System Architecture for Actuator Management in ITER PCS

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ASDEX Upgrade

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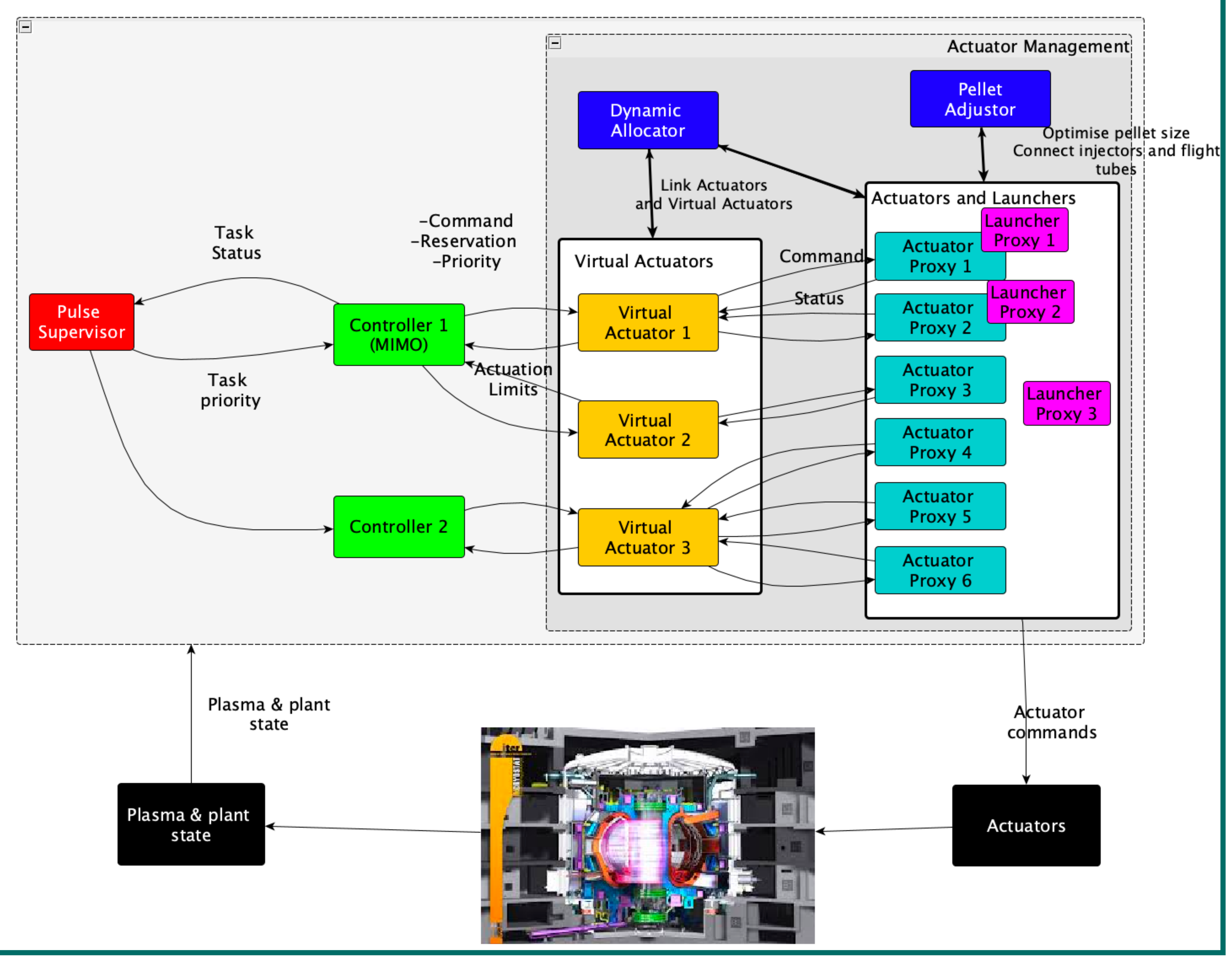
ITER SRO: Control Needs and Actuators

- H-mode at half I_p half B_t, L mode at full B_t and I_p
- Control comissioning is a key aspect of the research plan
  - Magnetic control: plasma current, position, shape
  - Heating and NTM control, sawteeth control
  - Fueling, detachment control and ELM pacing
  - Error field control
- Installed actuators:
  - PF coils, central solenoid, CC coils, in-vessel coils
  - **48 gyrotrons on 9 moveable mirrors**
  - **1 ICRH antenna**
  - **60 gas valves**
  - **4 pellet injectors**

Orchestration by Actuator Management

Actuator Management: Role and Basic Structure

- **Interface actuators and controllers**
  - Combine actuation amplitude
  - Increase robustness against actuator trips
  - Avoid/handle conflicting request
- Core component: **Virtual Actuator (VA)**
  - Set of actuators with comparable impact on plasma and command distribution (power, gas flow, pellet fire, deposition location command)
  - One Virtual Actuator per one controller output channel
- **Extension 1:** Dynamic changes of actuator role and properties by its allocation to different VA
  - Primarily ECH mirrors that are turned to point to different location (e.g. central heating to NTM control)
  - Extendable to other actuator types
- **Extension 2**: Actuator properties optimization associated with downtime
  - Pellet injection properties: **flight tube change**, pellet size change
  - Not foreseen to be relevant for other actuator type
- Non-overlapping use cases => treat them with different components: **Dynamic Allocator** and **Pellet Adjustor**



Architecture extensions

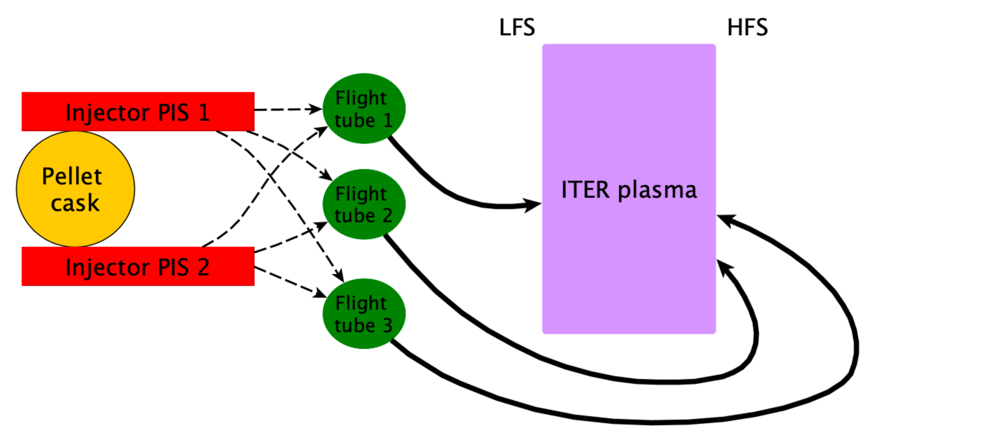
- The Dynamic Allocator/Pellet Adjustor decide based on:
  - **Priority, resource reservation and purpose** (e.g. local or bulk heating) of the task the VA serves to
  - **Suitability of each actuator for the purpose of VA**
- The decision strategies are configurable for both components
- For each VA, the **resource allocation status** is output for PSC:
  - **Fully Satisfied**: the VA has what it needs
  - **Resource shortage**: Resources for VA not available

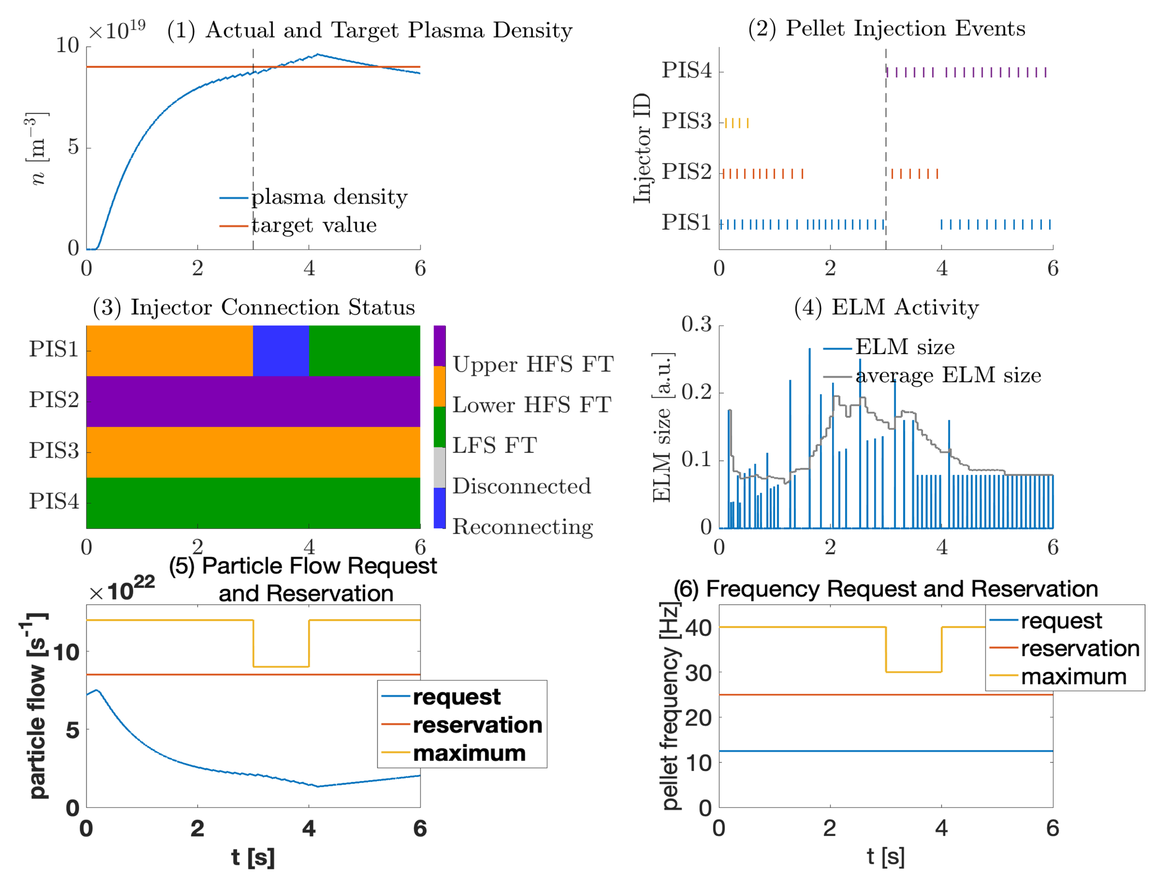
Example 1: Optimisation of pellet injector-flight tube connection

- 4 pellet injectors connectable to 6 flight tubes
- Pellet virtual actuator deals with both **fueling** and **ELM pacing**
  - **Pacing**: small LFS pellets
  - **Fueling**: large HFS pellets
- **Illustrative physics models**:

$$\frac{dn_e}{dt} = -\frac{n_e}{\tau} + c(size, inj.point) \cdot \Gamma_{pel}$$

- **Probabilistic ELM triggering**, LFS pellets have higher prob. to trigger ELM's
- **Initial settings optimised for fueling**: 3 HFS flight tubes, 1 LFS flight tube
- **At 3 s, pacing becomes more important than fueling**
- **PIS1 is connected to LFS flight tube** to improve system performance for pacing
  - **ELM size control improved**



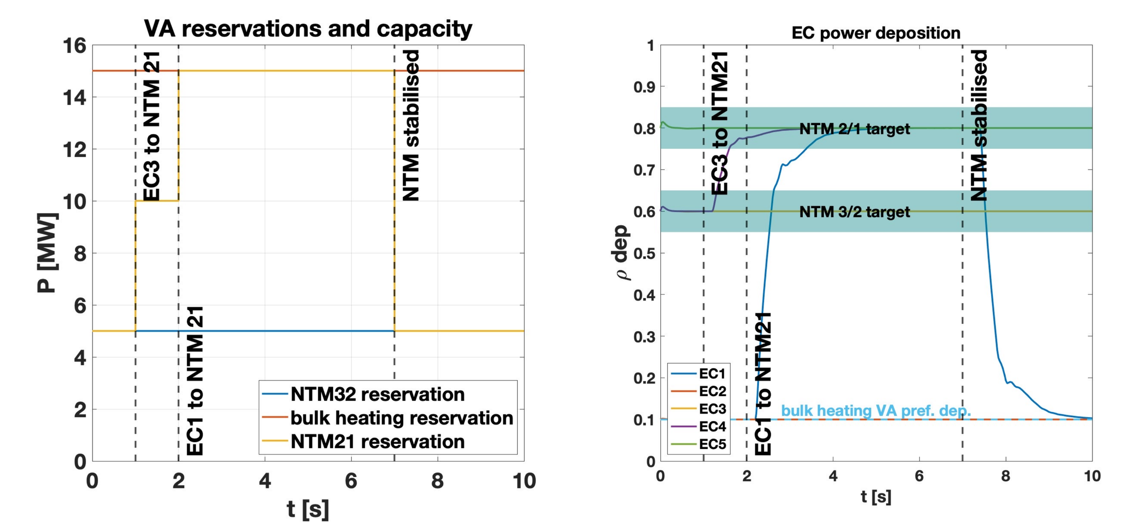


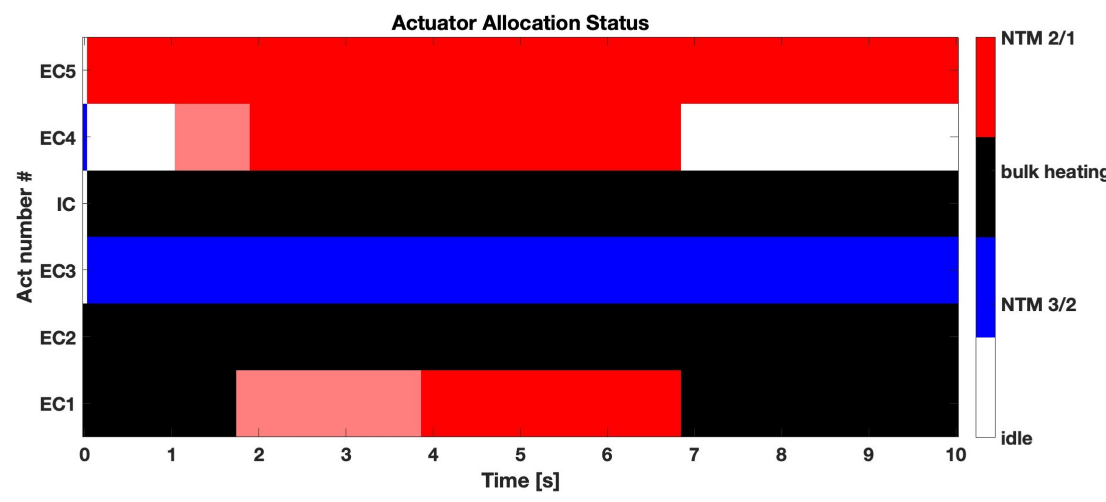
Example 2: Dynamic allocation of the ECH mirrors

- **Tasks:** NTM 2/1, NTM 3/2, bulk heating
- **Actuators:** 5 moveable EC mirrors between rho 0.1 and 0.9, 1 IC antenna, each 1 MW

Virtual Actuator	Priority	Reservation	Initial Allocation	Requested Deposition Location
Bulk Heating	0.2	15 MW (3 act)	IC, EC1, EC2	preferred at $\rho = 0.1$
NTM 3/2	0.5	10 MW (2 act)	EC3, EC4	$\rho = 0.6 \pm 0.05$
NTM 2/1	1.0	5 MW (1 act)	EC5	$\rho = 0.8 \pm 0.05$

- **Strategy:** full satisfaction of VA's associated with the most important tasks
- **Scenario:**
  - **t = 0 s**: NTM 3/2 stabilized, reservation reduced
  - **t = 1 s**: NTM 2/1 appears, reservation increase, idle actuator EC4 assigned
  - **t = 2 s**: NTM 2/1 still grows, EC1 taken from bulk heating to stabilize NTM 2/1
  - **t = 7 s**: NTM 2/1 stabilized, EC1 returned to bulk heating, EC4 used as backup





Conclusions and Outlook

- Architecture of the Actuator Manager extended by rule based algorithms to:
  - Dynamically **change the purpose of an actuator** by allocating it to different VAs
  - Dynamically **adjust pellet injector-flight tube connection** to optimize performance for fueling/ELM pacing
- Replace rule-based algorithms with cost-function minimization-based algorithms that are **rock-solid RT compatible**!
  - Known worse case scenario: Deterministic highest number of operations to find optimal/good enough solution
  - The worst case must be feasible within ~ 10 ms
  - Problem size: **15 actuators** (11 EC mirrors, 2 IC antennas, 2 NBI's), **6 virtual actuators** (1 for bulk heating, 2 for profile control, 2 for NTM control, 1 for backup)
- Possible algorithms:
  - **Brute force**: no-go for the problem size, $6^{15} \sim 5 \cdot 10^{11}$
  - **Quadratic Integer Programming**: iterative, hard to guarantee the maximum number of operations
  - **Linear Integer Programming**: deterministic maximum number of operations, formulating the problem as linear is non-trivial

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