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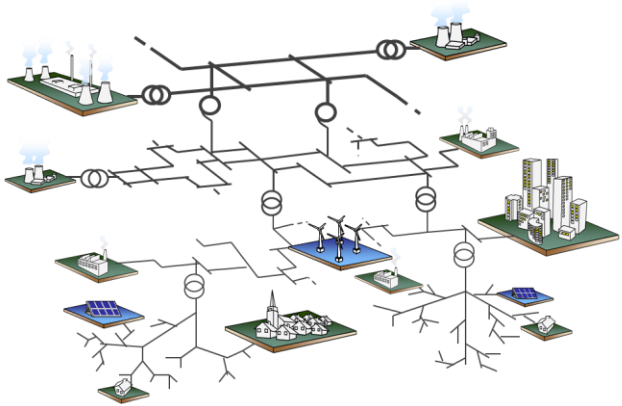
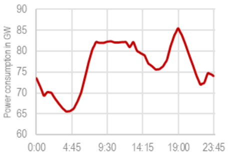
ADAPTATIONS OF A NUCLEAR REACTOR MODEL TOWARDS MORE FLEXIBILITY *in order to accommodate a power system with a high insertion of variable renewable energy sources*

July 2nd 2021

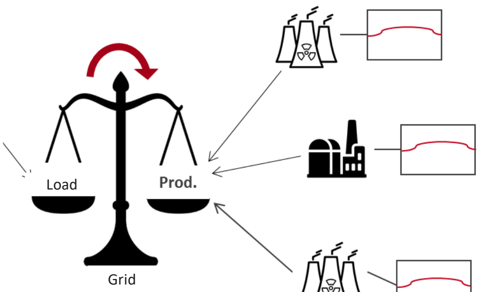
5th Technical Workshop on Nuclear Fuel Cycle Simulation (TWoFCS)

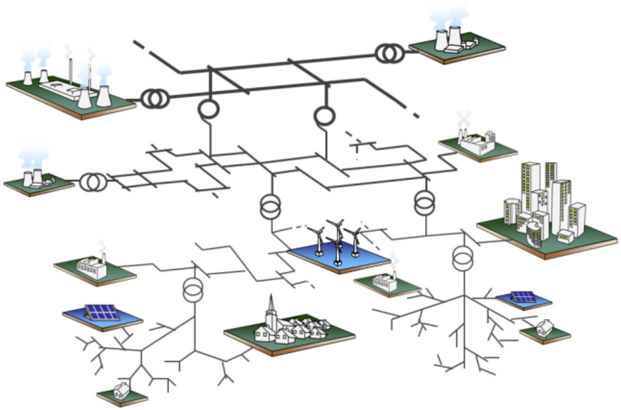


- Power system:
  - Role: transport electricity from generating units to load locations
  - Objective: ensure production and consumption balance at all time
- Historically: imbalance on the load side only



Load curve for a typical week day 02/04/2019

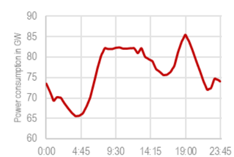




- <u>Power system:</u>
  - Role: transport electricity from generating units to load locations
  - Objective: ensure production and consumption balance at all time

- <u>Historically:</u> imbalance on the load side only

- <u>Actual and upcoming challenges:</u>
  - Demand side: Continuous variation of the load BUT demand management, new uses, ...
  - Supply side: RES* ↑ and high CO2 emitting power plant→ 0 BUT electric mobility park, decentralised productions...



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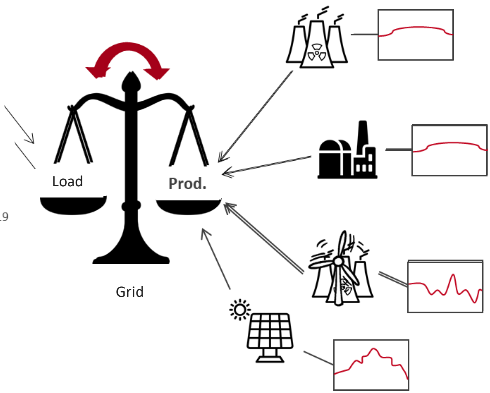
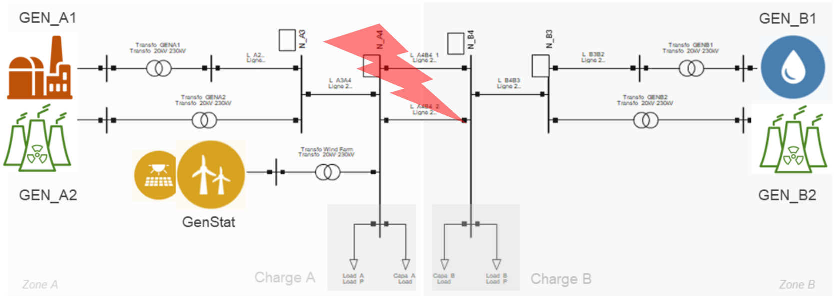


RES: Renewable Energy Sources

- <u>In case of disturbance:</u>
  - Caused by load or generation variation, grid default, …
  - Frequency controls occur



Primary control
- < 30 sec
- Balance the production-consumption
- Automatic

Secondary control
- < 15 min
- Reduce the residual frequency gap
- Automatic

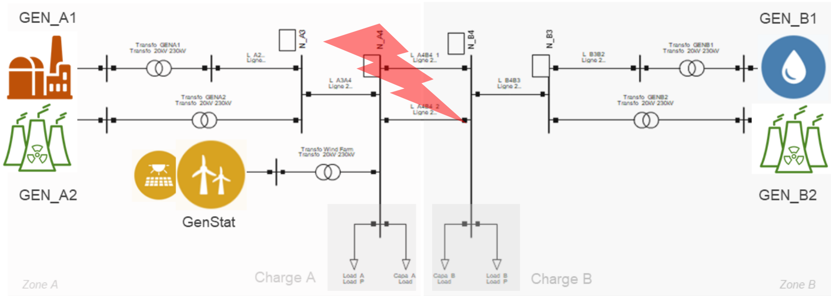
Tertiary control
- < 30 min
- Find an economic optimum
- Activated by the TSO

Grid following (Primary control, Secondary control)

Load following (Tertiary control)

- <u>In case of disturbance:</u>
  - Caused by load or generation variation, grid default, …
  - Frequency controls occur
  - Levers such as NPP or other dispatchable units

	%Pn/min max
Hydro	> 25
Diesel	25
Gas	7
Coal	5
Nuclear	5



- <u>Nuclear in the frequency control:</u>
  - Mainly used for load following because of the French fleet
  - Maximal power ramp of 5%Pn/min

→ *This work is part of an overall methodology approach capable of defining a criterion at the interface of power systems and nuclear design**

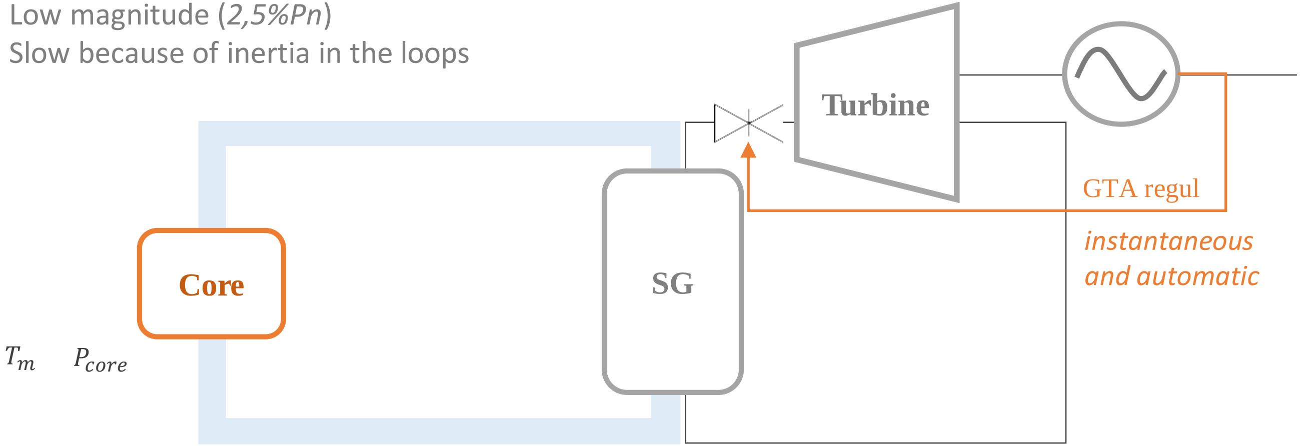
→ *Minimal electric power ramp to ensure stability for high RES disturbance (%Pn/min): INPUT of this study**

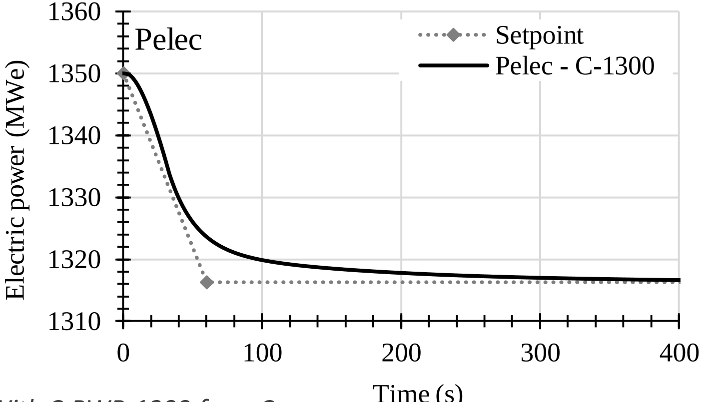
** Mazauric et al, EPJN, under review*

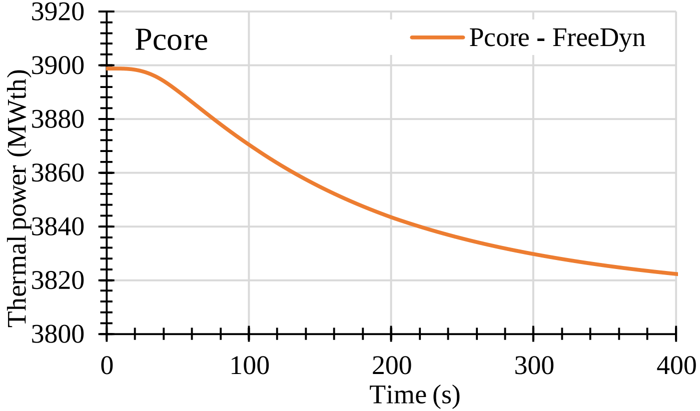
STATE OF THE NUCLEAR HELP TO THE FREQUENCY CONTROL

Free dynamic

- Low magnitude (*2,5%Pn*)
- Slow because of inertia in the loops



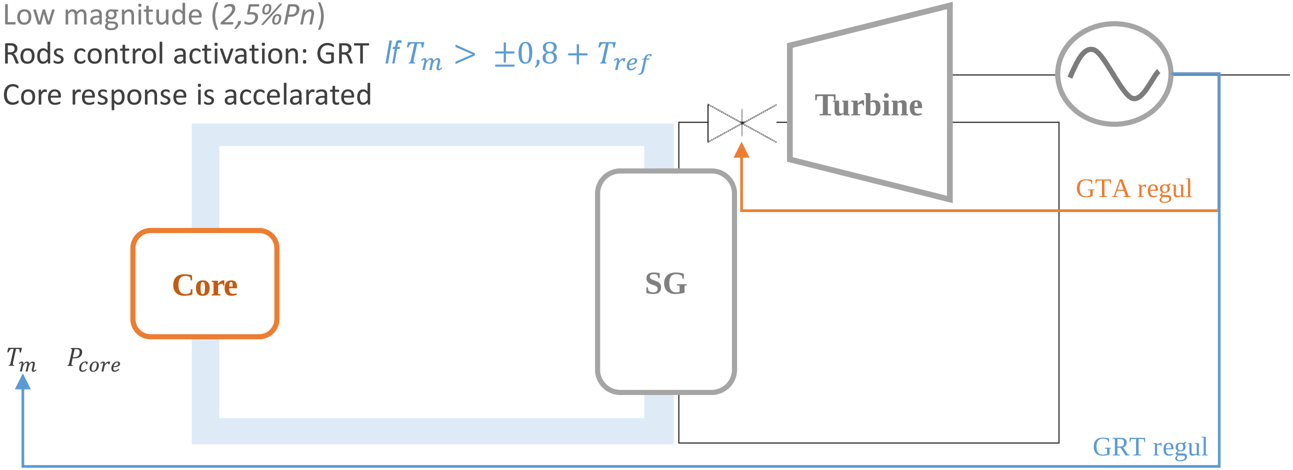


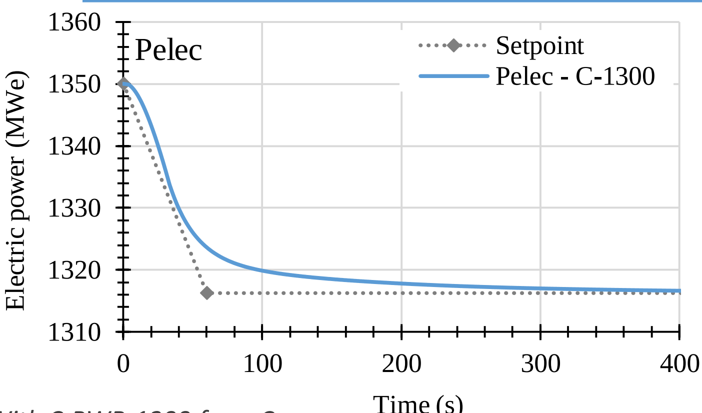


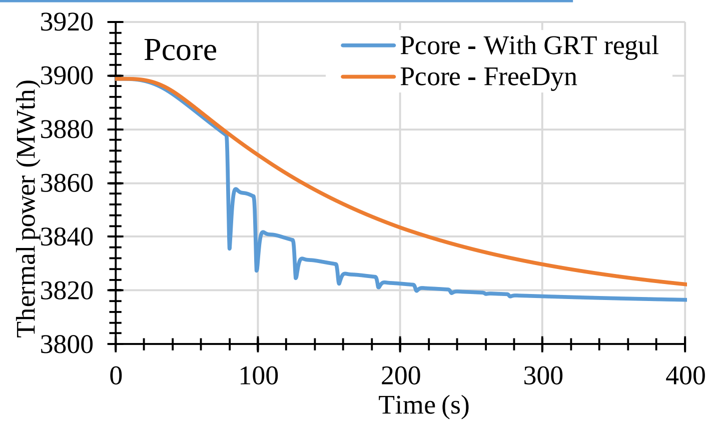
With C-PWR-1300 from Corys

Primary frequency control

- Low magnitude (*2,5%Pn*)
- Rods control activation: GRT *If* $T_m > \pm 0{,}8 + T_{ref}$
- Core response is accelarated



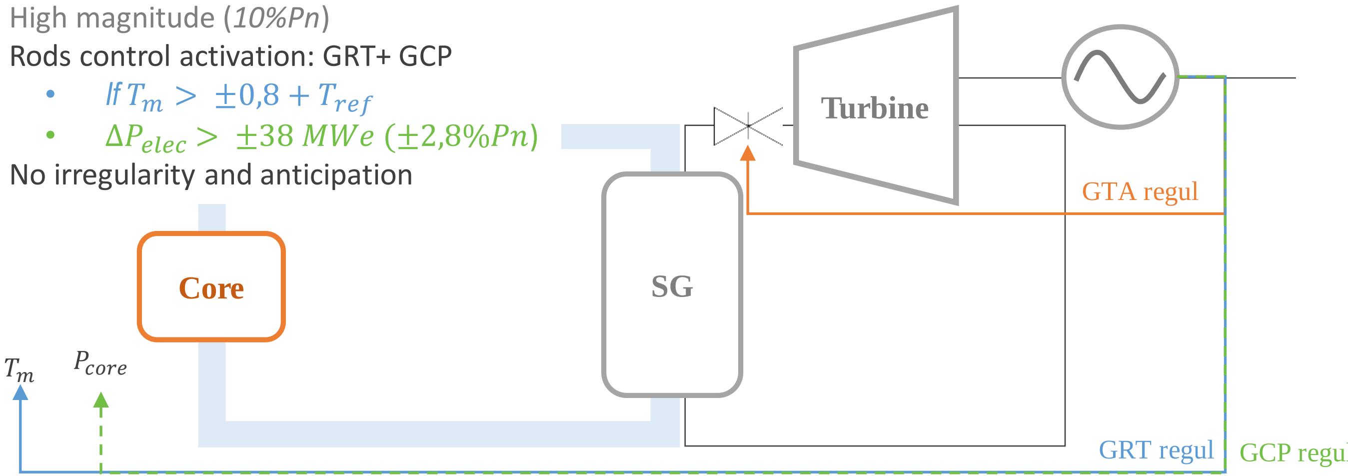


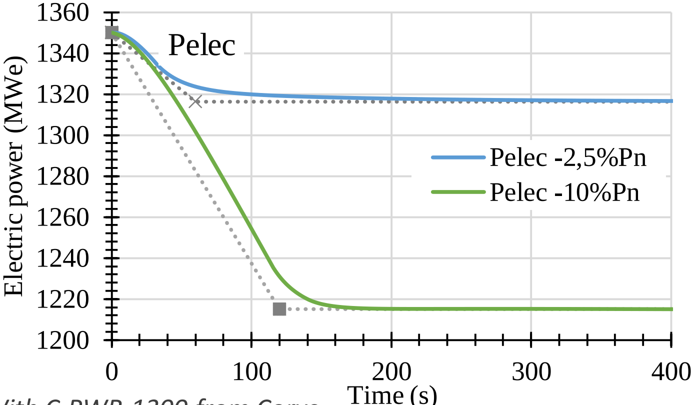


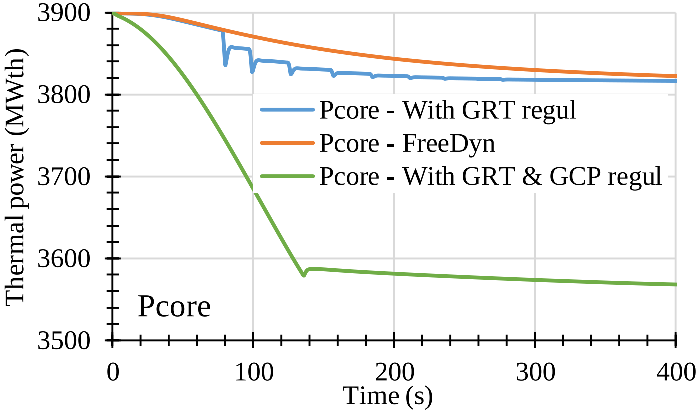
With C-PWR-1300 from Corys

STATE OF THE NUCLEAR HELP TO THE FREQUENCY CONTROL
Load following

- High magnitude (*10%Pn*)
- Rods control activation: GRT+ GCP
  - If $T_m > \pm 0{,}8 + T_{ref}$
  - $\Delta P_{elec} > \pm 38\ MWe\ (\pm 2{,}8\%Pn)$
- No irregularity and anticipation







With C-PWR-1300 from Corys

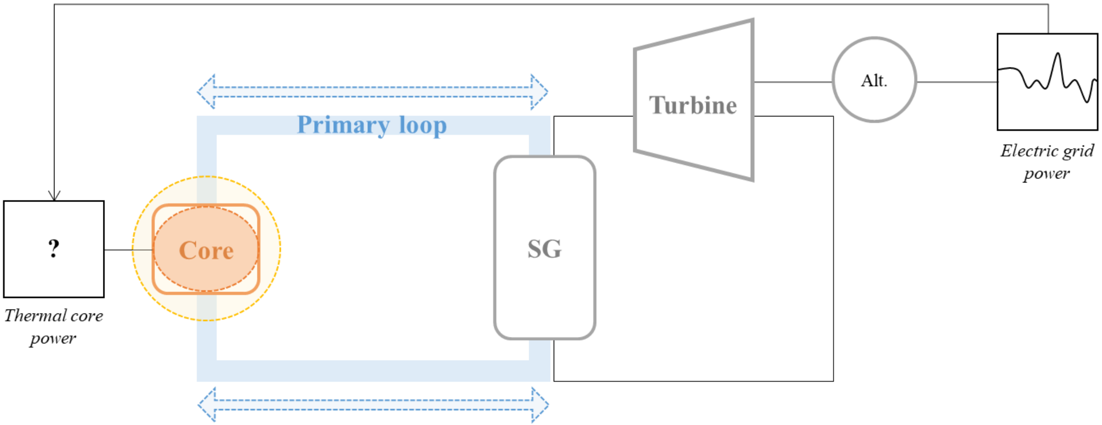
OBJECTIVES OF THE STUDY

- <u>Goal:</u>
  - Build a simple NPP model capable of reproducing frequency transients as much as possible
  - Deduce ways to study more flexibility in the design of the reactor model

  → Observe the behaviour of a reactor and the analysis of variables of interest during power transients imposed by the electrical network.
  - Modelling must be easily editable
- <u>Assumptions:</u>
  - Normal operation and close to the nominal operating point (100%Pn)
  - One simplified regulation is taken into account (instead of 2), therefore only transients described as follow will be considered:
    - Electric power ramps greater than 5%Pn/min (maximal nuclear power ramp)
    - Larger variation magnitude than 2,5%Pn (current primary frequency magnitude)

- Model of a 1300 MW PWR
- Limit condition : SG power linked directly to electric power

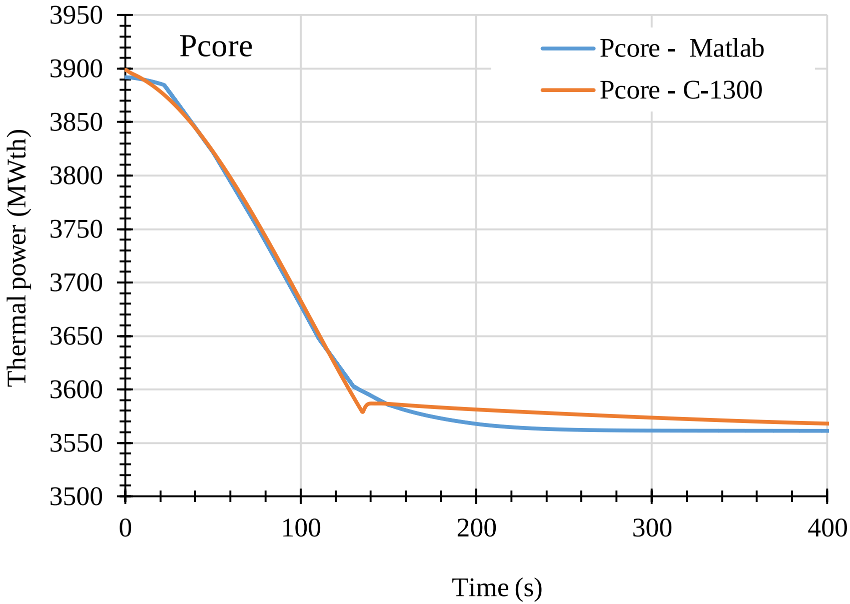
Neutronic point kinetic
Enthalpy balances
Thermal inertia



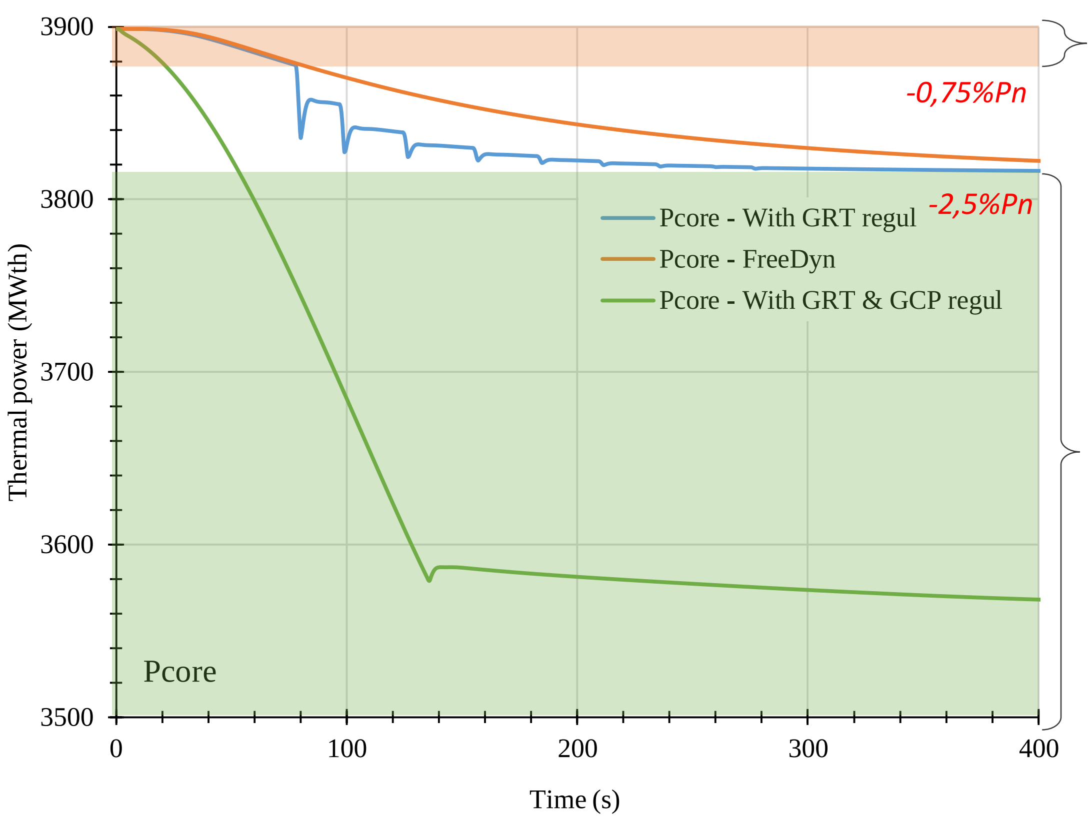
- Simplified regulation

VALIDATION

- With C-PWR-1300 from Corys : academic simulator
- High magnitude transient // load following :
  -10%Pn with *5%Pn/min* maximal power ramp



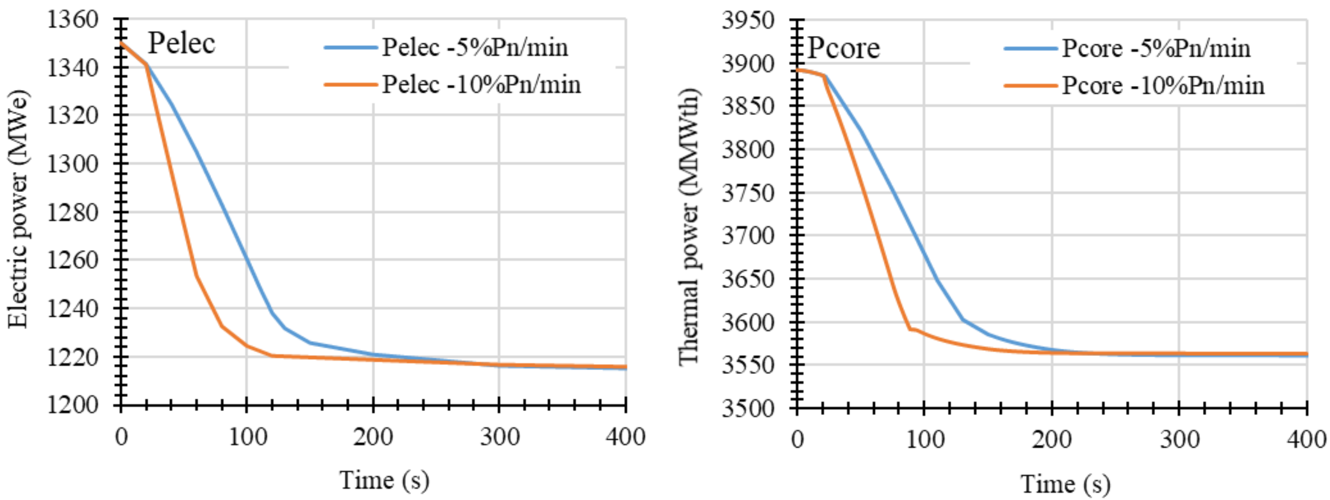
- *Free dynamic is also validated*



Free dynamic

Simplified regulation

- Higher ramp as input : *-10%Pn/min* and compared to the reference case *-5%Pn/min*



- Core response is accelarated
- But some safety parameters may be degraded because gradients are stronger

SENSITIVITY STUDY - CARACTERISTICS

- Objectives of the study*:*
  - Modifiy some parameters of the design
  - Quantify the impact on the model thanks to indicators

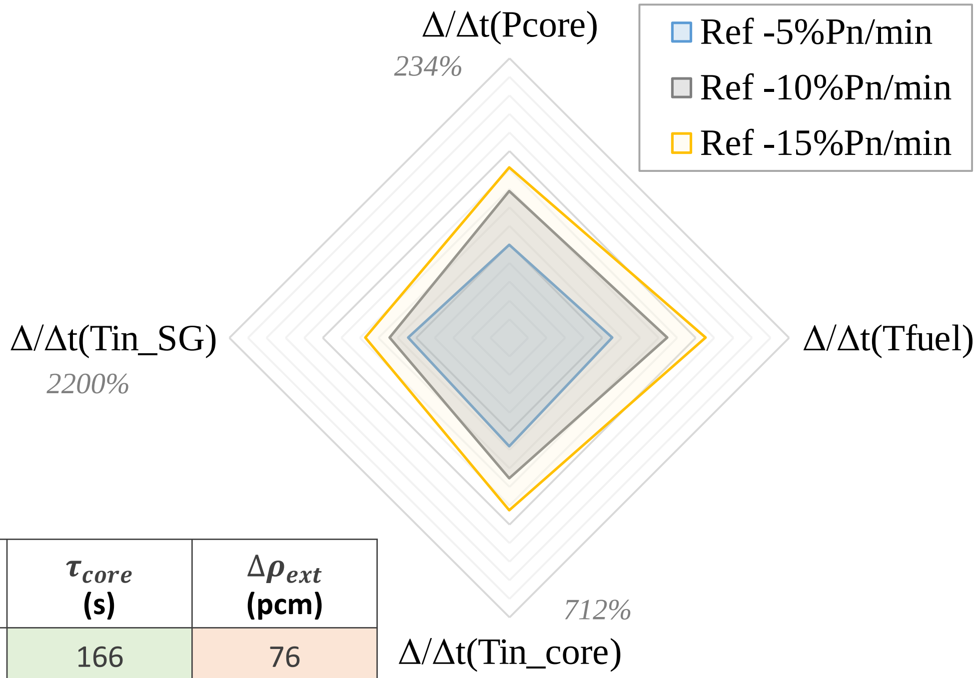
- Parameters*:*
  - Neutronic
  - Thermohydraulic
  - Control

→ *Time delay of the entire primary loop τ*

- Indicators*: safety, performance and control use (normalization is done)*

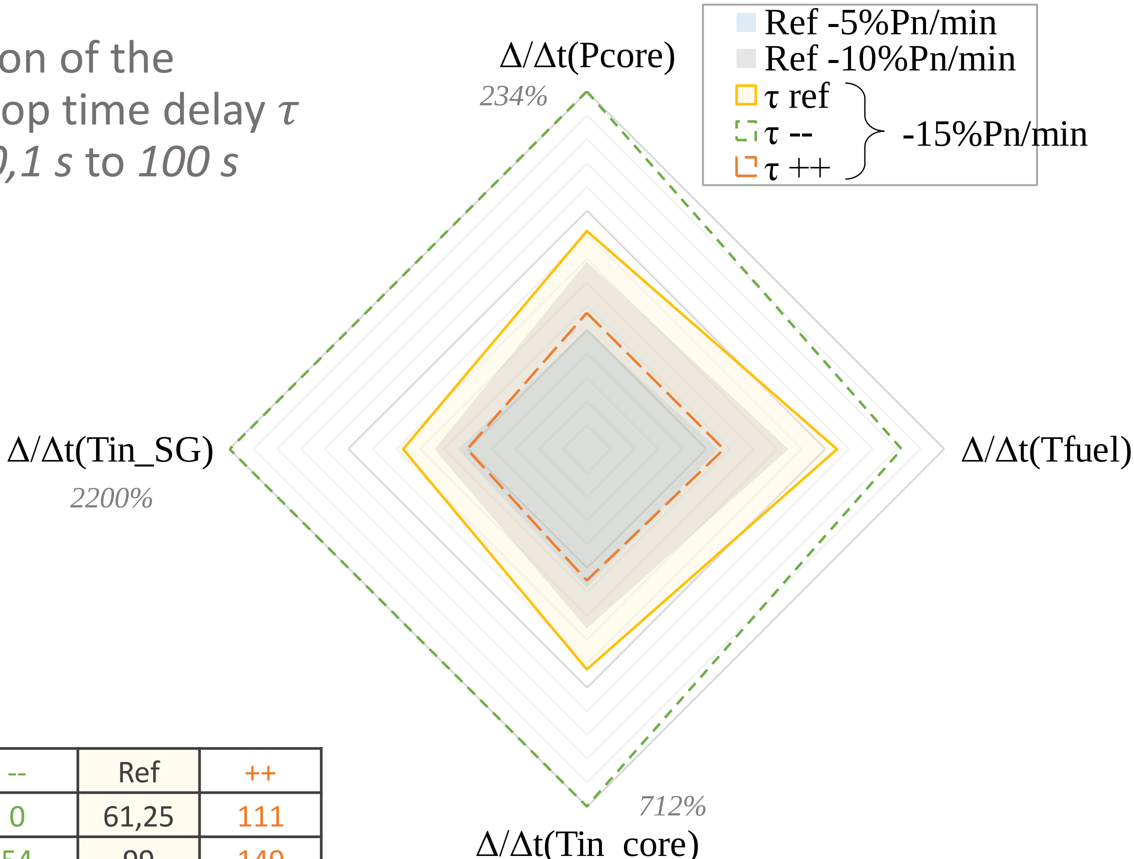
Factors	Unit	Factor's definition	Impacted domain
$\frac{\Delta}{\Delta t} P_{coeur}$	*MW/s*	Core power gradient averaged over 1 sec	Core performance
τ_{coeur}	*s*	Response time at 95% of core power i.e. time after which the core power has reached 95% of its final value	Core performance
$\frac{\Delta}{\Delta t} T_c$	*°C/s*	Fuel temperature gradient averaged over 1 sec	Safety of the core
$\frac{\Delta}{\Delta t} T_{e_{GV}}$	*°C/s*	Core inlet temperature gradient averaged over 1 sec	Safety of the steam generator
$\frac{\Delta}{\Delta t} T_{e_{coeur}}$	*°C/s*	Steam generator inlet temperature gradient averaged over 1 sec	Control rod use
$\Delta\rho_{ext}$	*pcm*	Maximum amplitude of reactivity inserted or withdrawn by the power control	Control rod use and associated safety

- Reference model with higher ramps



		τ_{core} (s)	$\Delta\rho_{ext}$ (pcm)
Current case	**-5%Pn/min**	166	76
Stressed ramp	**-10%Pn/min**	113	68,5
Stressed ramp	**-15%Pn/min**	99	61,25

- Modification of the primary loop time delay τ between *0,1 s* to *100 s*



τ (s)	--	Ref	++
$\Delta\rho_{ext}$ (pcm)	0	61,25	111
τ_{core} (s)	54	99	149

- Building of a simple PWR model capable of simulating frequency control transients driven by the input data *%Pn/min (*from power system)
- Possibility to modify some design parameters (example of τ)
- These parameters have impact on safety, flexibility, control use
- Part of a global approach at the interface of power system & nuclear design
- Perspectives :
  - Sensitivity of different parameters simultaneously in order to find a better compromise between perfomance / safety / control use
  - Towards the use of this model for other core designs
  - Coupling of the model with electric power system dynamic simulation software

THANK YOU FOR YOUR ATTENTION !

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