Dynamic Voltage Restorer Development and Testing

T.C. Monteiro, J. Camargo, S.U. Ahn, E. Bormio, T.M. Terrazas, F.P. Marafão, A.R. Giaretta, J.A. Jardini, L. Matakas Jr. and W. Komatsu

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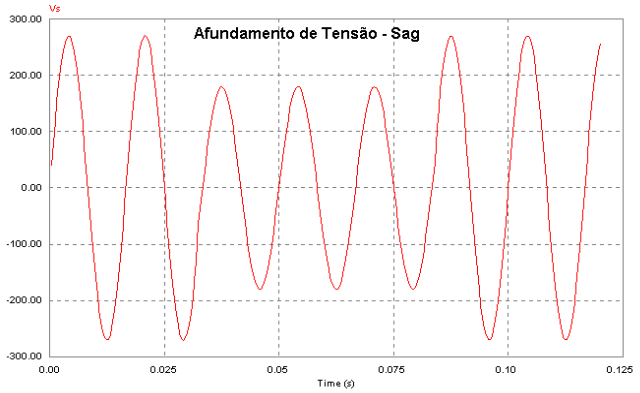
Overview

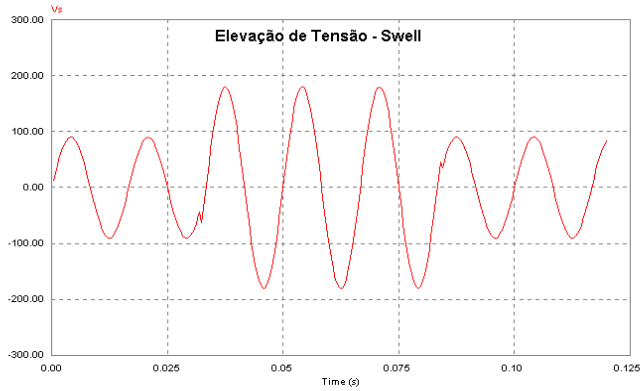
* Dynamic voltage restorer review
* Prototype description
* Reasoning for tests
* Tests
* Results
* Final remarks

The problem with sags and swells

PROBLEM – Voltage amplitude variations lasting between 0.5 seg ~ 1 min

- (*Sags*) → Voltage RMS value decrease in the order of 0.1 to 0.9 [pu]
- (*Swells*) → Voltage RMS value increase over 1.1 [pu]

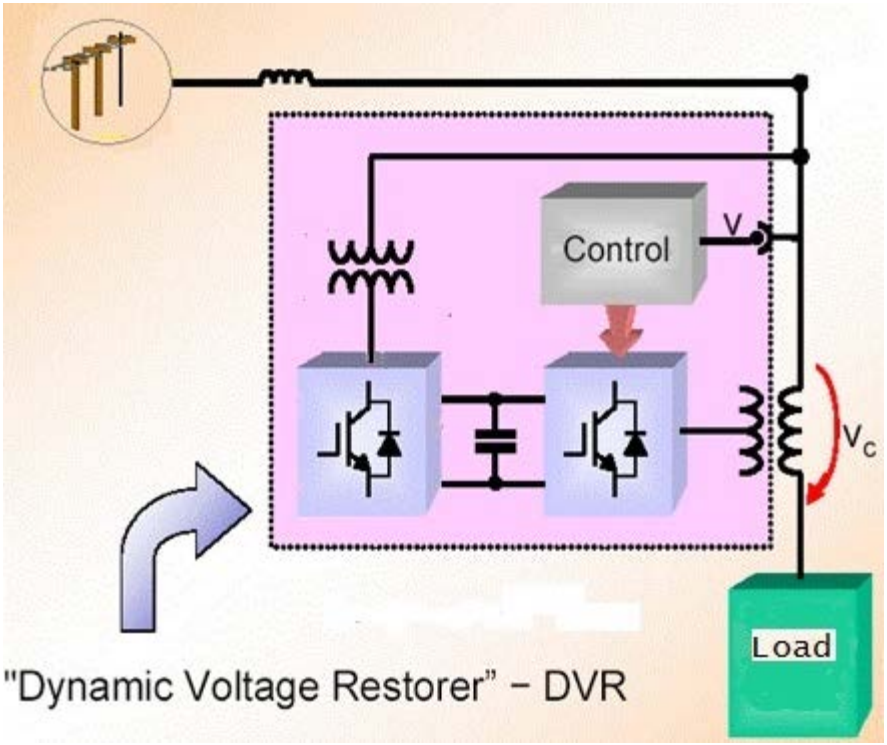


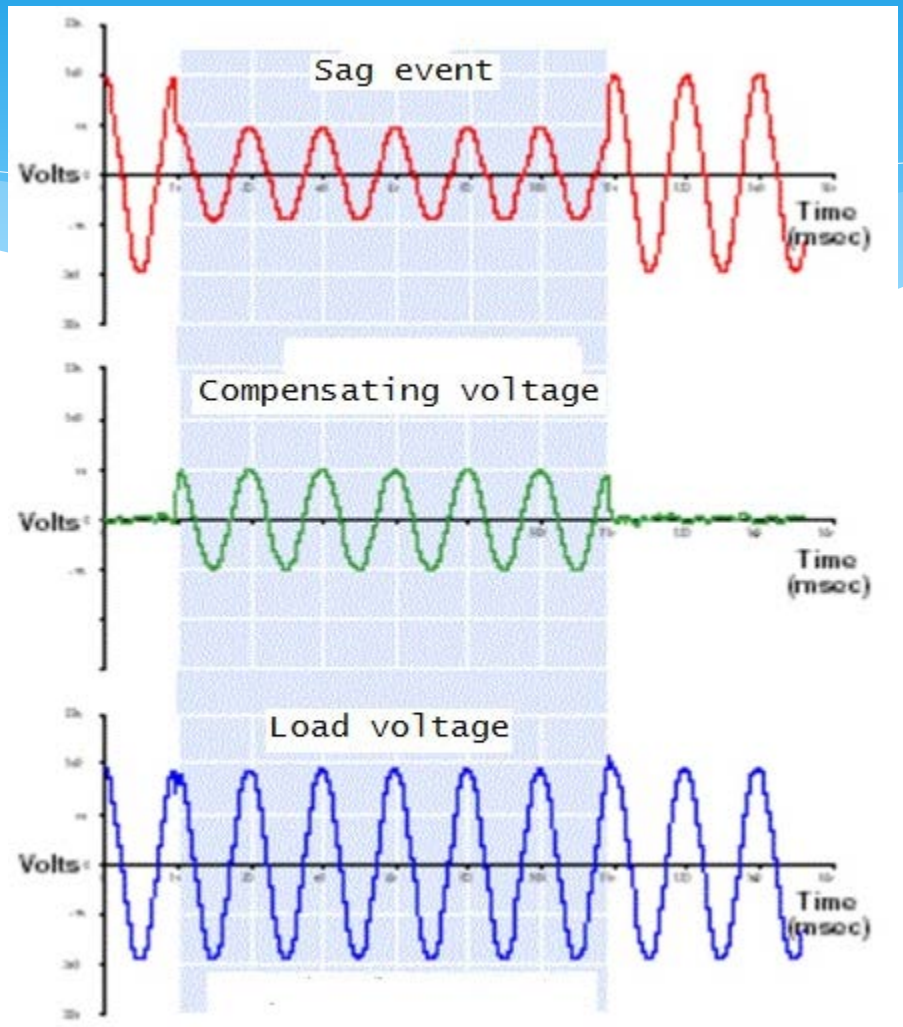


LOSSES CAUSED BY VOLTAGE SAGS (APPROX. MEAN COST, 1997 DATA):

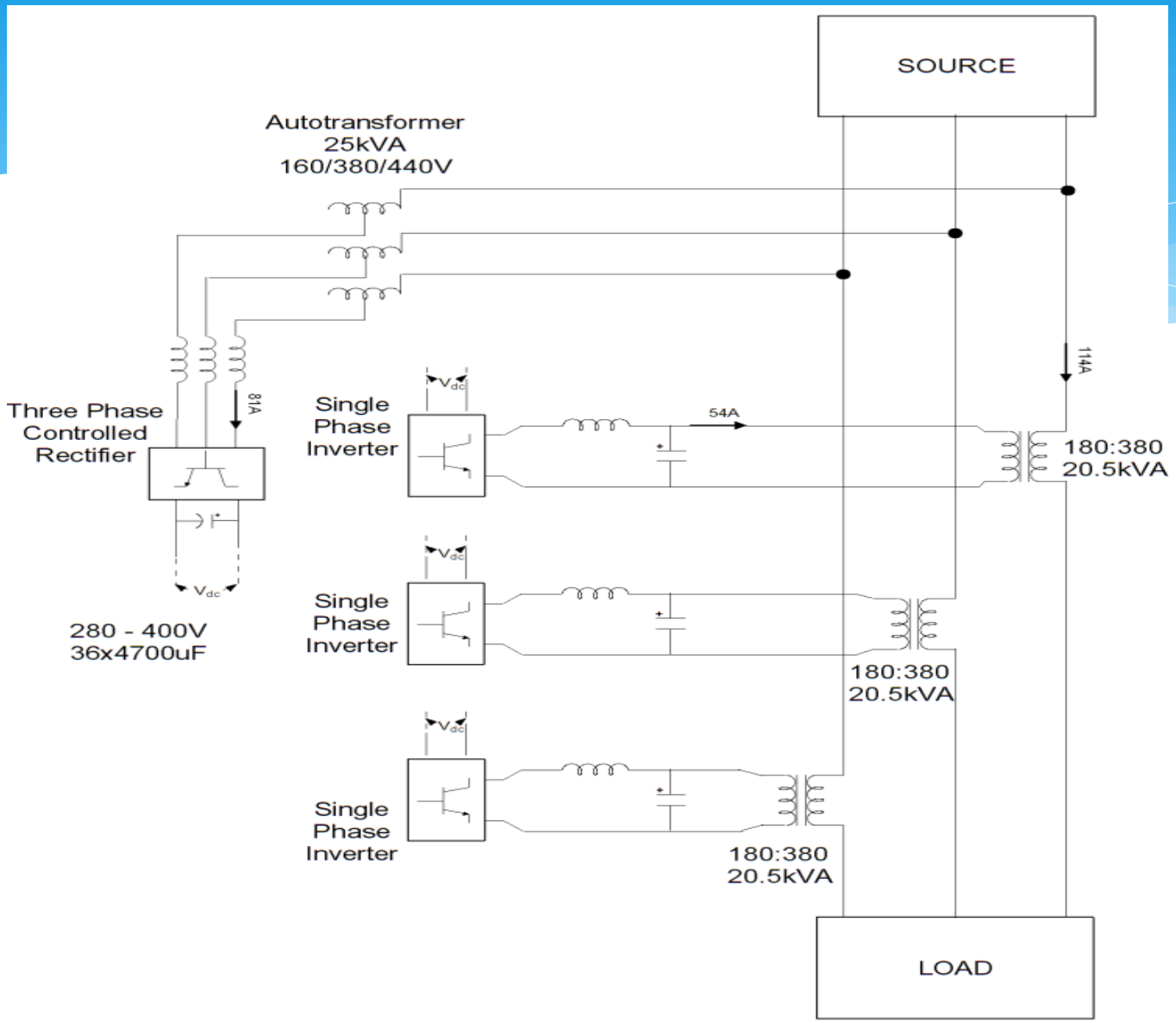
- Sags of 10% to 20%, for up to 15 cycle: US$7,694.00
- In the USA, Energy Quality events, especifically voltage transients, generated economical losses in the order of U$ 120 Billions / year.

DVR Fundamentals





Dynamic Voltage Restorer (DVR)



PD-171: Mini Dynamic Voltage Restorer (Mini -DVR)

Prototypes of Projects PD 71 and PD 171 (chronological order):

Mini DVR 1 and 3 (proof of concept)
S=10kVA, installed at research lab, University of São Paulo

Mini DVR 2
S=75kVA – 380/440V – first full scale prototype

Micro-DVR
S=300VA – for demonstration and software development

Mini DVR 4
S=75kVA – 380/440V – improved full scale prototype

Mini DVR 5
S=75kVA – 380/440V – alternative topology, full scale prototype

Mini DVR 6
S=75kVA – 380/440V – final prototype, aimed for pre-industrial production

Mini DVR 04

Main characteristics for Mini-DVR 04:

• Texas Instruments 2812 family DSPs (one for the series branch and other for the parallel branch, in a master-slave scheme);

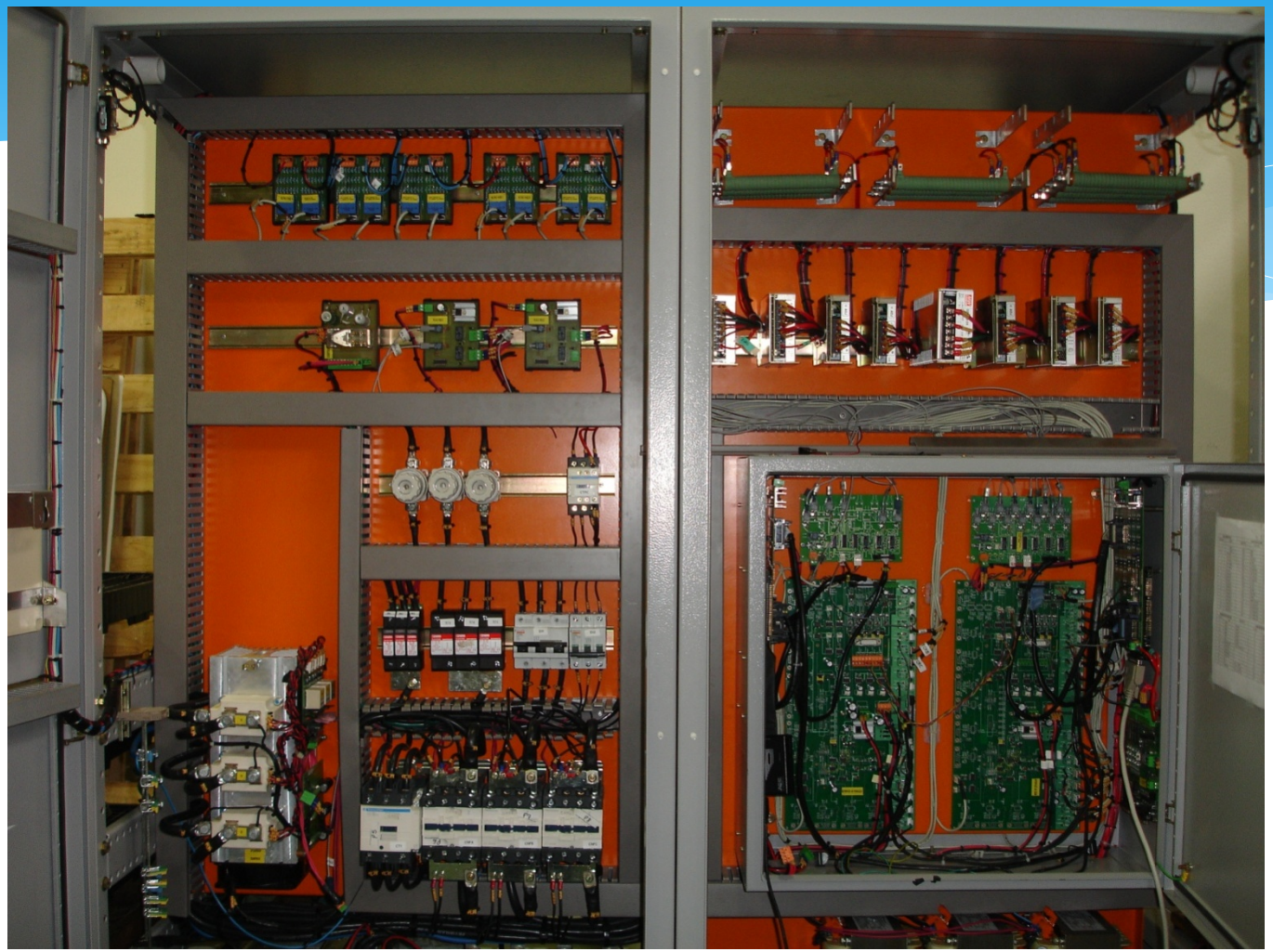
• IGBTs and AC static switches triggered by optical fiber connections;

• Major modifications on synchronizing software (compared to MDVR02);

• Major modifications on control techniques (compared to MDVR02), aiming better performance for non-linear and unbalanced loads;

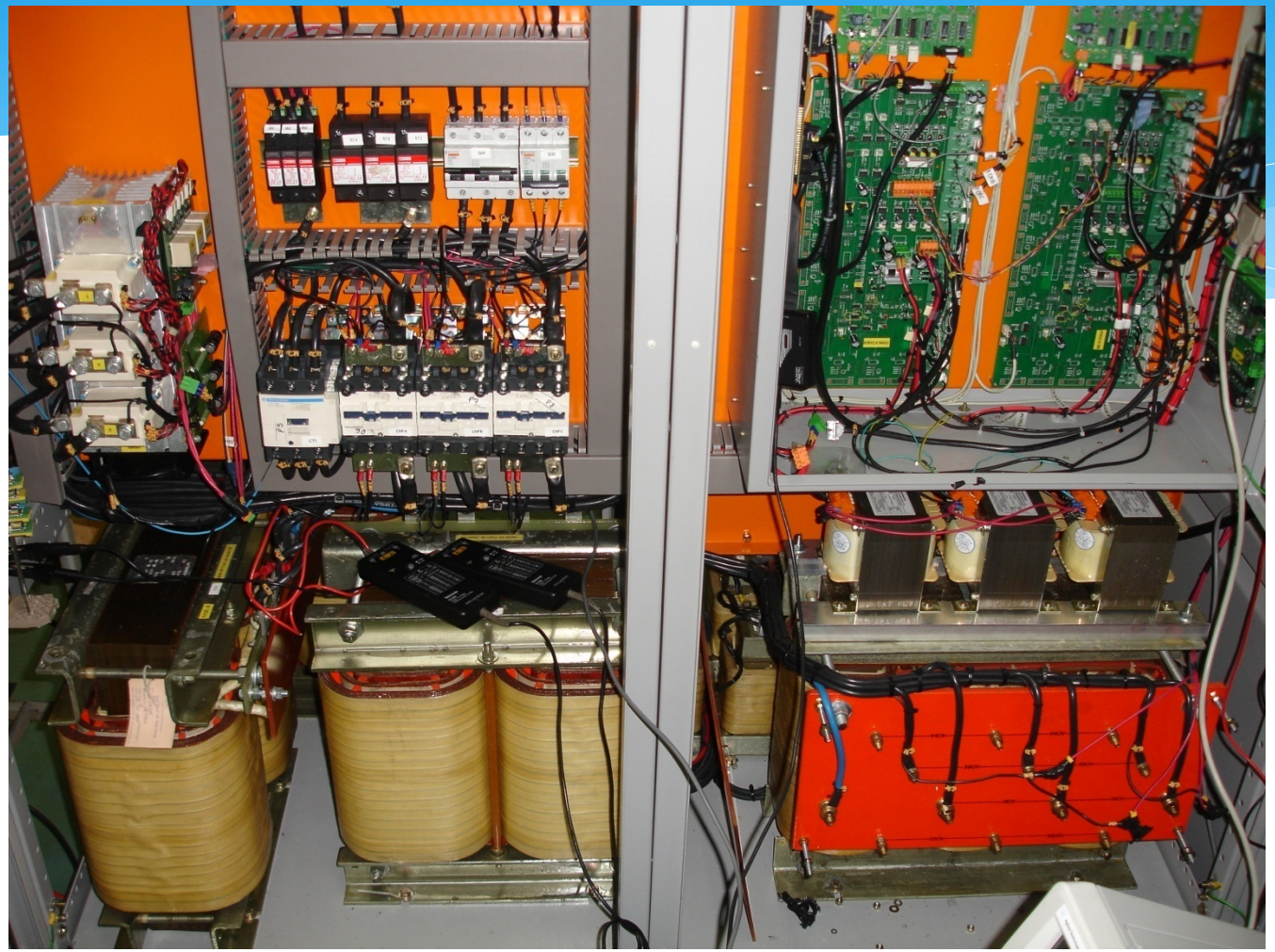
• Major modifications (compared to the MDVR02) on start/stop and system protection algorithms.

Mini DVR 04



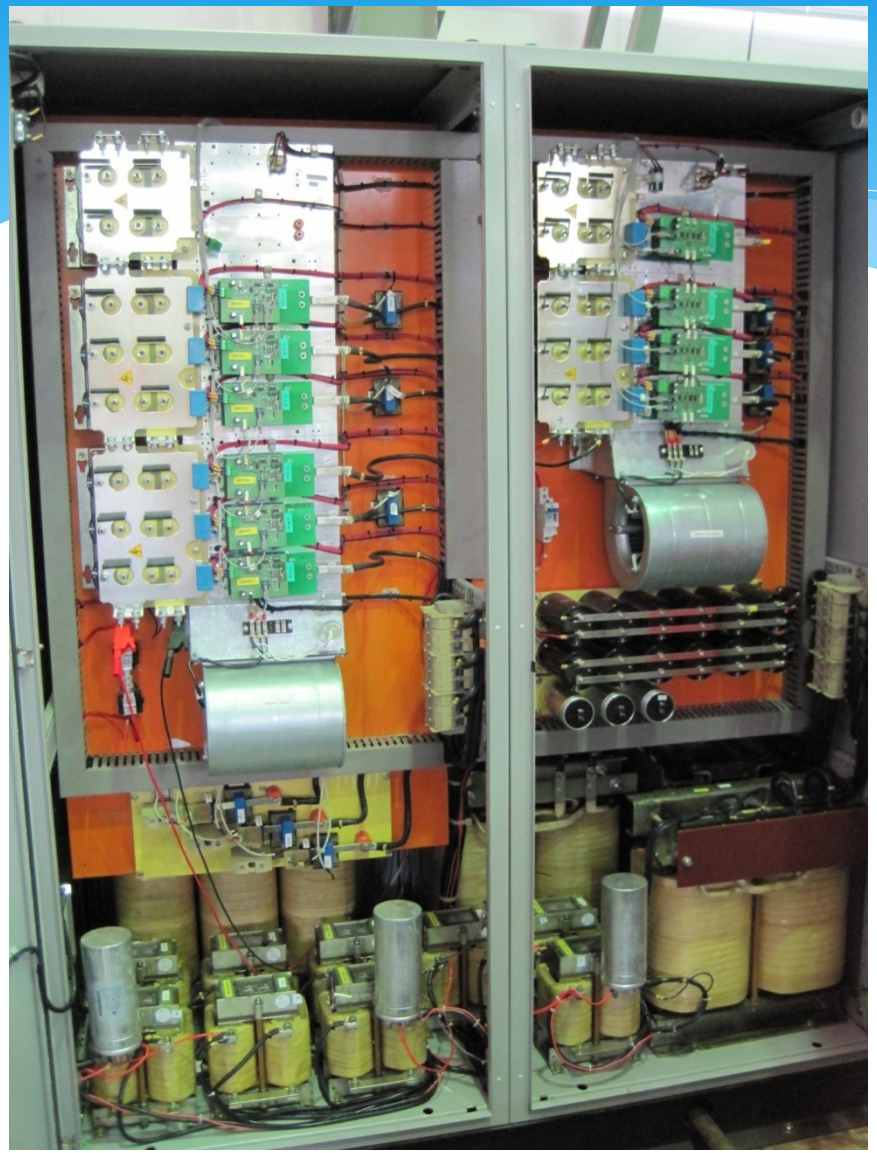
Front view – Protection, interface boards, sensors, power supplies.

Mini DVR 04



Front view – Protection, interface boards, static and mechanical bypass switches, autotransformer, series injection transformers.

Mini DVR 04



Rear view:

- Series Inverter Module
- Parallel (rectifier) Module
- DC link
- Output LC filters
- Injection Transformers

Dimensions (h x l x d):
2,0m x 2,0m x 0,8m

Mass ~ 2t

Mini DVR 04 – laboratory results

In a development laboratory, with limited available power (max 30kVA) some sag and swell tests were performed with representative loads:

✓Three-phase resistive loads of 15, 10 and 5 Ω;

✓Three-phase induction motor, rated 2 HP, with mechanical load (unloaded DC generator);

✓Non-linear load composed by three-phase rectifier with DC filter capacitor, connected to a variable resistive load;

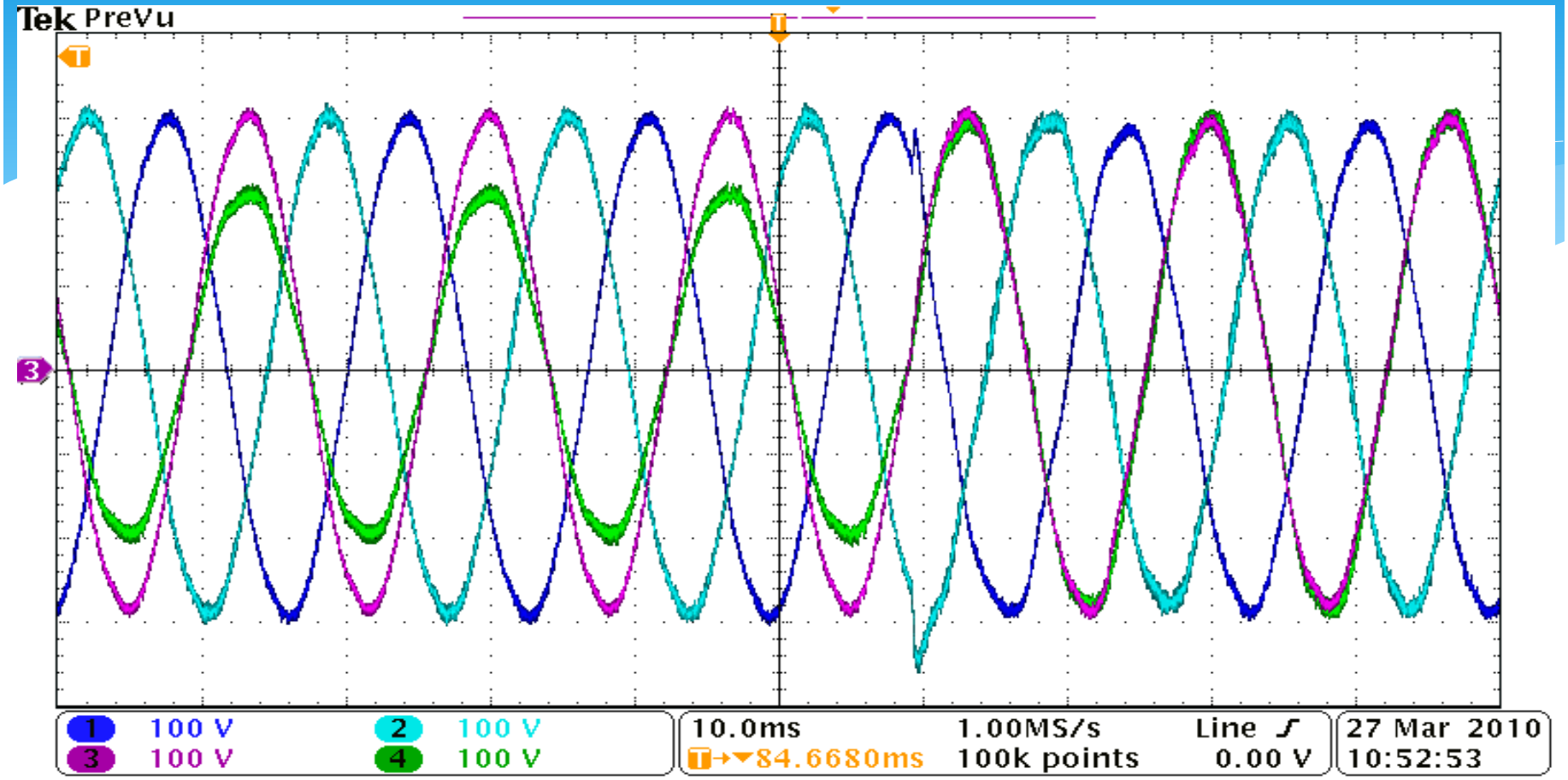
For all tests the equipment was fed through the Porto-SAG equipment, developed by EPRI (Electric Power Research Institute), generating sags and swells up to 25%, with 1 to 60 cycles duration.

Porto-SAG

Porto-SAG: EPRI´s portable sag and swell generator

(picture taken at EPRI´s laboratory, Knoxville TN, USA).

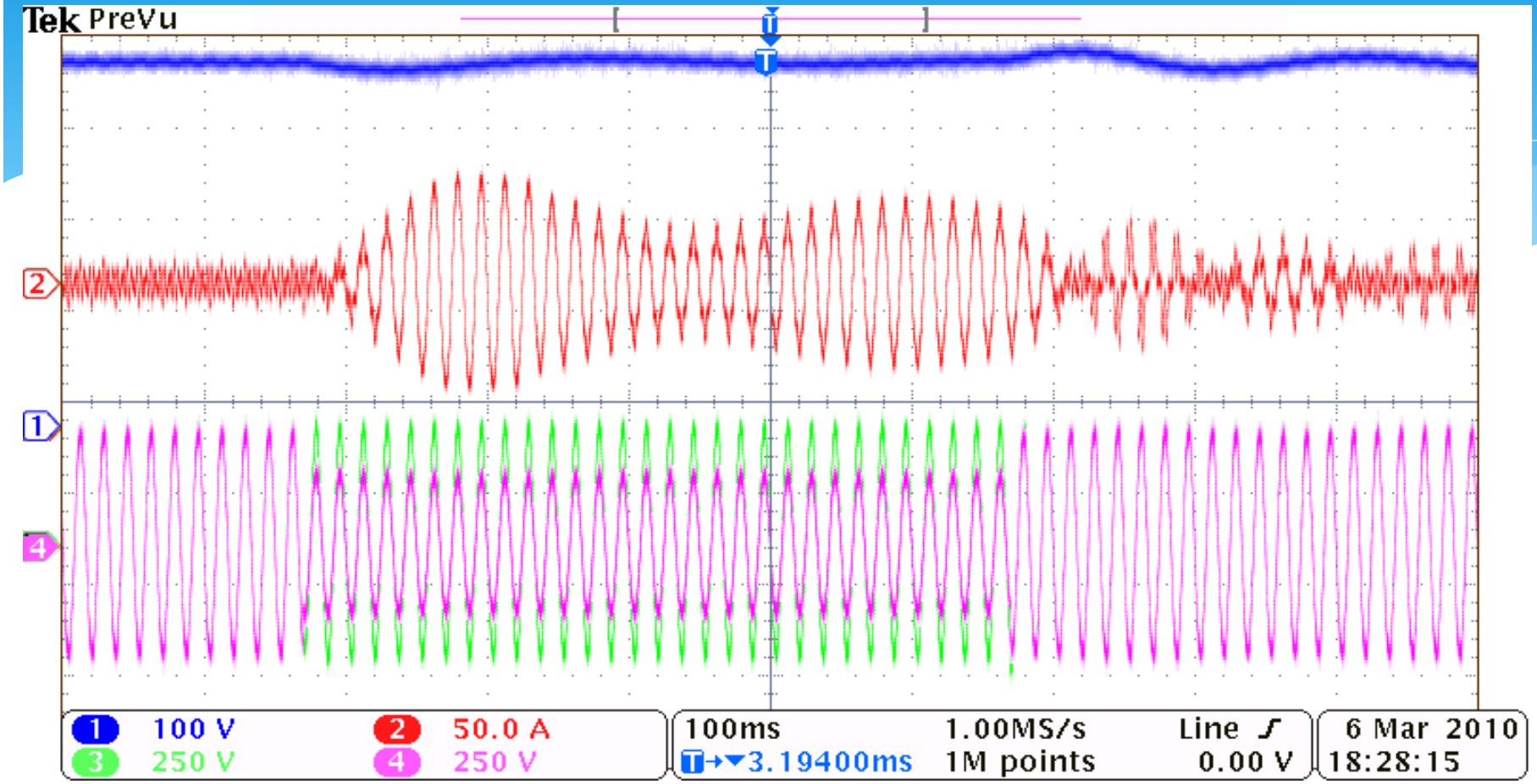
Mini DVR 04 – laboratory results



Detail of the end of a sag event – three-phase sag of 30 cycles to 60% of nominal voltage:

- In green (channel 4), sag-affected input voltage waveform.
- Other channels: corrected output voltage waveforms.

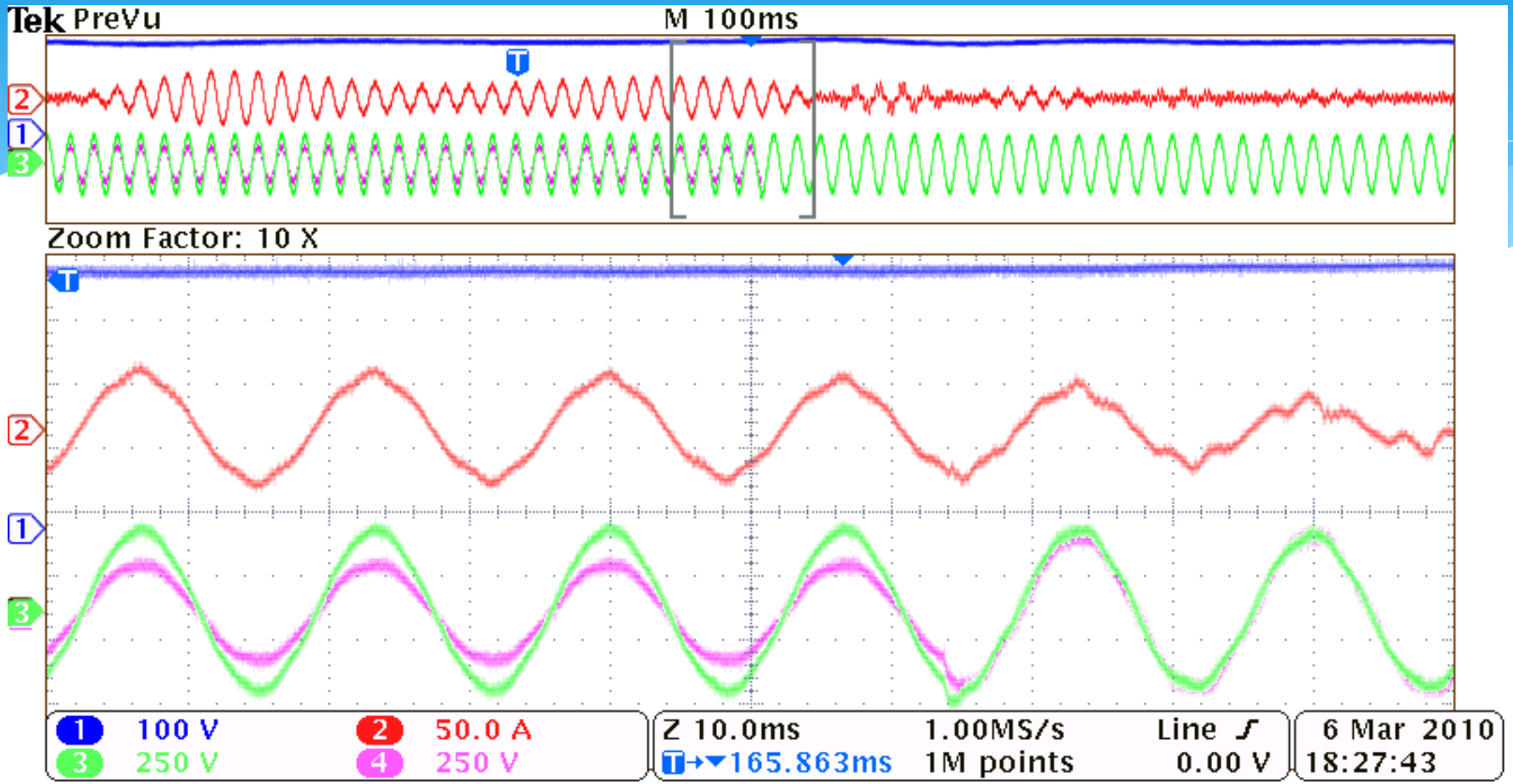
Mini DVR 04 – laboratory results



Sag event – three-phase sag of 30 cycles to 60% of nominal voltage:

- DC link voltage in blue (channel 1), parallel branch current in red (channel 2), remaining (input) voltage in pink (channel 4) and load voltage in green (channel 4).

Mini DVR 04 – laboratory results



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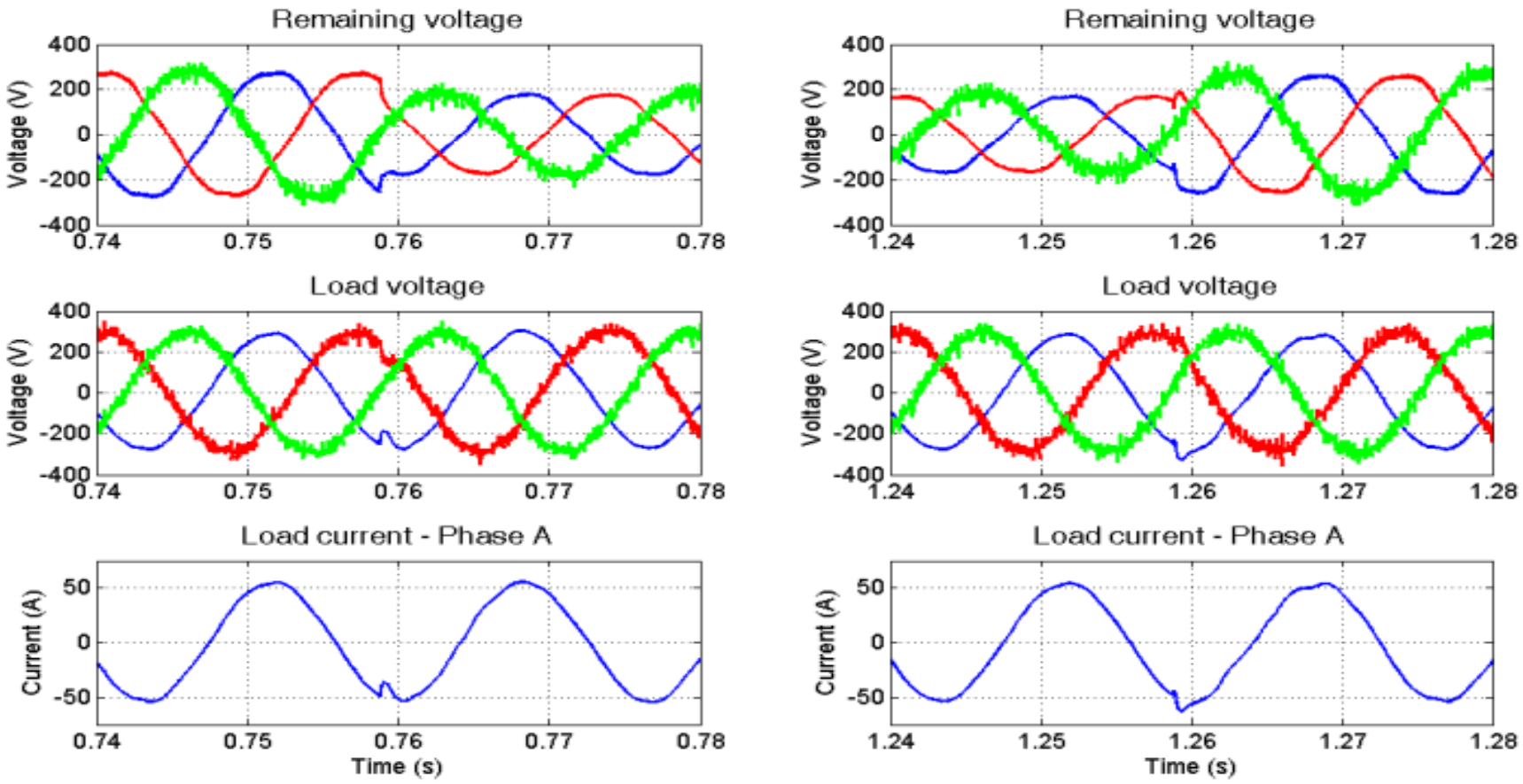
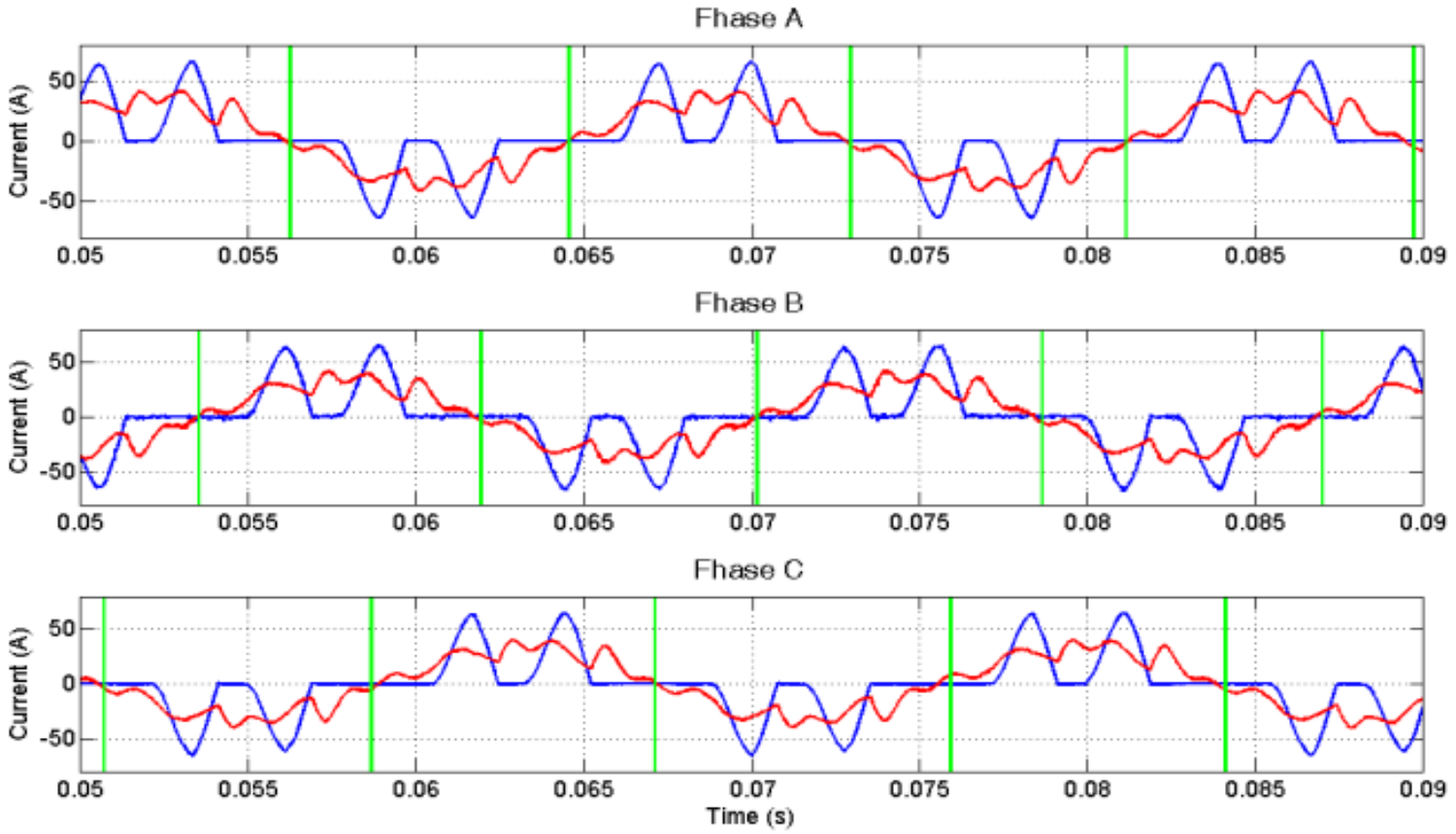
Mini DVR 04 – laboratory results



Details of a 30 cycle three phase voltage sag, at 60% remaining voltage:

- Remaining voltages, load voltages and load currents are presented, detailed at the beginning and the end of the event.

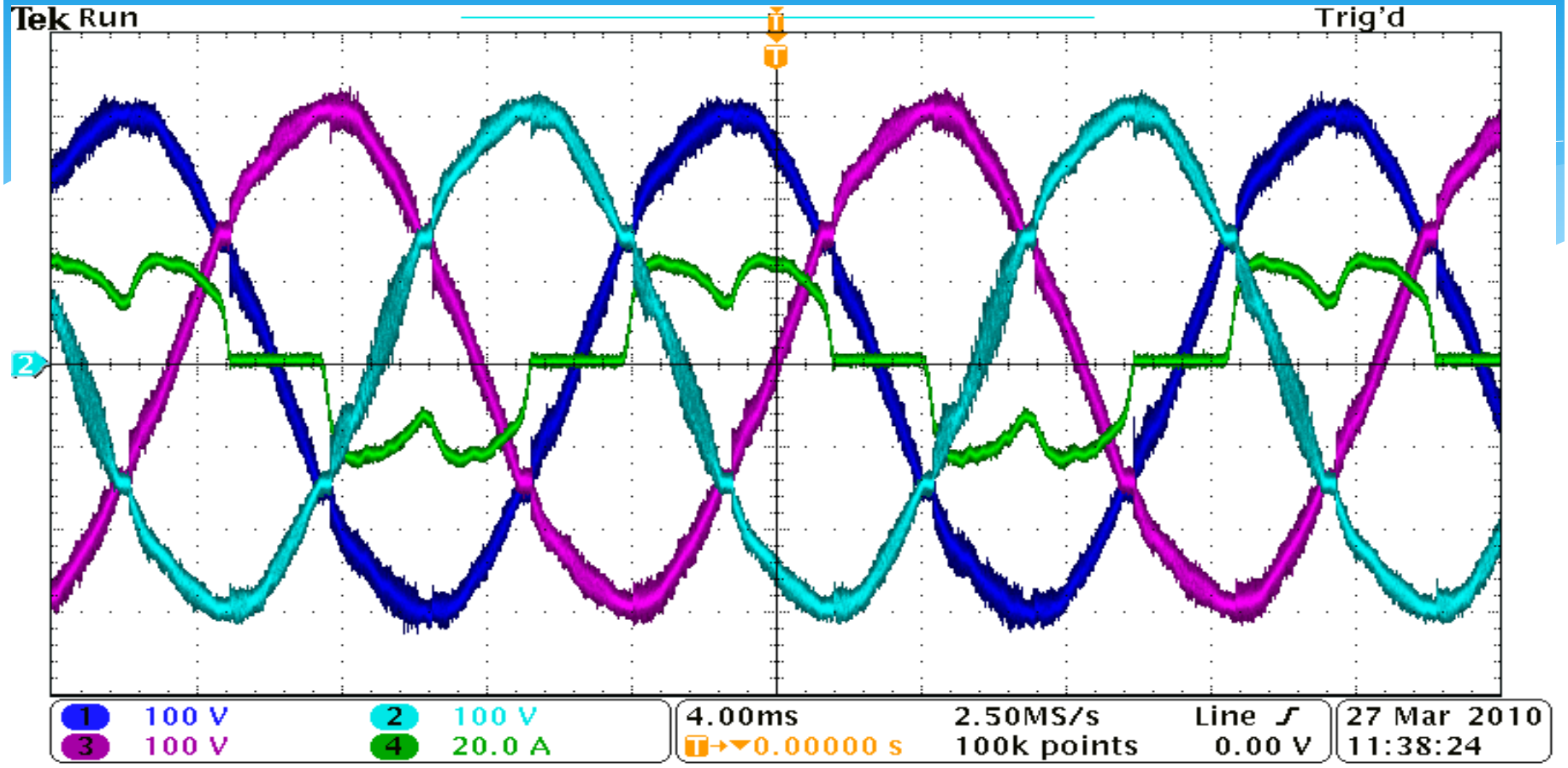
Mini DVR 04 – laboratory results



Active parallel filter behavior for a non-linear load:

- Non-linear load currents in blue, compensated currents in red, phase voltages in green (out of scale, showing only green vertical bars).

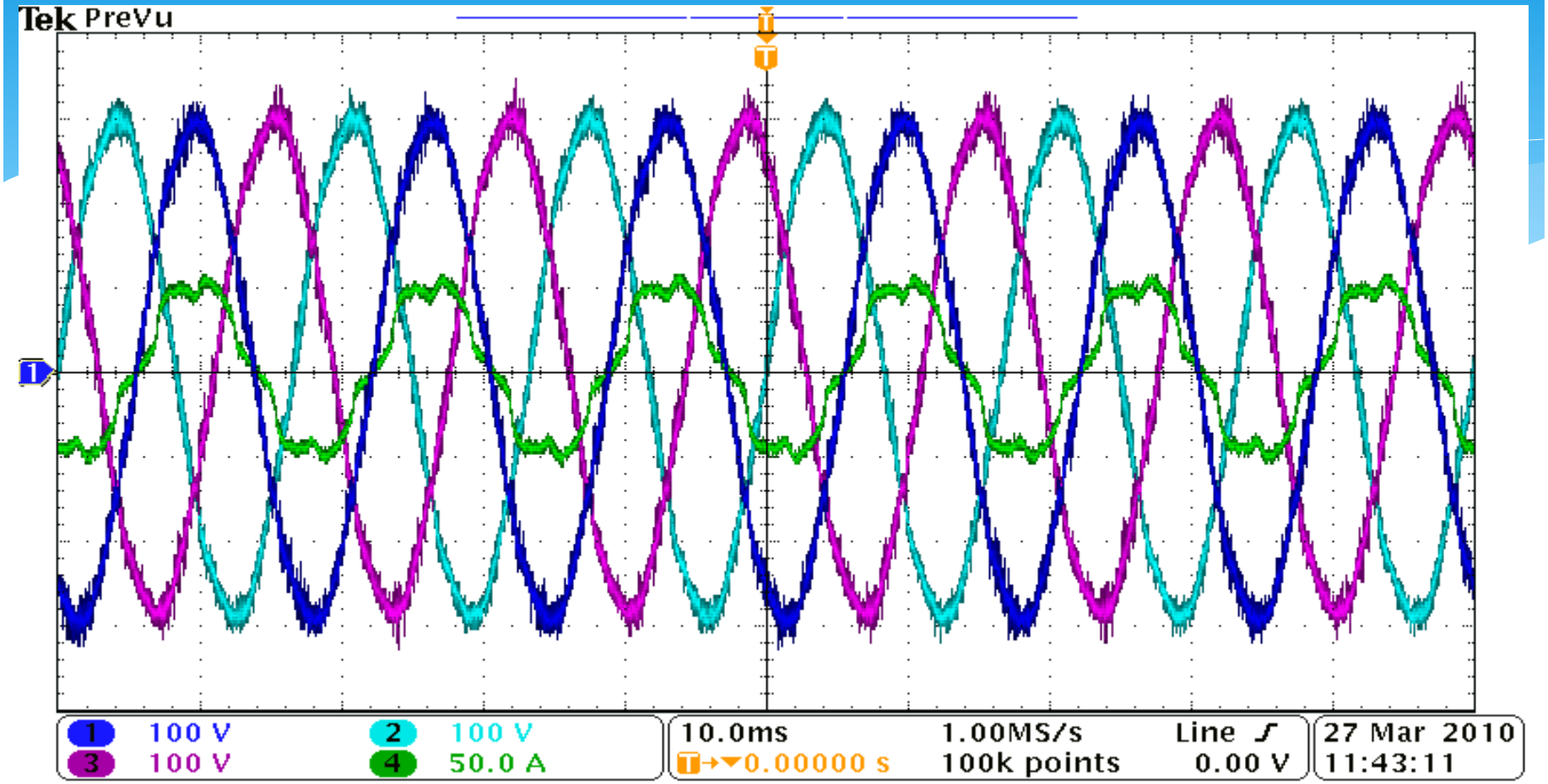
Mini DVR 04 – laboratory results



Behavior for a non-linear load without the active parallel filter:

- Load current in green, other channels with output voltage waveforms;
- Load THDi (total harmonic distortion of the current) of 32.7%.

Mini DVR 04 – laboratory results



Behavior for a non-linear load with the active parallel filter working:

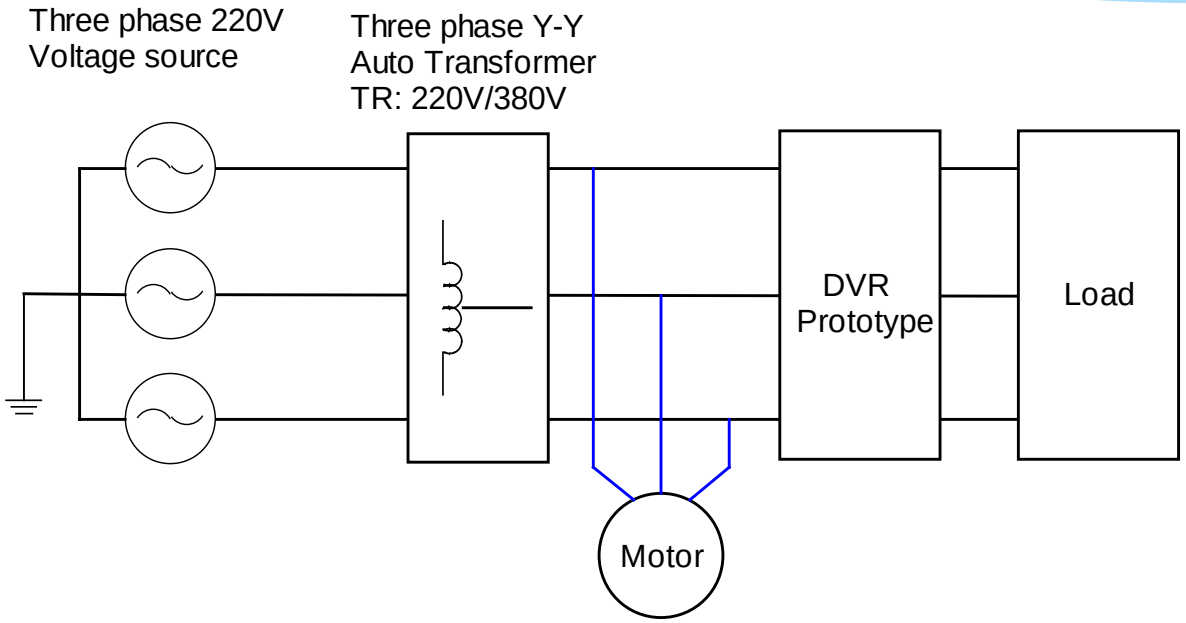
- Load current in green, other channels with output voltage waveforms;
- Load THDi (total harmonic distortion of the current) of 14.2%.

Mini DVRs tests at the IEE/USP

For industrial certification purposes, the Mini-DVRs 4, 5 and 6 were submmited to the following tests:

- Regulation, eficiency, harmonic distortion, for no-load, half-load and full-load conditions;
- Load rejection and MDVR energization with load present, for half-load and full-load conditions;
- Voltage sag with nominal load;
- This presentation shows results for MDVR04 tests.

Mini DVRs tests at the IEE/USP

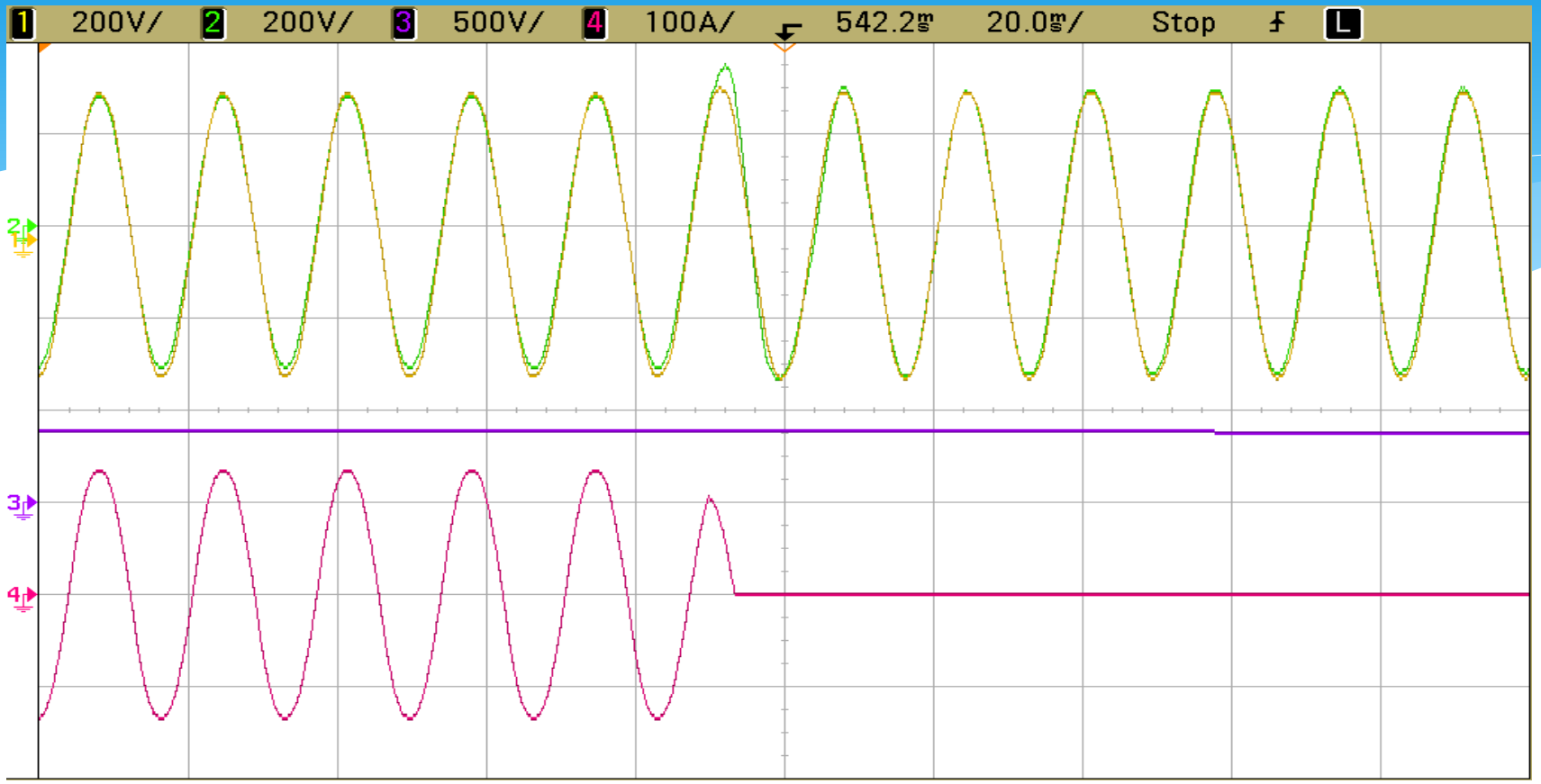


Experimental setup applied at IEE/USP in order to obtain sags at nominal power: Induction motor startup generates the required voltage sag.

Mini DVR 04 – IEE/USP tests

Transport and tests preparation

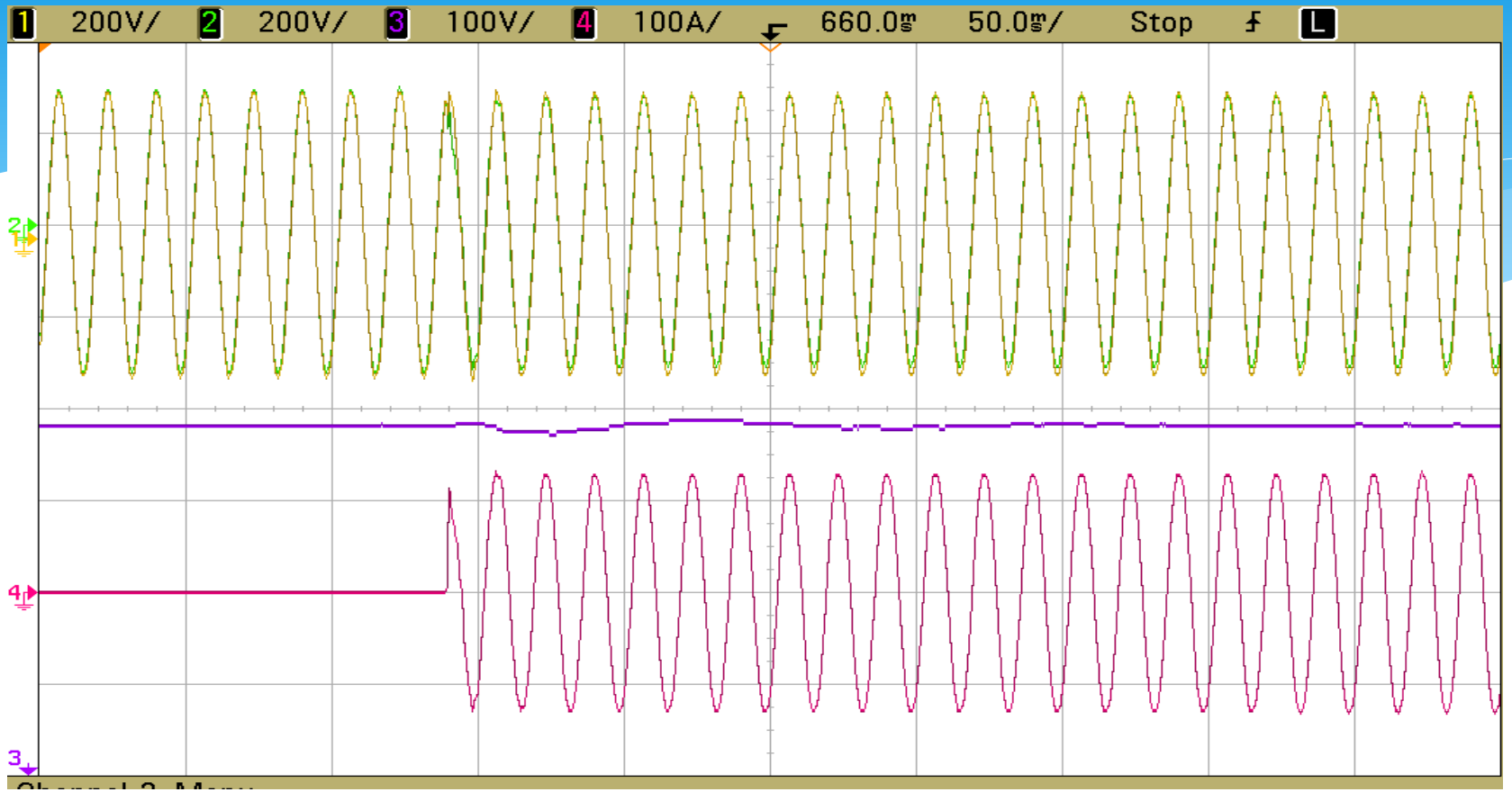
Mini DVR 04 – IEE/USP tests results



Three-phase nominal load rejection:

- AC input voltage (yellow), load voltage (green);
- DC link voltage (purple) and load current (pink).

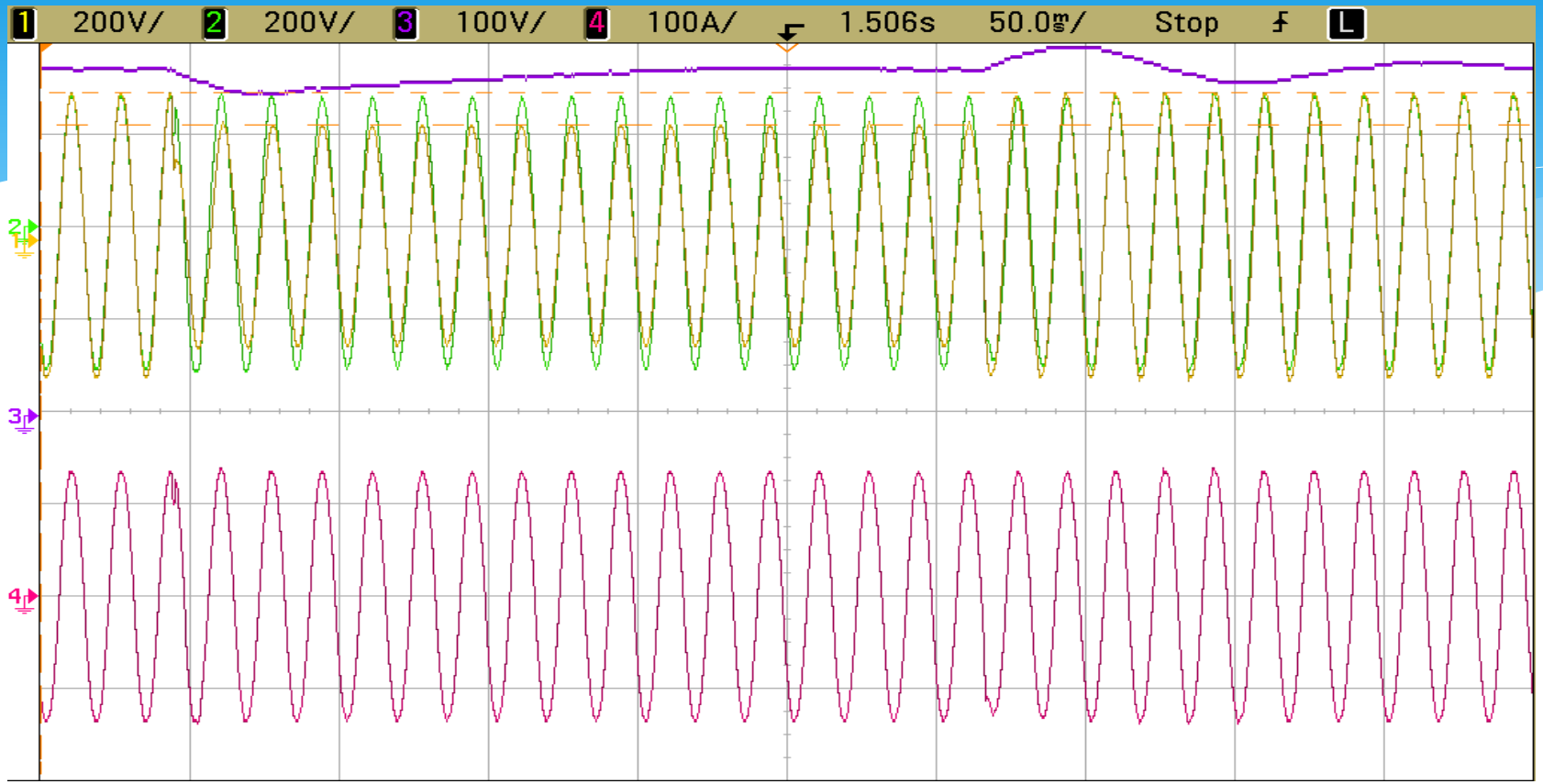
Mini DVR 04 – IEE/USP tests results



Three-phase nominal load energization:

- AC input voltage (yellow), load voltage (green);
- DC link voltage (purple) and load current (pink).

Mini DVR 04 – IEE/USP tests results



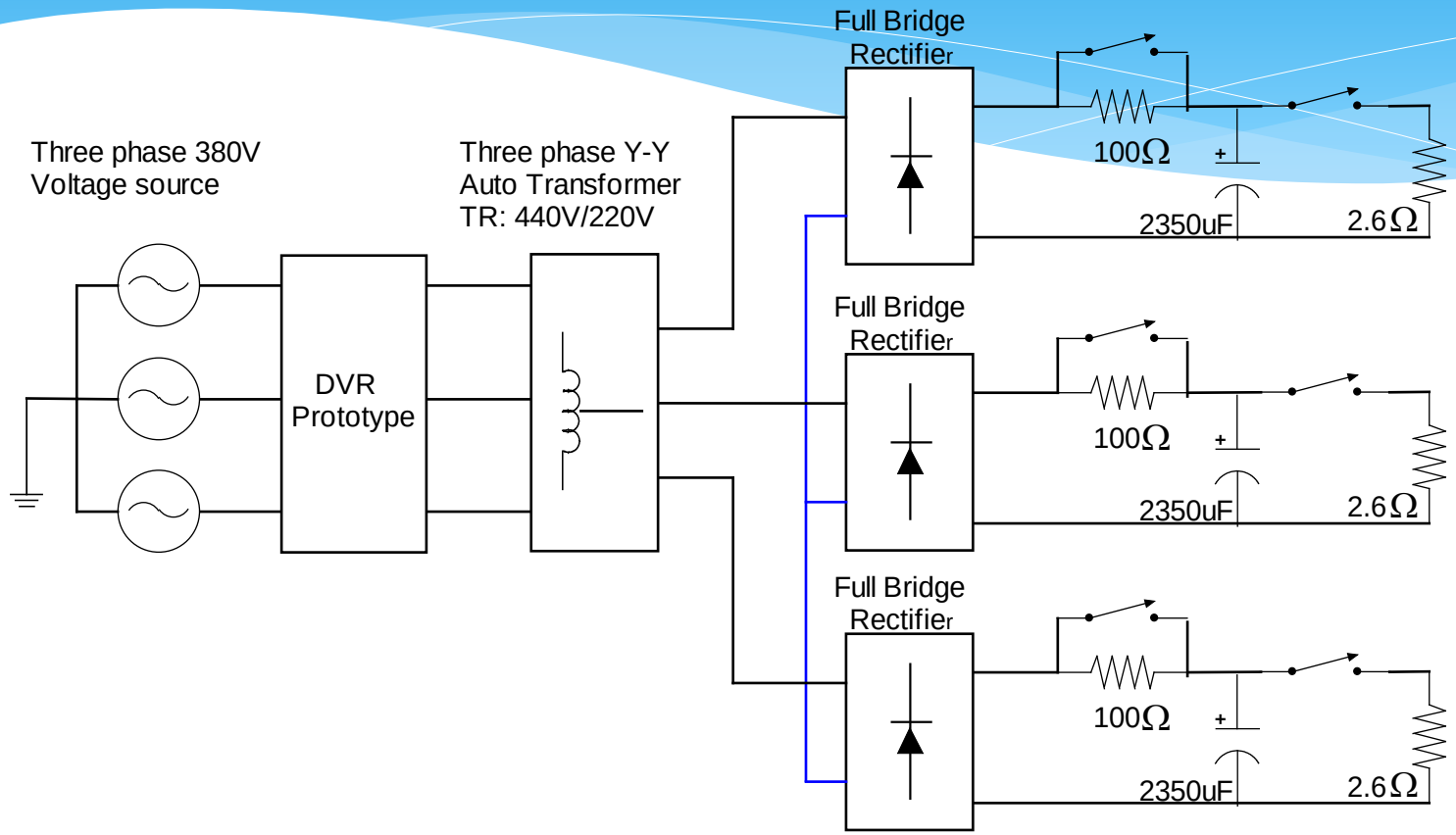
Three-phase sag to 75%, 16 cycles, nominal resistive load:

- AC input voltage (yellow), load voltage (green);
- DC link voltage (purple) and load current (pink).

Mini DVRs tests at the IEE/USP

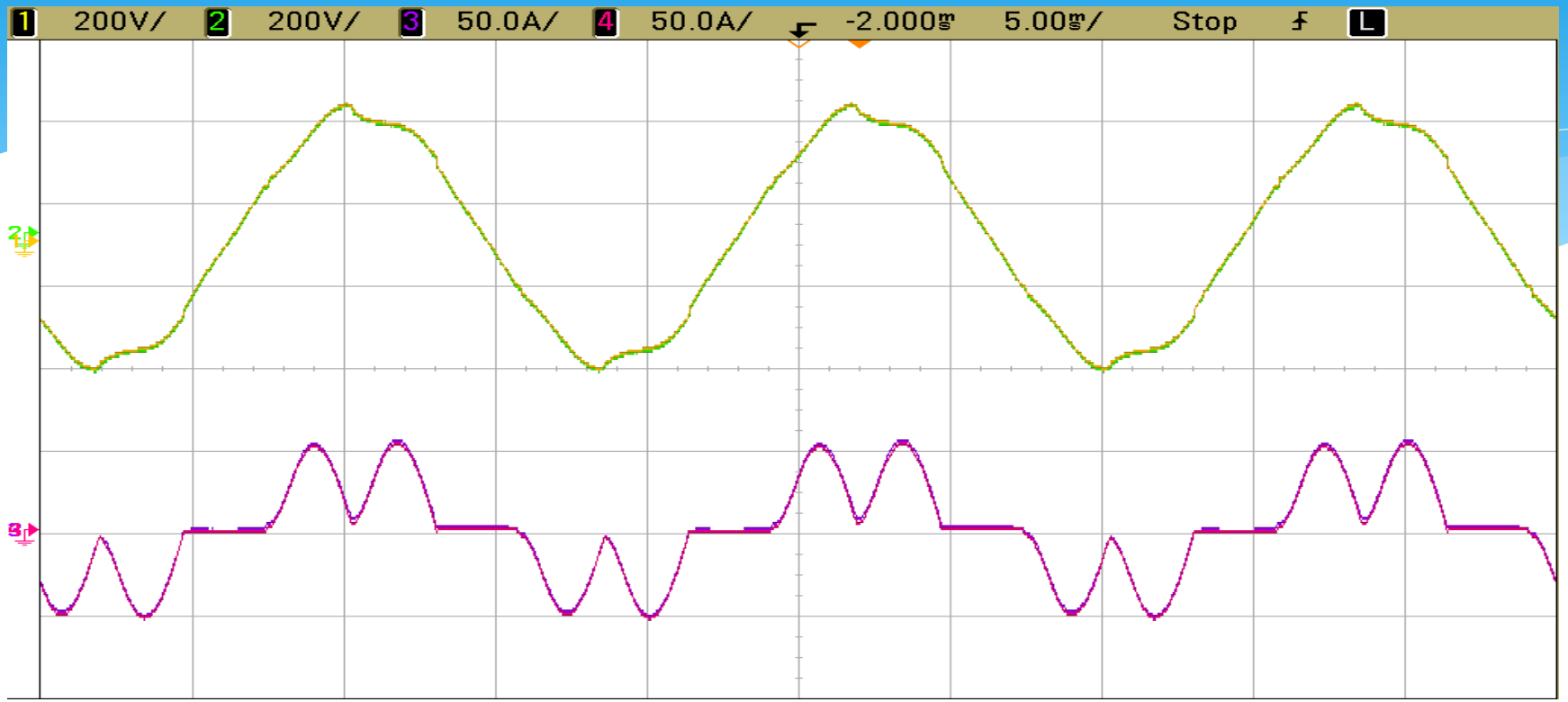
Picture shows MDVR05 at the IEE/USP.

Mini DVR 04 – IEE/USP tests



Non-Linear load experimental setup at the IEE/USP.

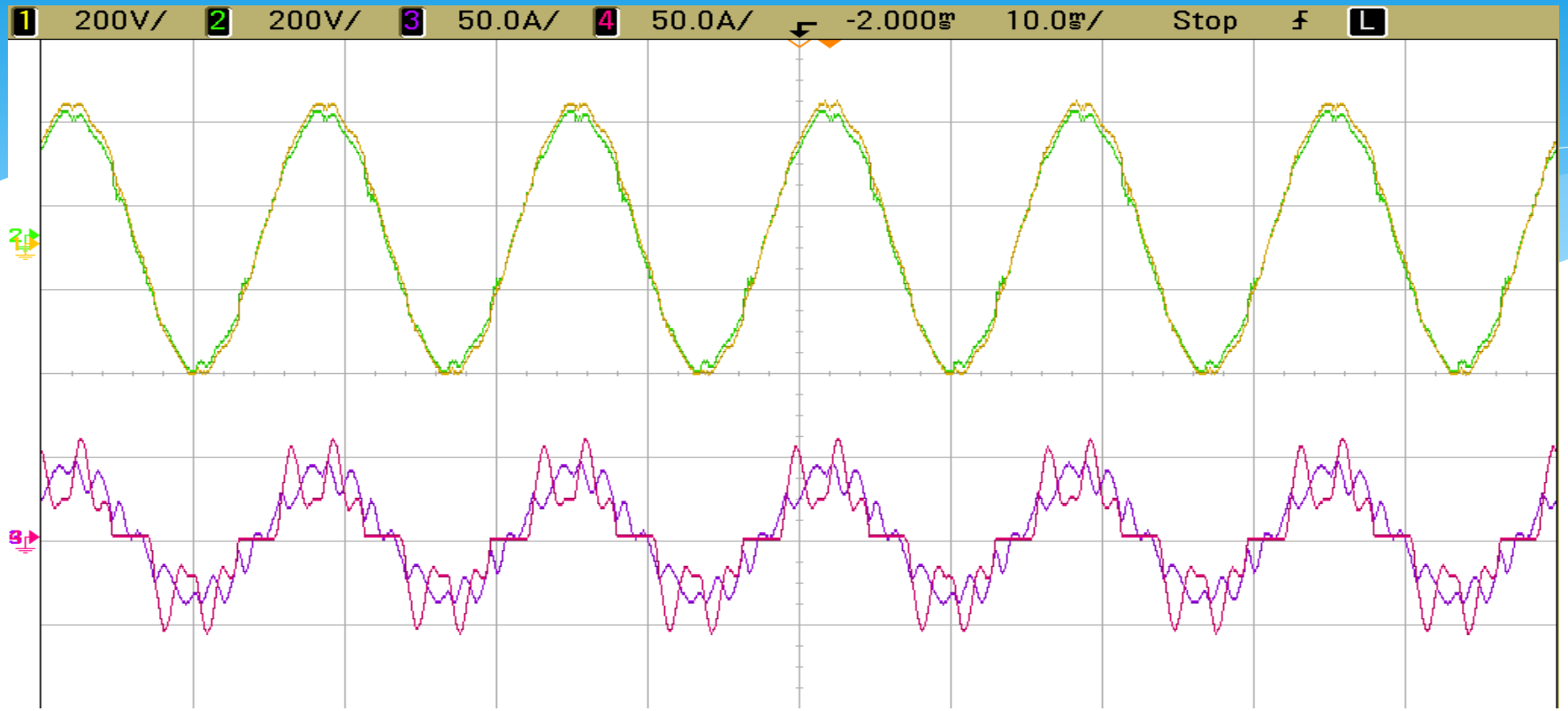
Mini DVR 04 – IEE/USP tests results



Non-Linear load, with active filter turned off:

- Mains voltage (yellow), load voltage (green);
- Mains current (purple), load current (pink) (both superposed in the picture);
- THDi of 57.2%

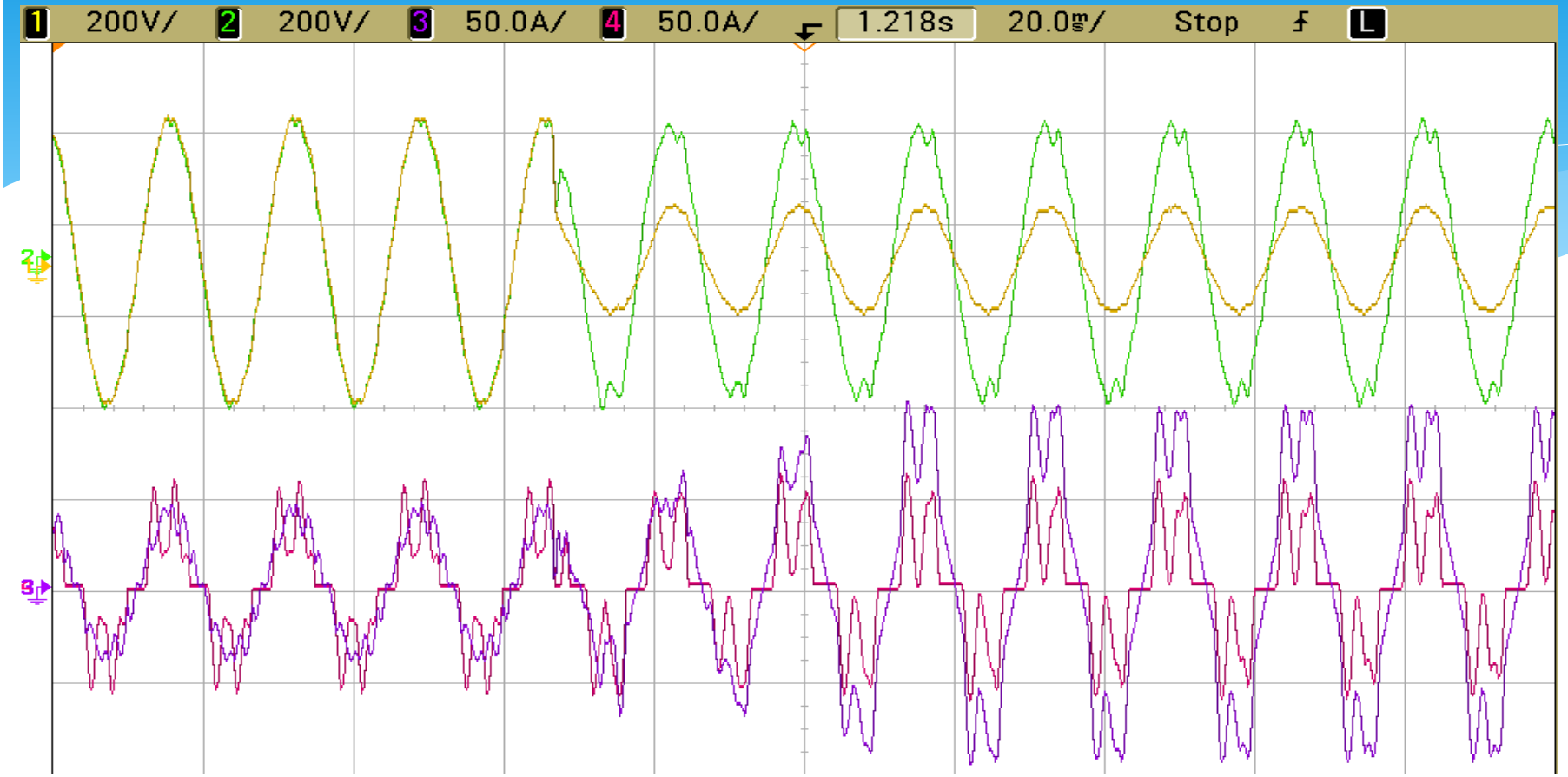
Mini DVR 04 – IEE/USP tests results



Non-Linear load, with active filter turned on:

- Mains voltage (yellow), load voltage (green);
- Mains current (purple), load current (pink);
- THDi of 12.9%

Mini DVR 04 – IEE/USP tests results



Non-linear load, with active filter working during steady state behavior, turns off during voltage sag.

Mains voltage (yellow), load voltage (green), mains current (purple), load current (pink).

Mini DVR 04 – IEE/USP tests results

Efficiency measurements

Load type	Non linear	Linear	Linear
Input power (kW)	17,5	37.2	71.9
Efficiency (%)	88	94	95

- In no-load condition, input power is 1.45kW with power factor pf=0.66.

Final remarks

- Proposed DVR family (Mini DVR) to solve power quality issues;
- Performed validation tests:
  - Development laboratory environment, limited power, versatility;
  - Certification laboratory, nominal power, specific set of tests for industrial certification purposes.
- Research and Development project results aiming for a future industrialization process.

Thank you!

Seun Ahn
Edison Bormio Jr

seun@cpfl.com.br
bormio@cpfl.com.br
(19) 3756-8140

José A. Jardini
Lourenço Matakas Jr
Antonio R, Giaretta
Wilson Komatsu

wilsonk@usp.br
matakas@pea.usp.br
(11) 3091-5483

Josué Camargo
Thiago C. Monteiro

josue@expertise-eng.com.br
(19) 3289-3435

Fernando Pinhabel Marafão
Thiago M. Terrazas

fmarafao@sorocaba.unesp.br
(15) 3238-3404