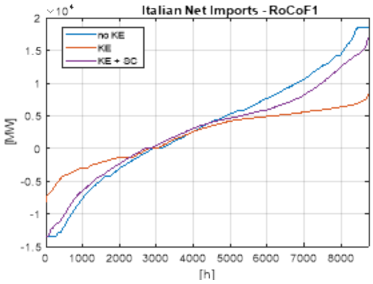
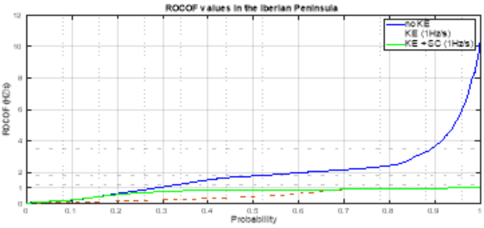
Zoom on the interconnectors' flows

- Visual effect of the KE constraint on the import / export values
- In the Italian case, less import means power inadequacy and power failure
- SCs investments enable to keep the flows nearly to their optimal values

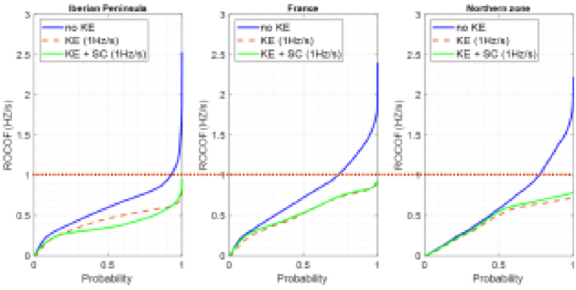


Zoom on the dynamic validation – Iberian Peninsula case

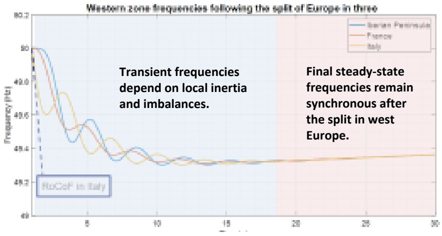
- KE constraint (with or without SCs) is effective in ensuring that RoCoF calculated through a 500 ms time windows are lower than 1 Hz/s
- Illustration of the duration curve of RoCoF in Iberian Peninsula in the three cases

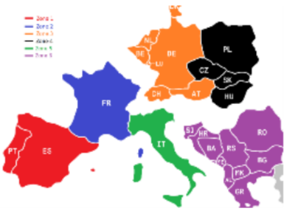


Zoom on the dynamic validation – Europe in 3 case



Duration curves of RoCoF in the modelled zone





Frequencies behavior when France, Italy and Iberian Peninsula separate from the rest of Europe