FPGA acceleration of Model Predictive Control for ITER Plasma current and shape control

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Overview

- Plasma Current and Shape Controller (PCSC) for ITER
- Singular Value Decomposition (SVD)-based Model Predictive Control (MPC) using a dual Fast Gradient Method (dFGM) quadratic programming (QP) solver
- FPGA acceleration with a High-Level Synthesis (HLS) approach
MPC online optimization problem

- **MPC Quadratic Program** – hard input and soft state constraints

\[
\begin{align*}
\min_{z,s} & \quad \frac{1}{2} z^T H z + c^T z + \frac{1}{2} s^T W s + w^T s \\
\text{subject to } & \quad c_x z \leq b_x + s \\
& \quad c_u z \leq b_u \\
& \quad s \leq 0
\end{align*}
\]

- **Dual Fast Gradient Method**

\[
v^k = v^k + \beta^k (v^k - v^{k-1}) \\
y^k = -H^{-1}(c^T v^k + c) \\
v^{k+1} = v^k + Cy^k - \text{prox}_{h,w,w}(v^k + Cy^k)
\]

\[
\text{prox}_{h,w,w}(t) = \begin{cases} 
    t_i & \text{if } t_i \leq b_i \\
    b_i & \text{if } t_i > b_i \text{ and } i \text{ hard} \\
    t_i + W_{ii} b_i - w_i & \text{if } b_i + w_i \geq t_i > b_i \text{ and } i \text{ soft} \\
    \frac{t_i}{W_{ii} + 1} & \text{if } b_i + w_i < t_i \text{ and } i \text{ soft}
\end{cases}
\]

Iterative algorithm
Microparallelization
(matrix-vector multiplication within iterations)
Several approaches to speeding up M*v multiplication

**TL;DR:** Speed-up via HLS achieved but not automatically