Real-Time Modeling and Analysis of Electromagnetic Transients of “Large” Power Systems (Hardware-In-the-Loop Applications)

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Presentation Layout:

- **Introduction to the analysis of electromagnetic transients (EMTs) in Power System**
- **Real-Time (RT) Analysis of EMTs**
- **Applications**
- **Limitations**
- **State-of-the-Art Real-Time Simulator Technology**
- **Future Trends**

Introduction

Applications of Electromagnetic Transients Analysis Tools:

- **analysis, design and performance evaluation of protection systems**
- **analysis and performance evaluation of control systems**
- **analysis, design and performance evaluation of Equipment**
- **identification of dynamic and interactions phenomena**
- **system performance evaluation and characterization**

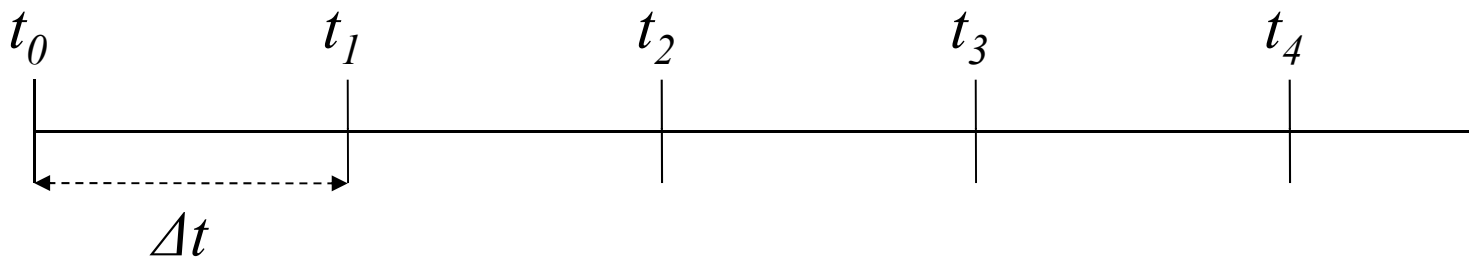
Introduction

Analysis of Electromagnetic Transients:

- **Model: nonlinear differential-algebraic equations**
- **Solution: step-by-step numerical integration, (1st-order) trapezoidal integration method**

Power System Simulation

- **trapezoidal numerical integration**



Digital Simulators

Off-line Simulation

$t_c > \Delta t$

Real-time Simulation

$t_c \leq \Delta t$

Off-line (non-real-time) simulation platforms

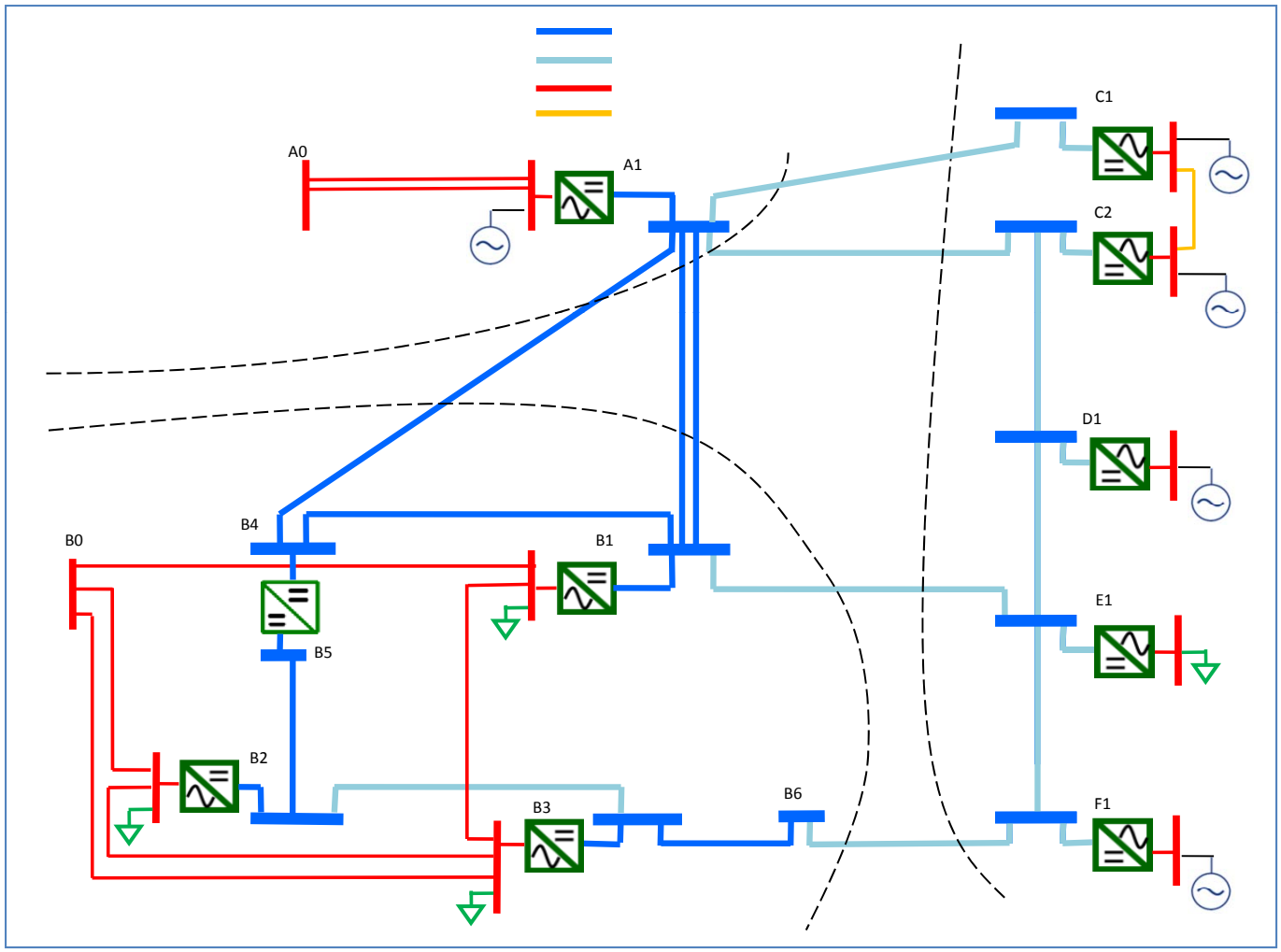
- **Features**
  - **frequency bandwidth (0 to 2-MHz)**
  - **high-accuracy**
  - **inexpensive**
  - **wide array of verifies component models**
  - **hybrid simulation environment**
  - **multi-platform interface capability**

- **Limitations**
  - **slow (realistic-size power systems)**

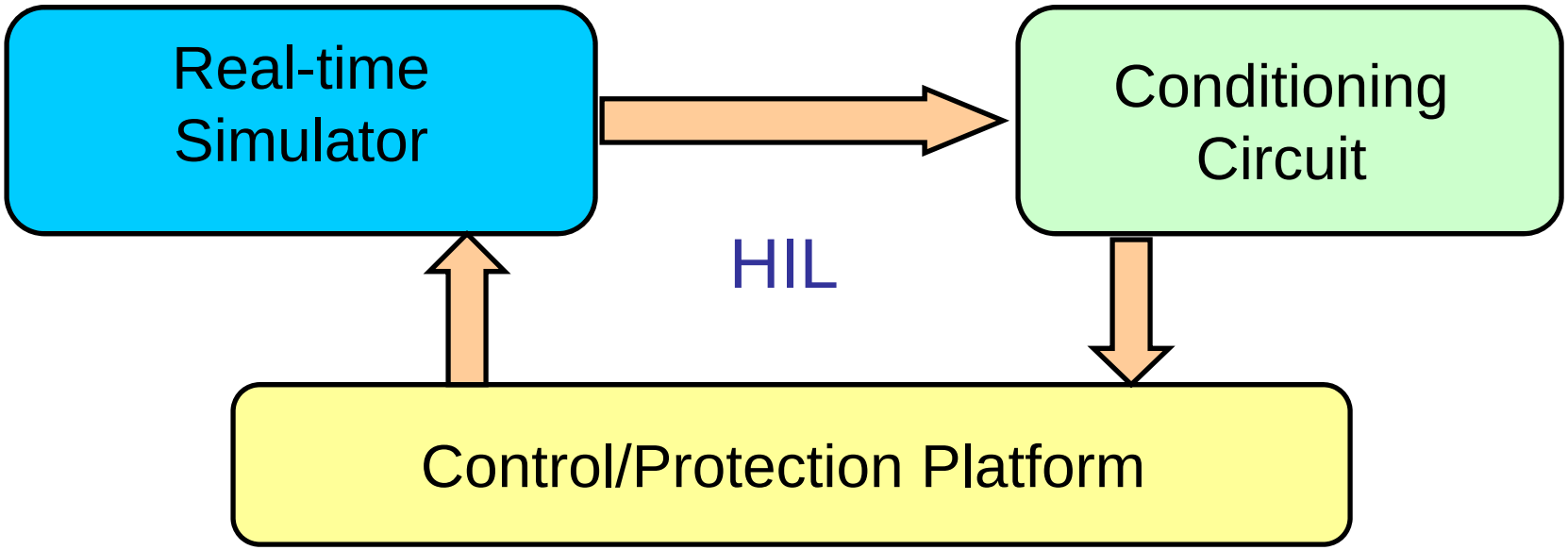
Reasons for Excessive Computational Time of Off-Line Simulation:

- high number of switch-mode converters
- emergence of converter configurations with high number of switches (4000-6000 switches in a MMC)
- Emergence of sub-systems that include hundreds of switching devices and nonlinear controls (wind and solar-PV power plants)
- components/algorithms that tightly couple low- and high-frequency dynamics (phase-locked loops)
- operational conditions/requirements that tightly couples low- and high-frequency dynamics (transient ride-through capability)

CIGRE B4-58 VSC-HVDC grid test system



Structure of Control Hardware-in-The-Loop (CHIL) Real-Time Simulators:

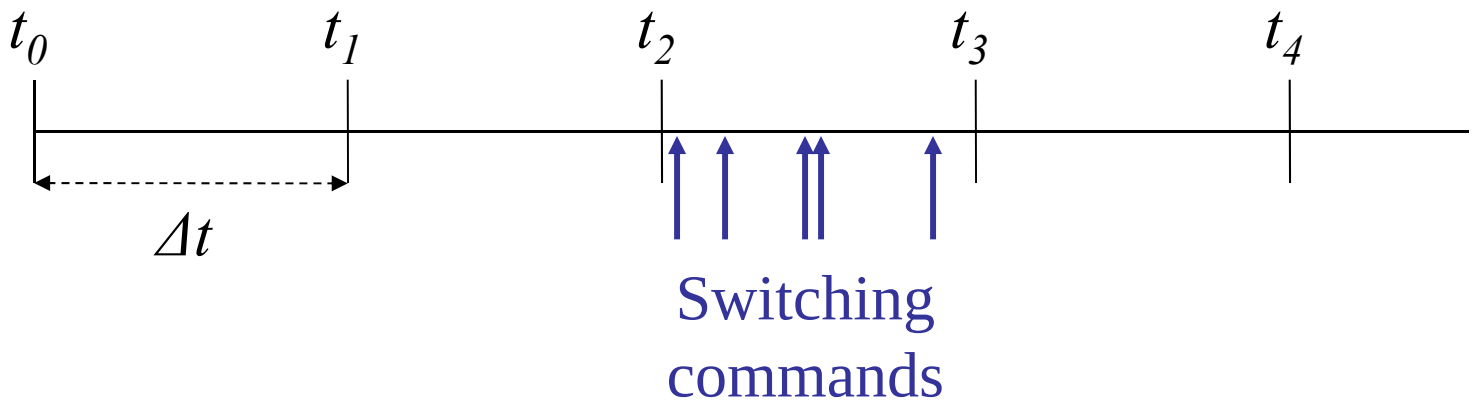


Structure of Exisiting Real-Time Simulators for CHIL:

- Architecture is based on parallel processors
- General Purpose Processors (GPP) or Digital Signal Processors (DSP), or computer clusters are utilized
- Equations are distributed among the processors to reduce the computational time to achieve real-time calculation
- The minimum simulation time-step depends on:
  - Speed and the number of processors
  - Communication and synchronization overhead time
  - Efficiency of the software Code

Limitations/Challenges of Processor-based RTS for HIL Applications

- **ITS and MITS problems**

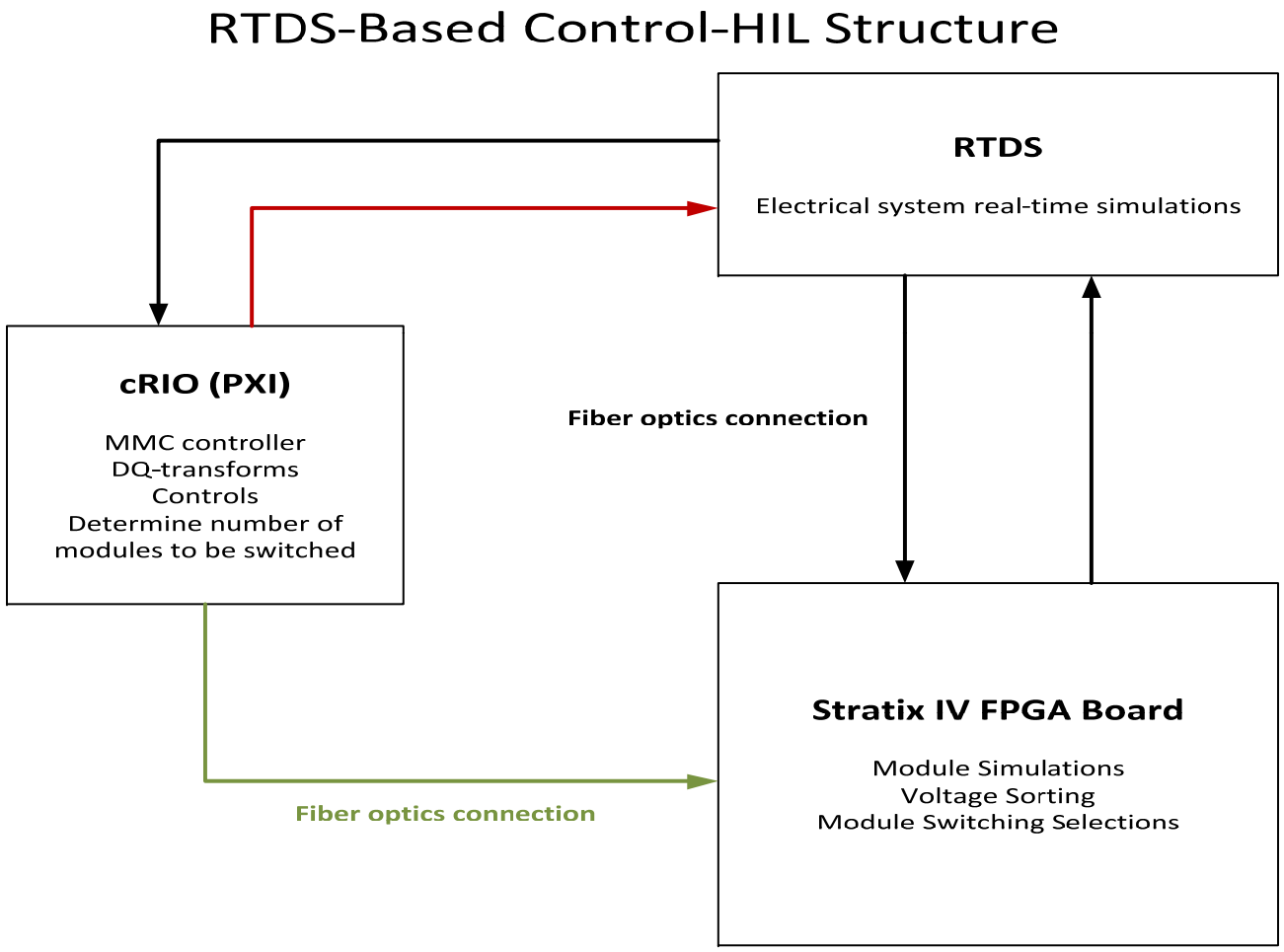


MITS Practically limiting real-time simulations to converters with switching frequency of up to ≈ 1 kHz

Methods to enable existing Real-Time simulators for large (realistic) size systems applications:

- Augmentation of processor-based simulation platform with production-grade FPGA boards
  - availability of production-grade platforms (+)
  - wide array of verified apparatus models (+)
  - availability of user support (+)
  - limited accuracy (-)
  - expensive for large (realistic) size applications (-)
- Development of FPGA-based structure band equivalent model(s) of sub-system(s)
  - no production grade platform (-)
  - relatively inexpensive (+)
  - high accuracy (speed) (+)
  - scalability (+)
  - hardware re-configurability (+)

Augmentation of RTDS by FPGA boards for the simulation of large systems



Red: May be removed if fiber optics RIO module is used

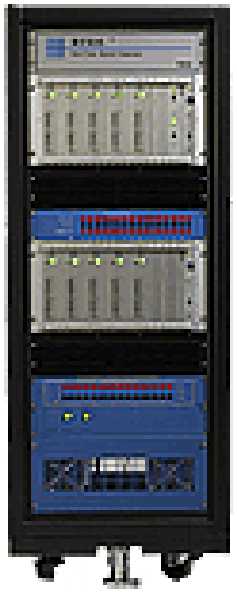
Green: May be added if fiber optics RIO module is used

Analog IO
AC side voltages
AC side currents
Circulating Currents
DC Voltage

Analog IO
Commanded voltage

RTDS

Electrical system
Generation of "On modules per arm" command



cRIO (PXI)

PLL
dq-transforms
MMC controller
PI controls (voltage, current, circulating currents)

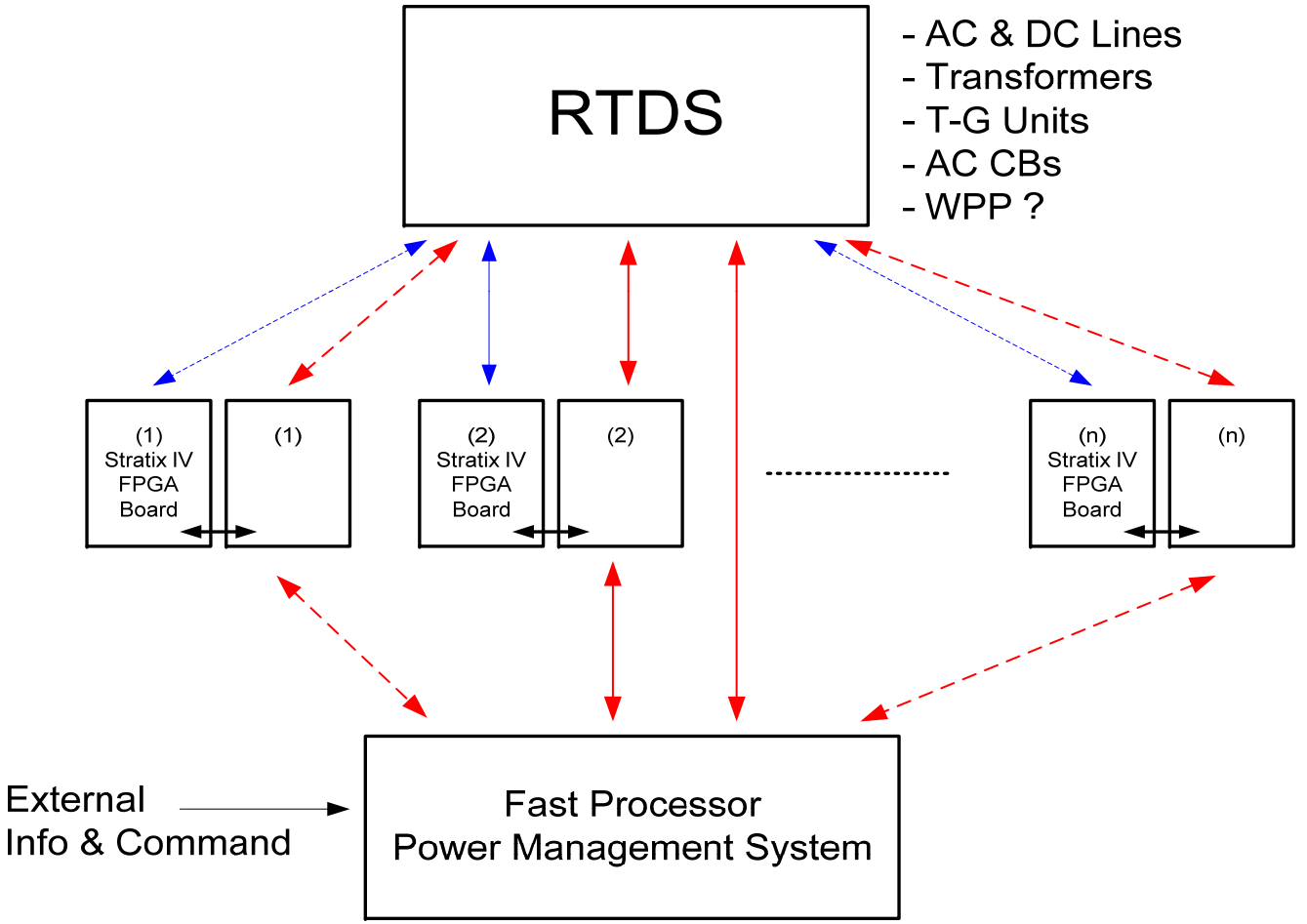
Fibre optics connection
Arm currents
On modules per arm

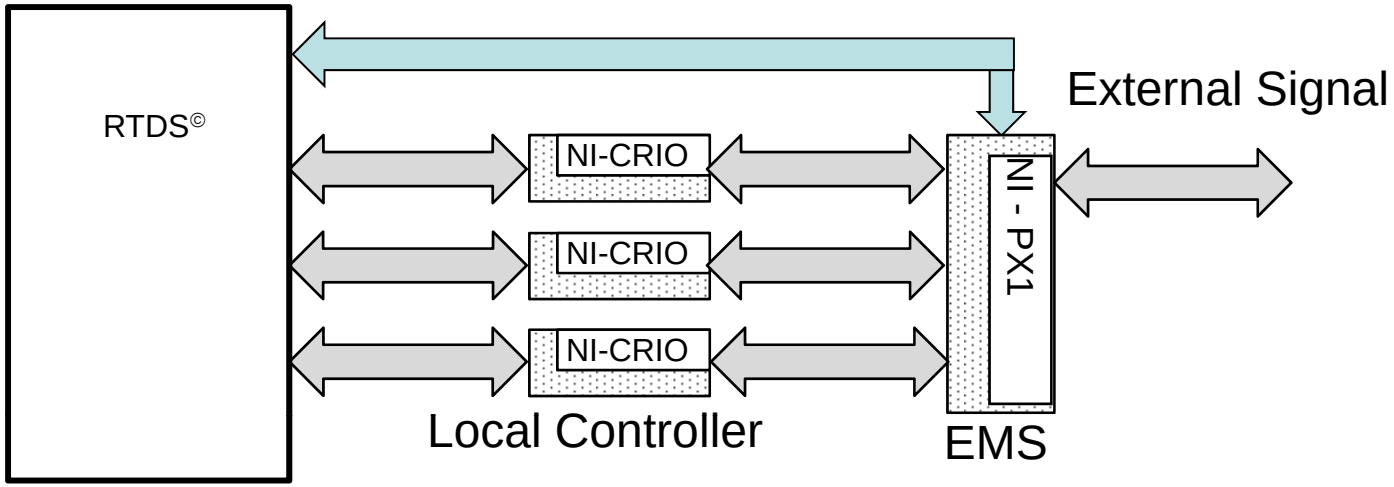
Fibre optics con
Arm Voltag

Stratix IV FPGA

Module voltage calculations
Module voltage sorting
Module switching selections

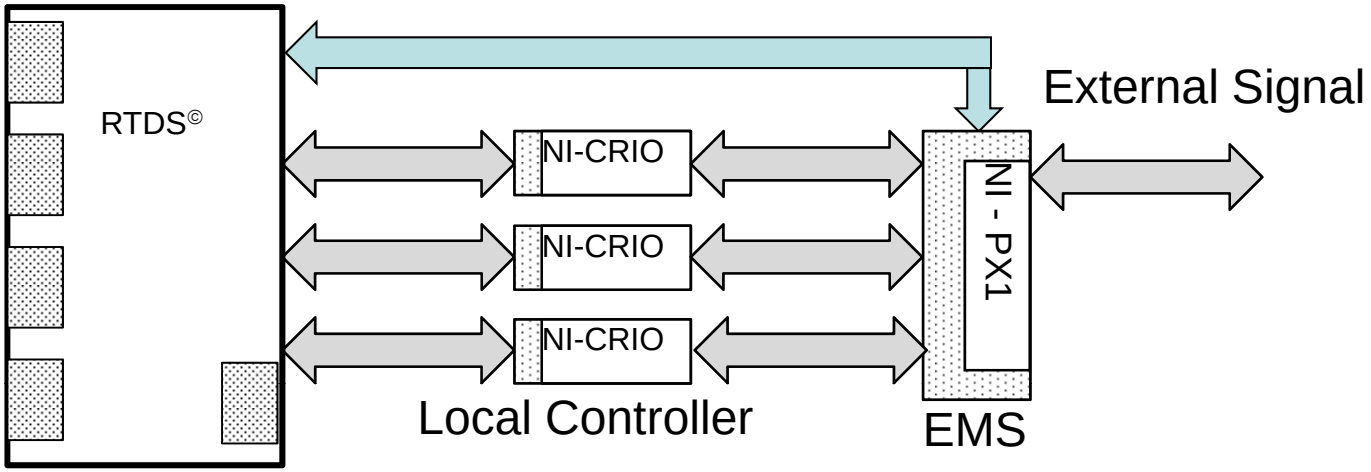
RTDS-based Control-HIL Real-Time Simulation Environment





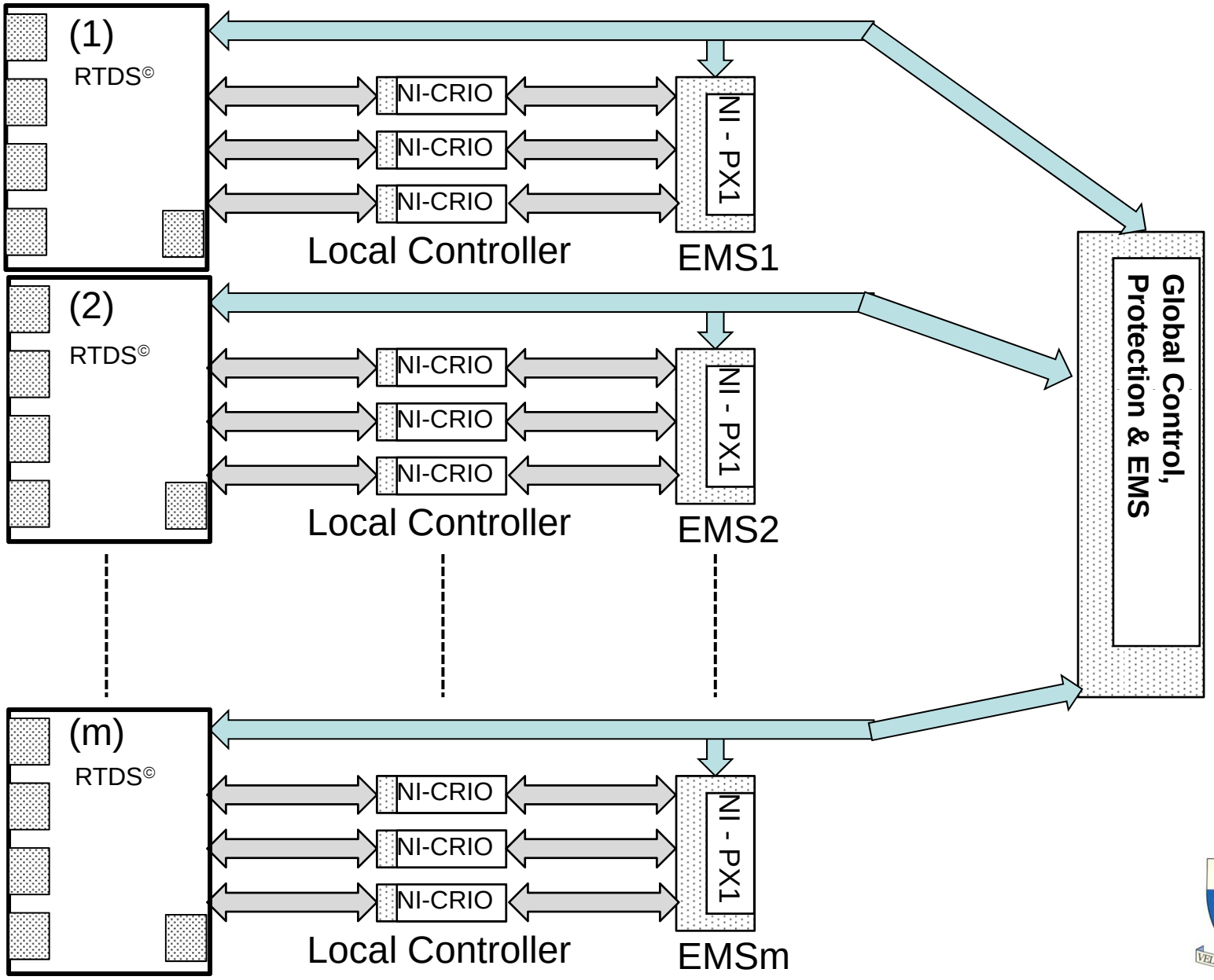
Existing Structure

Real-Time Hardware-in-the-Loop (HIL) Simulation Platform



Next-Generation

Real-Time Hardware-in-the-Loop (HIL) Simulation Platform


(1)
RTDS©
NI-CRIO
NI-CRIO
NI-CRIO
NI - PX1
Local Controller
EMS1
(2)
RTDS©
NI-CRIO
NI-CRIO
NI-CRIO
NI - PX1
Local Controller
EMS2
(m)
RTDS©
NI-CRIO
NI-CRIO
NI-CRIO
NI - PX1
Local Controller
EMSm
Global Control, Protection & EMS

Conclusions

- **Off-line software tools for the analysis of EMTs of “large” systems exhibit serious limitations due to the required computational time**

- **Real-time HIL simulation of the “large size” systems is feasible and the proof of concept has been demonstrated.**