SYSTEM ARCHITECTURE FOR ACTUATOR MANAGEMENT IN ITER PCS

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ITER is the world's largest tokamak, currently under construction in the south of France. Its objective is to generate 500 MW of fusion power for up to 500 seconds while achieving a fusion gain of Q = 10. Plasma pulses will be controlled by the Plasma Control System (PCS), utilizing several heating, fueling, and magnetic actuators to regulate many plasma parameters [1]. A critical component of the PCS is the Actuator Manager (AM), which coordinates actuator operations to enhance the system's flexibility and robustness. This contribution will present the AM architecture, which has been considered by the ITER Organization for implementation in the PCS. Actuators with similar effects on plasma are dynamically grouped into "virtual actuators," allowing controllers to manage them as single entities [2]. Another key function of the AM is the real-time optimization of actuators to maximize their efficiency. This is particularly relevant for pellet injectors, which can dynamically adjust pellet size. The PCS development follows a flexible strategy that enables continuous optimization throughout the project's evolution. In alignment with this approach, each PCS component is designed to fulfill requirements in a specific stage of ITER operation and undergoes integrated testing for that phase. Lessons learned from these tests are used to refine each component for subsequent operational stages [3]. This contribution details the AM architecture for the Start of Research Operation (SRO) phase [4].

During the SRO phase, ITER is expected to achieve a plasma current of 15 MA with a toroidal field of 5.3 T in L-mode and demonstrate H-mode operation with a plasma current of 7.5 MA and a toroidal field of 2.65 T. The system will utilize 40 MW of ECRH heating delivered through nine movable mirrors, one ICRH antenna providing 10 MW of power [5], and four pellet injectors with adjustable pellet sizes, which can be directed through various flight tubes. First, heating and fueling actuators must be carefully coordinated to ensure the correct initiation, maintenance, and termination of H-mode. Second, instability control must be demonstrated and optimized. For example, neoclassical tearing modes (NTMs) will be stabilized using ECRH power from the movable mirrors, while edge-localized modes (ELMs) will be mitigated or paced through a combination of resonant magnetic perturbation (RMP) coils and pellet pacing. The AM will serve the following purposes:

1. Orchestrate the high-level requests from controllers into specific individual actuator commands in such a way that conflicts are avoided
2. Dynamically allocate resources to the control tasks based on their evolving needs and their priority provided by the pulse supervisor.
3. Optimize actuator properties in real-time to match their purpose, for example by taking a pellet injector out of operation for some time to change the pellet size.

The objectives of the AM, as outlined above, are achieved through a flexible architecture, schematically represented in Figure 1. Controllers associated with specific control tasks issue their commands and resource requests to their respective **Virtual Actuators** (VAs). The virtual actuators then distribute the aggregated commands among the **Actuator Proxies**, which serve as generic representations of the real actuators which includes an adapter to the individual actuator types. In cases where the connection between an actuator proxy and its launcher is not fixed—such as with pellet injectors and their flight tubes—the actuator proxy is extended with a **Launcher Proxy**, which represents the launcher it utilizes. These elements form the "ground level" of the AM architecture.

Two higher-level components address additional use cases. The first, the **Dynamic Allocator**, adjusts actuator proxy membership within a virtual actuator based on plant and plasma conditions using a configurable strategy. For example, if an NTM appears, this component can allocate additional resources to the NTM controller. In practice, this means that some ECH actuators will be reassigned to another virtual actuator, and the mirrors will be adjusted to align their power deposition location with the NTM position. Once the alignment is complete, the ECH actuators' power will be available to the NTM controller.

The second component, the **Pellet Adjustor**, is specifically designed for pellet injectors and their flight tubes. No other actuator can be adjusted in the way described. It focuses on optimizing injector properties during a pulse, which involves actuator downtime but does not change virtual actuator (VA) membership. Each pellet injector can be connected to a different flight tube or adjust the pellet size, enhancing efficiency for fuelling and ELM pacing. However, this optimization comes at a cost: flight tube reconnection requires 1 second of downtime, while changing the pellet size results in a downtime of 3 to 30 seconds.

The key distinction between the Dynamic Allocator and the Pellet Adjustor is the impact on availability. The Pellet Adjustor introduces unavoidable downtime, during which the injector is out of operation and cannot be accessed, even in urgent situations. In contrast, actuators reassigned by the Dynamic Allocator remain available at all times, even if they are temporarily repurposed.

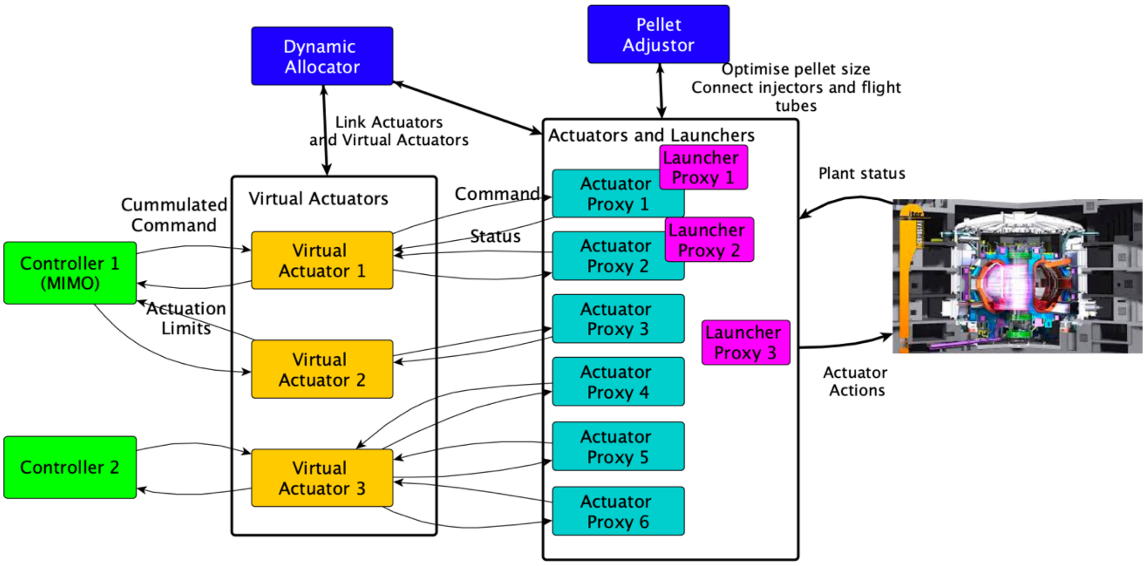

Figure 1: *Schematic representation of components on the actuator management and their prospective controllers.*

This contribution will outline the architectural design choices, along with their underlying physics and technical motivations. Currently, most of the aforementioned elements have been implemented in the Plasma Control System Simulation Platform (PCSSP) and are actively used in the design of ITER's heating, fuelling, edge-localized mode (ELM), and neoclassical tearing mode (NTM) control systems. The contribution will detail examples from these areas.

References:

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