Goals

Integration of distributed generation with power electronics on rural LV grids to improve power quality

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EMTP-RV User group Meeting, Aix en Provence
A new paradigm in electrical energy

- Distributed generation
- Energy storage
- Electrical vehicle integration
- Demand side management
- Energy management
TeknoCEA introduction

**teknoCEA** is a spin-off company from the Technical University of Catalonia (UPC – BarcelonaTech)

More than **20 years of experience** in power converters, DSP based **digital control**, industrial communications, and power system analysis

Founders are professors of the Electrical Engineering Department (UPC) and members of the **CITCEA-UPC** research centre

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What do we do?

**teknoCEA** power electronics portfolio covers a wide range of applications, such as testing, emulation, education and research.

**Components**

Ready to use equipment for research, industry and utility sectors.

*Power converters, Control boards, SiC drivers and interface*

**Systems**

We design, develop and build custom solutions by integrating our power converters, control boards and communications systems.

*Programmable emulators, DSP Starter Kits, Microgrids, Custom systems*

**Services**

We provide renting and leasing services of lab equipment for our customers, and engineering services.

*Consulting, Electrical and Energy Engineering Analysis and studies*
Modular and flexible converters

Applications and usage

- AC-DC active front-end (PV inverter, active filtering, V2G applications, microgrids ...)
- DC-DC converters: half bridge, H-bridge, interleaved converter
- AC motor drive

Main Features

- Three phase voltage source converter
- 20 kVA, 40 kVA, 60 kVA and 100 kVA
- 800 VDC maximum voltage
- 64 kHz max. switching frequency
- Isolated drivers (UVLO, desaturation protection)
- Isolated current and voltage measurement
- Isolated digital I/O for external control functions
- Fit teknoCEA control boards
Fully customized power electronics systems and cabinets

Applications and usage

• Custom research testbed
• Renewables grid integration
• Microgrids and Smart Grids
• Testing set-up
• Power electronics applications

Main Features

• 10 kVA, 20 kVA, 40 kVA, 60 kVA and 100 kVA three phase converters available
• 400 VAC, 800 VDC
• Customizable output power inductor and capacitor filter, and transformer
• Protections, and EMI filtering
• Electrical schematics included
• Programing code examples

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Objectives and Motivation

• The rural distribution networks are more vulnerable than urban distribution grids but the emergence of distributed generation can contribute to overcome this weakness.
• Increased efficiency, power quality and network resilience must be assured.
• The rural distribution networks require a new type of thinking as new options and new technologies emerge. This need is now imminent.

• Developing an Intelligent Distribution Power Router (IDPR)
• Developing a data and energy control system that manages local micro-production units and IDPRs
• Integrating all the novel features into one, single platform
• Demonstrating and validating the system full-scale in two European regions to assess the technological and economic feasibility of this new, innovative platform.
Case study

Transformer

MV Switchgear

Smartmeters technologies

Fuses for the LV lines

MV Switchgears
Case study
Case study

Normal operation

Mode 1: Connected to the main grid

Mode 2: Isolated by planned tasks

Emergency operation

Mode 3: When the main grid is not operative

Mode 4: When there is/are inoperative internal sections
IDPR

Operational modes

- **Grid mode:**
  - Produce/consume active power
  - Produce/consume reactive power (compensation)
  - Compensate unbalanced loads
  - Harmonics compensation

- **Island mode:**
  - Create an stable network voltage
IDPR

Main Characteristics

- 4 branches
- Dc bus midpoint connected to the neutral
- Interleaved DC/DC
- Sinusoidal modulation
- Transformerless (no common mode).
- No 100 Hz oscillations from battery are transmitted
Power module

Laboratory IDPR version
- 34.5 kW (4x CCSPC stack)
- Size: 710x310x340mm aprox
- $L \approx 400 \ \mu H \ (\overline{Ø} = 165 \ mm)$
- Big, accessible but heavy and complex to assembly

IDPR pilot area unit version
- 20 kW (1 x CCSPC stack)
- Size: 440 x 133 x 210 mm
- Rack mounting enclosure
- AC LC-type coupling filter included
  - $L \approx 500 \ \mu H \ (\overline{Ø} = 100 \ mm) + C \ \text{up to} \ 30 \ \mu F$
- Optional extra DC-link
- Easy to parallelize
- Weight: $\approx -25 \ kg$ than lab version
Master control board
- 1 per each IDPR
- Based on DSP from TI F28M36 (BGA)
  - Two cores: DSP+ARM

Slave control board
- Each one manages 2 power cells
- Based on DSP from TI F28M35 (HTQFP)
  - Two cores: DSP+ARM

Battery
- LiFePO₄ battery
- 320 V-60 Ah
- BMS RS-485
- 320 x 809 x 1178 mm

Power cell
- 20 kW
- Three-legs 1200 V – 25 A
- SiC technology
- Compact LC output
- 1.35 mF per power cell
  - Forced air-cooling
  - High performance heat-sink
  - \( L \approx 500 \, \mu \text{H} + C \) up to 30 \( \mu \text{F} \)
- 440 x 133 x 210 mm

Extra DC-link
- + 3.9 mF
- Integrated discharge circuit
- 440 x 88.9 x 210 mm

Interleaved DC/DC converter
Four-wire three-leg inverter with DC-link split capacitor
Control

Scheme when batteries are considered
GSI (grid-connected)
GCI (grid-disconnected)

Scheme when no batteries are considered
GSI (grid-(dis)connected)
Control

Low voltage grid
400 V – 50 Hz

Loads
Zt Zs Zr

Sg

IDPR

inverter stage

dc/dc stage

Battery

Boost battery voltage
DC-link active balancing

Battery: 294 VDC
DC-link: 800 VDC

DC-link: 800 VDC
+ to dcn: 450 VDC
dcn to -: 350VDC

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Control

Resonant controllers

Conventional formulation

\[ G_{PR-HC}(s) = k_P + k_I \frac{s \omega_0}{s^2 + \omega_0^2} + \sum_{k=2}^{n} \frac{k_{1k}}{s \omega_k} \frac{s \omega_k}{s^2 + \omega_k^2} \]

New formulation

\[ G_{R\alpha} = \frac{\omega_0 s^\alpha}{s^2 + \omega_0^2} \]

![Magnitude and Phase Plots](image-url)
General architecture

![Diagram](www.teknocea.cat)
DC Bus control

\[ V_{dc}^* \]

\[ V_{dc}^+ + V_{dc}^- \]
\[ f_{pll} \]

Notch adaptive
\[ f_c = f \pm 2 \text{ Hz} \]

\[ V_{dc} \]

\[ V_{dc}^* \]

\[ V_{dc}^+ - V_{dc}^- \]
\[ f_{pll} \]

**Notch adaptive**
\[ f_c = f \pm 2 \text{ Hz} \]

**DC Bus control**

**DC Bus control**

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Current loop (active filter)
P/Q Setpoints

AC Voltage control

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EMTP-RV Modelling
Simulation Results

• Reactive current compensation
• Unbalance current compensation
• Harmonics compensation
• Linear load transient
• Non linear load transient
• Over load (OL) response
Reactive current compensation (grid-connected)

- The master reads the load current.
- It calculates the direct, inverse and zero sequence current components (Fortescue transformation).
- To compensate unbalance, the IDPR injects the inverse and zero sequence of the load.
- To compensate reactive, the IDPR injects the quadrature (dq0 transformation) component of the direct sequence.

<table>
<thead>
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<th>Test conditions</th>
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<tbody>
<tr>
<td>$Z_r$</td>
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<tr>
<td>$Z_s$</td>
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<tr>
<td>$Z_t$</td>
</tr>
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<td>Harmonic current compensation enabling</td>
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<tr>
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<tr>
<td>Active power setpoint</td>
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Green $V_r$

Cyan $I_p / I_{gr}$

Magenta $I_s / I_{gs}$

Black $I_l / I_{gt}$

Graphs showing grid current before and after compensation.
Unbalance current compensation (grid-connected)

- The master reads the load current.
- It calculates the direct, inverse and zero sequence current components (Fortescue transformation).
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<td>( Z_s )</td>
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<tr>
<td>No load</td>
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<tr>
<td>( Z_l )</td>
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<tr>
<td>( I_{lr}/I_{gr} )</td>
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![Graph showing load and grid currents](image)

![Graph showing load and grid currents](image)
Harmonics compensation

(grid-connected)

- The master reads the load current and calculates de odd harmonics up to the 15th component.
- The master establish as set-point the sum of the harmonics components from the 3rd to the 15th.
- The harmonic compensation set-point is calculated at a 10 kHz frequency. It limits the THD compensation.
- At this frequency, the THD reduction can be more than 30 times when some predictive control lead phases are considered.

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**Grid current ($I_{gr}$)**

THD: 0.87%

**Load current ($I_{lr}$)**

THD: 61.1%

**IDPR current ($I_{cr}$)**

THD: 0.91%
**Linear load transient**

(grid-disconnected)

- In case of a grid fault event, the DSO is able to use the IDPR to generate a island to feed the local loads.
- The IDPR can generate an stable AC voltage at the PCC (Point of Common Coupling) while feeding any kind of load (in this case Linear loads).

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![Diagram of island mode and PCC](image)

![Graph of grid disconnected voltage](image)
In case of a grid fault event, the DSO is able to use the IDPR to generate an island to feed the local loads.

The IDPR can generate an stable AC voltage at the PCC (Point of Common Coupling) while feeding any kind of load (in this case non-linear loads).
In case of a grid fault event, the DSO is able to use the IDPR to generate an island to feed the local loads.

The IDPR can generate an stable AC voltage at the PCC (Point of Common Coupling) while feeding any kind of load (in this case over-load response fixing the rms limit of the current at 42 A).
Over-load (OL) response (II)

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Steady state with overload limitation

(a) **OL disabled**

(b) **OL enabled**
Final implementation

• Three different installations
  – Artigues
  – Verger
  – Planallonga

• Two with battery, one without
Artigues’ IDPR

- Sub-station location
- Operates as CC-VSI when grid-connected
  - Compensates harmonic current components
  - Compensate unbalance currents
  - Compensate reactive currents
  - Manages active power
- Operates as VC-VSI when grid-disconnected
  - Able to feed loads

- 4x Power cells
  - 2x DC/DC
  - 3x Inverter
- 1x extra DC-link modules
- 2x slave control boards
- 1x master control board

Pictures during FAT
(at CITEA-UPC’s facilities)
Verger’s IDPR

- Sub-station location
- Operates as CC-VSI when grid-connected
  - Compensates harmonic current components
  - Compensate unbalance currents
  - Compensate reactive currents
  - Manages active power
- Operates as VC-VSI when grid-disconnected
  - Able to feed loads

- 6x Power cells
  - 3x DC/DC
  - 3x Inverter
- 3x extra DC-link modules
- 3x slave control boards
- 1x master control board

Pictures during FAT
(at CITEA-UPC’s facilities)

Pictures during SAT
(at Estabanell’s pilot area)
Planallonga’s IDPR

- Pole location
- Only operates as CC-VSI
  - Compensates harmonic current components
  - Compensate unbalanced currents
  - Compensate reactive currents
  - Not able to feed loads: no battery
  - Not able to manage active power: no battery
- 1x Power cell
- 1x extra DC-link module
- 1x slave control board

Pictures during FAT
(at CITEA-UPC’s facilities)

Pictures during SAT
(at Estabanell’s pilot area)
IDPR
Auxiliary batteries
Auxiliary batteries charger
RTU (LC + TC)
Industrial PC (LEMS)
Communications
Switchgear
Real results
Conclusions

Goals

• Explore improvements in the design in order to reduce wiring, weight, maintenance and cost from the IDPR laboratory version
• Design, build, test & validate of functional pilot area IDPR units

Achievements

• New inner controller formulation tested under real conditions, with satisfactory performance
• Validation of the reference generator over Ethernet in a master/slave hierarchy in order to allow harmonic + unbalance + reactive compensation
• Physical (working pilot area prototypes and storage integration)
Thank you for your attention

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Worldwide energy challenge needs smart engineers to develop smart solutions with a very strong knowledge and life-long learning.