CCLIBS The CERN Power Converter Control Libraries

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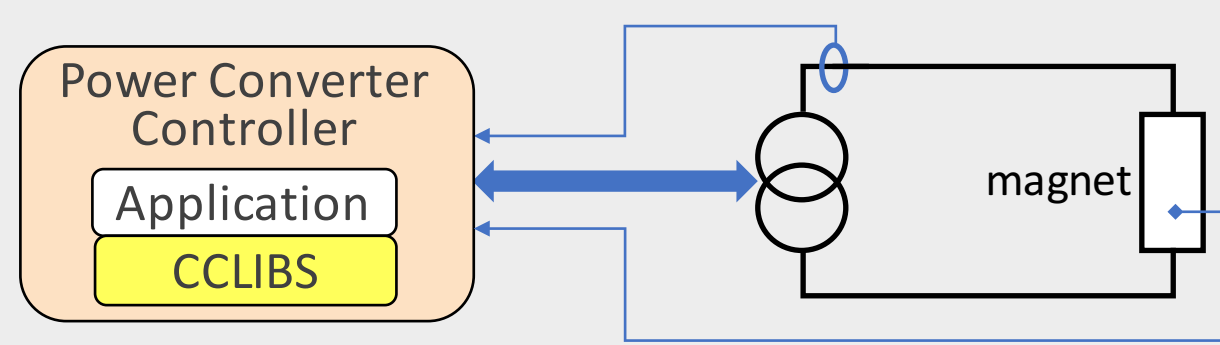
CERN

Introduction
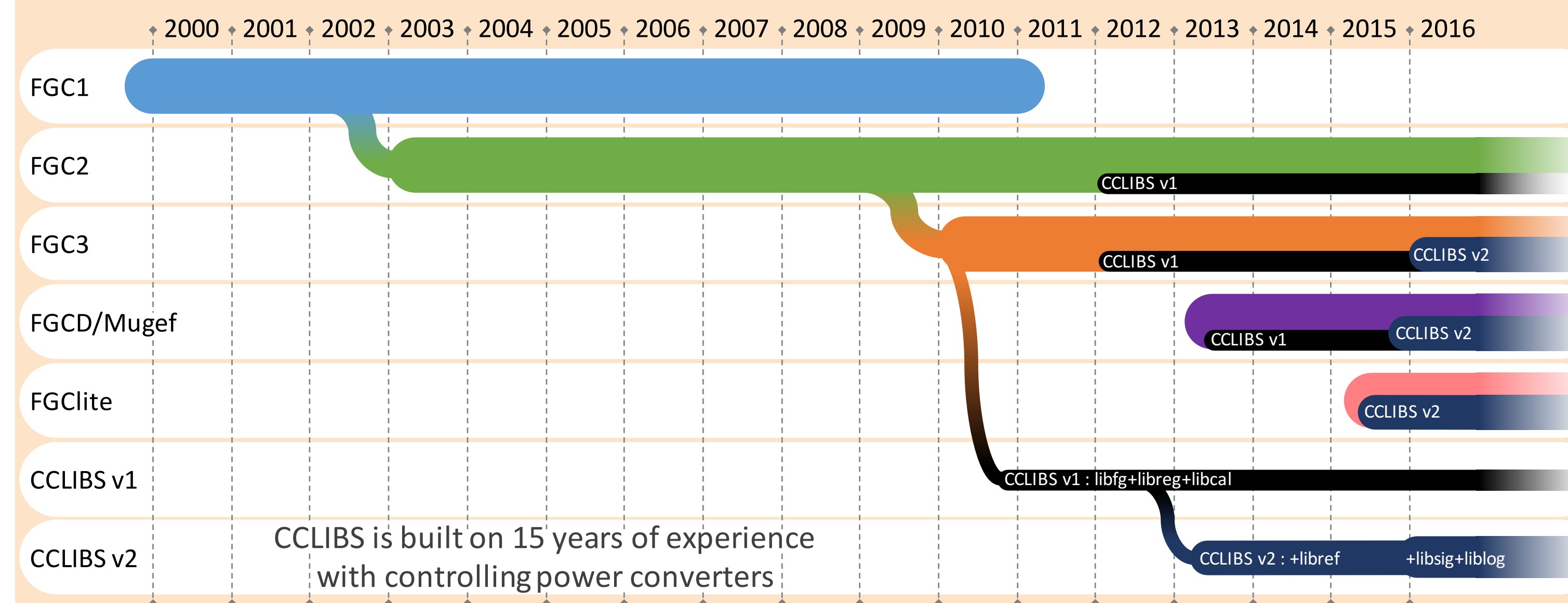
The CERN converter control libraries are a collection of libraries written in C, available under the GNU Lesser General Public License from https://github.com/cclibs.

Power Converter Controller
Application
CCLIBS
magnet

CCLIBS currently includes four libraries and two more will be added in 2016. Together they provide a rich set of features for the regulation of power converters in accelerators:

- **libsig** Measured signal management (*planned for 2016*)
- **libcal** ADC, DAC, DCCT, field and voltage probe calibration
- **libref** Reference manager
- **libreg** Current, field and voltage regulation
- **libfg** Function generation
- **liblog** Analog and digital signal logging (*planned for 2016*)

Road map for CCLIBS

2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

FGC1
FGC2 — CCLIBS v1
FGC3 — CCLIBS v1 — CCLIBS v2
FGCD/Mugef — CCLIBS v1 — CCLIBS v2
FGClite — CCLIBS v2
CCLIBS v1 — CCLIBS v1 : libfg+libreg+libcal
CCLIBS v2 — CCLIBS v2 : +libref +libsig+liblog

CCLIBS is built on 15 years of experience with controlling power converters

CCLIBS v1 at ICALEPCS'11

This poster focuses on the reference manager library, libref, which is new in CCLIBS v2.
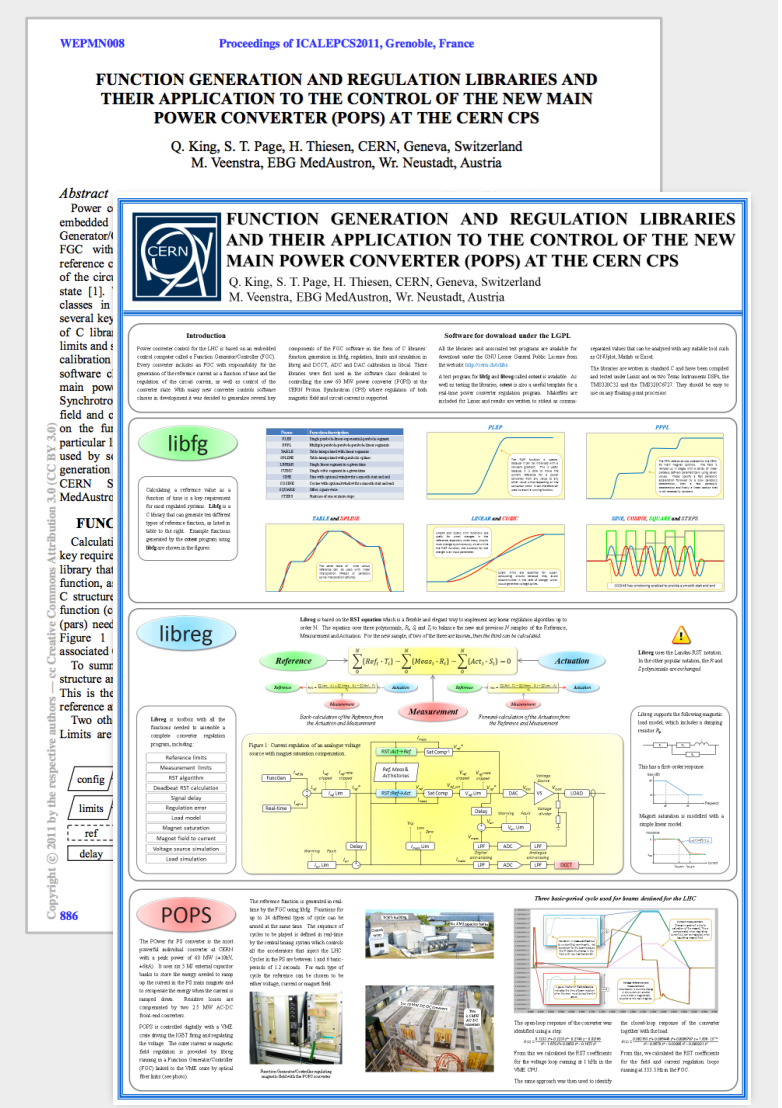
The function generation and regulation libraries, libfg and libreg, were already presented in a paper and poster at ICALEPCS 2011 (WEPMN008).

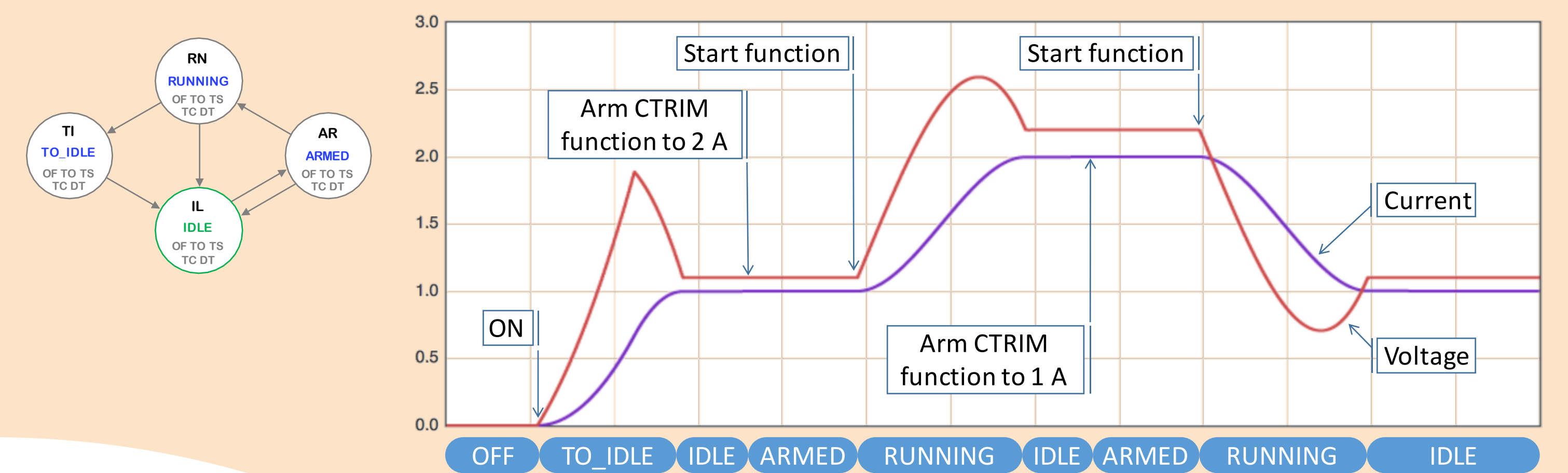Both libfg and libreg have been significantly improved in CCLIBS v2.

Cycling Reference Functions

Start cycle 1 Start cycle 2 Current
Voltage
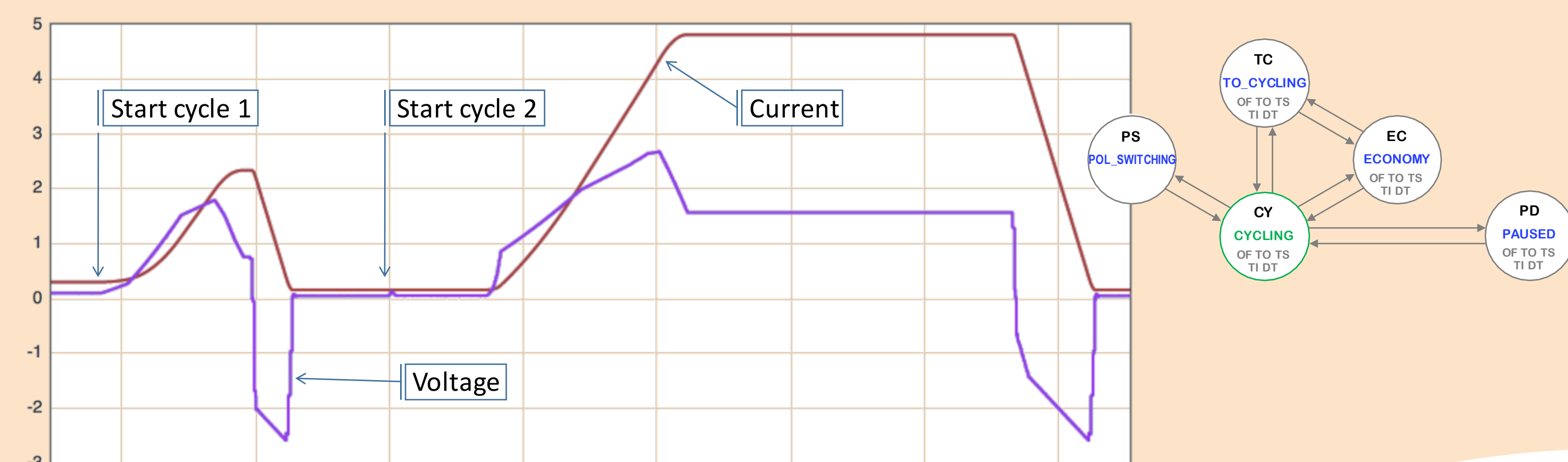
The CYCLING state is used for fast cycling accelerators. Reference functions are armed in advance. The real-time selection of functions is made by the timing system.

- The function can be suspended and resumed with timing events. It will wait in the PAUSED state.
- The CYCLING state can automatically perform a magnetic pre-cycle to improve magnetic reproducibility between cycles.
- An "economy" cycle with reduced RMS can run if no beam is injected, without affecting the next cycle magnetically.
- If a polarity switch is in use, it can switch automatically as required.

The DIRECT state allows the reference to be set at any time and is ideal for DC applications.

- The DIRECT state can automatically perform a magnetic pre-cycle to improve magnetic reproducibility.
- The DIRECT state can automatically perform a degauss cycle when arriving at zero (provided the converter is bipolar).
- If a polarity switch is in use, it can switch automatically as required.

Pre-cycle MAX
REF = -1 REF = +1 REF = 0
Pre-cycle MIN
Magnetic pre-cycle Degauss cycle

DIRECT Reference

Single-use Reference Functions

Start function Start function
Arm CTRIM function to 2 A
ON
Arm CTRIM function to 1 A
Current
Voltage

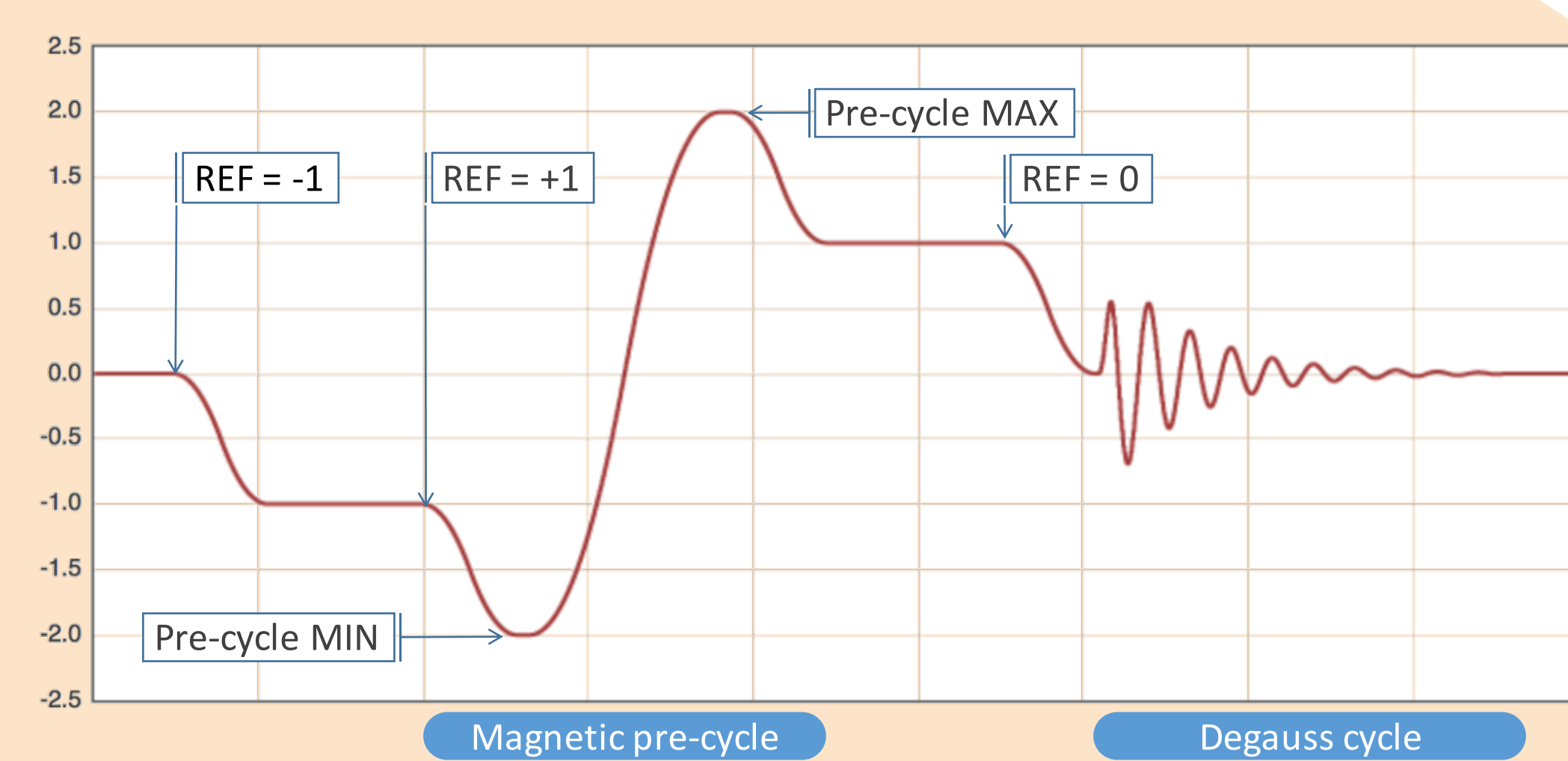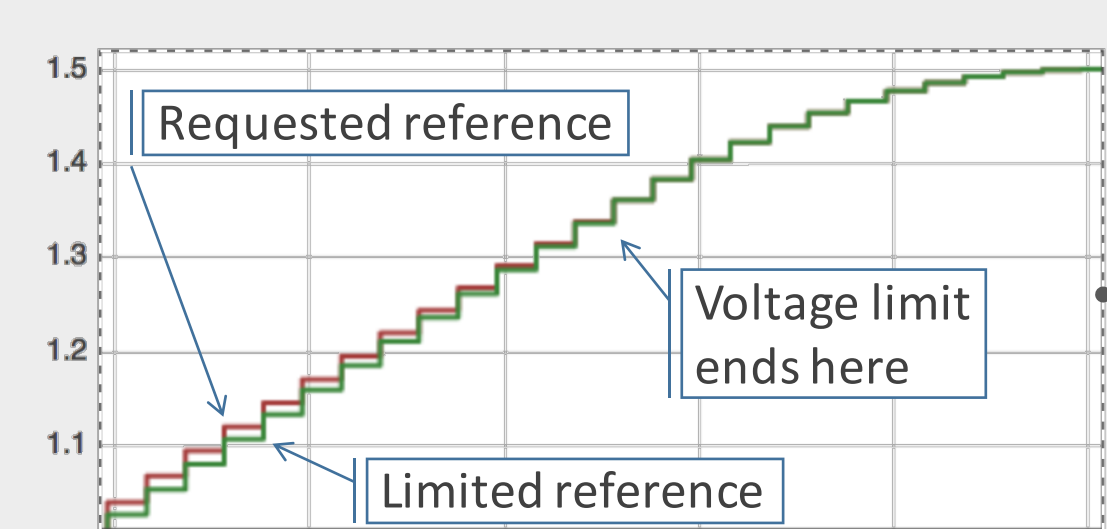OFF TO_IDLE IDLE ARMED RUNNING IDLE ARMED RUNNING IDLE

The IDLE, ARMED and RUNNING states are used by the CERN LHC converter controllers to run functions synchronously on demand.

- A function can be armed in the IDLE state, resulting in the state changing to ARMED.
- The new function must start from the actual reference.
- The armed function is started with a timing event and the state changes to RUNNING.
- The function is disarmed automatically on completion and the state machine returns to IDLE.
- The function can be aborted before the end by returning to TO_IDLE state.

Reference Manager State Machine

SB STANDBY OF TO TC TI DT
TS TO_STANDBY OF TO TC TI DT
TO TO_OFF OF TS TC TI DT
TI TO_IDLE OF TO TS TC DT
RN RUNNING OF TO TS TC DT
AR ARMED OF TO TS TC DT
IL IDLE OF TO TS TC DT
OF OFF
DT DIRECT OF TO TS TC TI
PS POL_SWITCHING
TC TO_CYCLING OF TO TS TI DT
EC ECONOMY OF TO TS TI DT
CY CYCLING OF TO TS TI DT
PD PAUSED OF TO TS TI DT

Libref allows a low-cost unipolar converter to be used with a polarity switch to drive a bipolar circuit. The polarity can be set manually, or can be controlled automatically when in the DIRECT or CYCLING states, based on the polarity of the reference function.

Example of the CERN-designed 700A 1-channel self-protecting polarity switch

POSITIVE Voltage Current
NEGATIVE Voltage Current

Polarity Switch Manager

DT DIRECT OF TO TS TC TI
PS POL_SWITCHING
OF OFF
CY CYCLING OF TO TS TI DT

The RAMP function
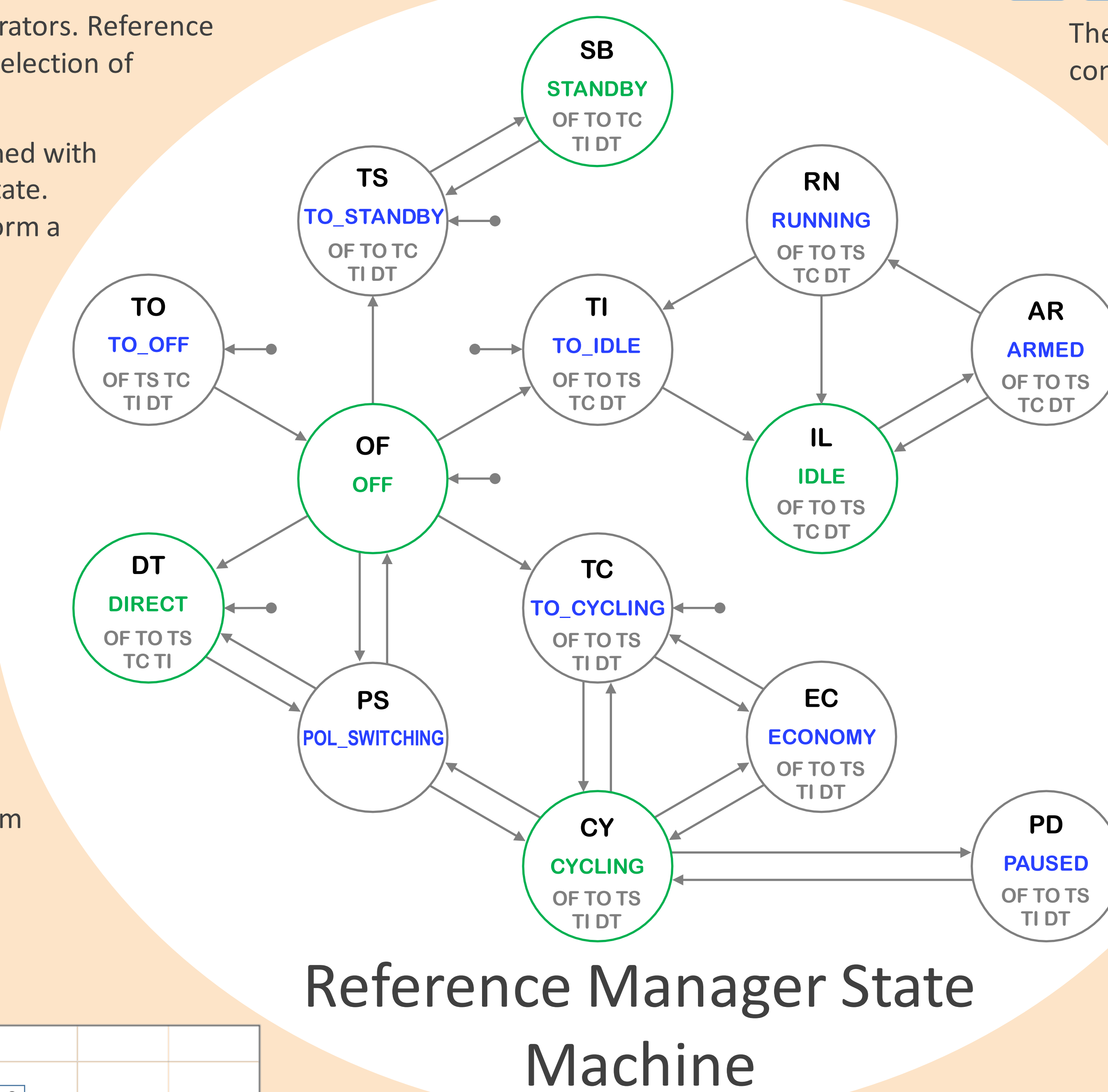
A reference function is needed that can:
- Ramp smoothly from one reference value to another
- Work even if the voltage reference is being clipped

This is provided by the RAMP function in libfg. It is a special parabola – parabola function, which can accumulate a time offset if the reference is being limited.

Requested reference
Voltage limit ends here
Limited reference

If the reference from the previous iteration was clipped, the time offset is adjusted so that the clipped reference would have been generated.
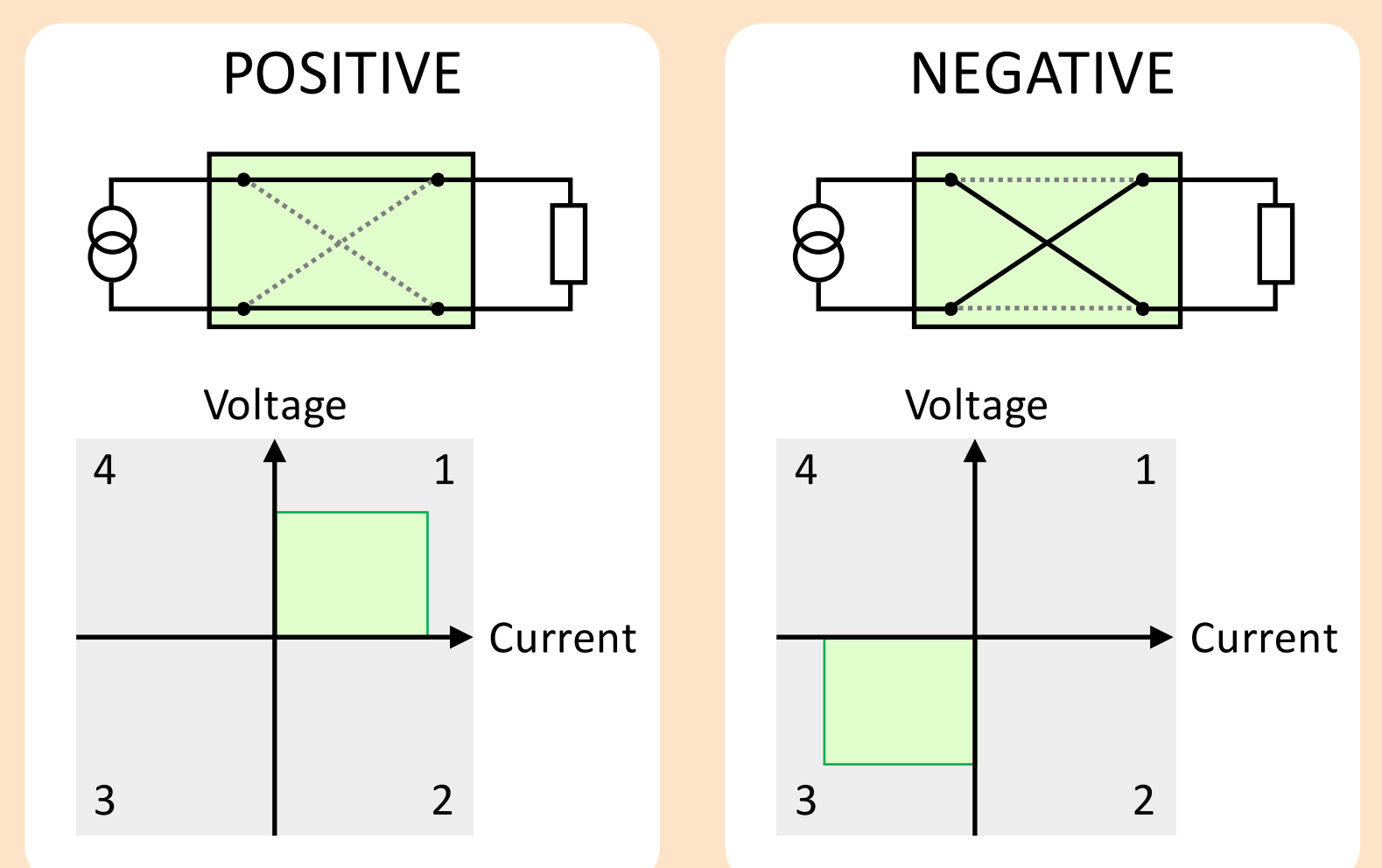
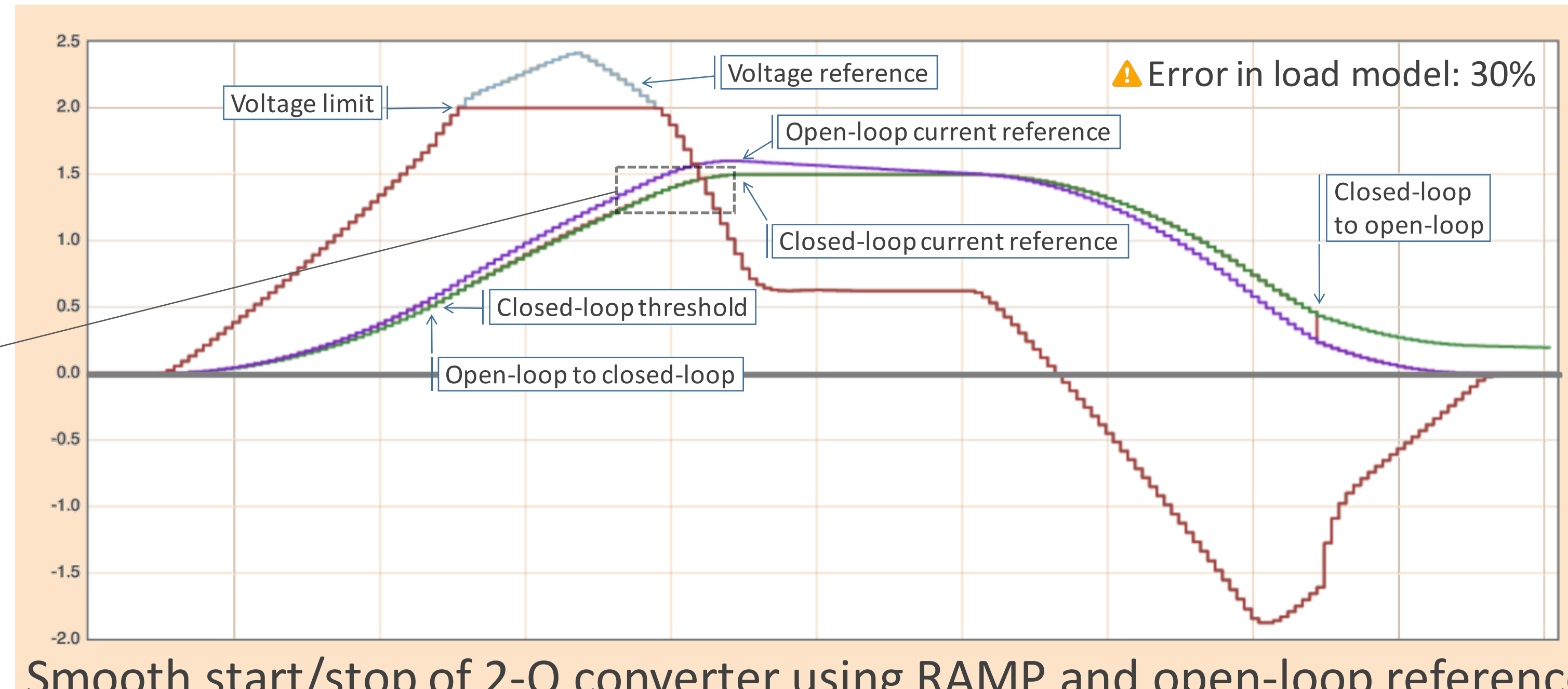## Smooth start/stop of 2-Q converter using RAMP and open-loop reference

Voltage limit
Voltage reference
⚠ Error in load model: 30%
Open-loop current reference
Closed-loop current reference
Closed-loop threshold
Closed-loop to open-loop
Open-loop to closed-loop

Open-loop ↔ Closed-loop

Libreg implements an internally stable closed-loop RST regulator, which connects the three regulation variables:

Closed-loop Reference

$$\sum_i \{Ref_i \cdot T_i\} - \sum_i \{Meas_i \cdot R_i\} - \sum_i \{Act_i \cdot S_i\} = 0$$

Actuation
Measurement

The RST realizes a (pseudo) dead-beat control and allows up to 2.4 periods of delay. Libreg also implements an open-loop model (for an inductive load), which connects the open-loop reference with the actuation:

Open-loop Reference

$$\sum_i \{Ref_i \cdot T_i\} - \sum_i \{Act_i \cdot S_i\} = 0$$

Actuation

Both open-loop and closed-loop algorithms can work in either direction, so when running in open-loop, the closed-loop reference is being calculated, and vice-versa. When combined with the RAMP function, this allows smooth transitions from open-loop to closed-loop when starting and stopping.