NEW CONFIGURATIONS OF POWER CONVERTERS FOR GRID INTERCONNECTION SYSTEMS

Prof.-Dr. Marco Rivera
Universidad de Talca, Curicó, CHILE
Outline

• Chile in the World

• The University of Talca

• Energy Conversion and Power Electronics Research Group

• Introduction

• Micro-grids

• Power Converters in Micro-grids

• Power Converter topologies with MF/HF Isolation for Grid Interconnection Systems

• Conclusions
Chile in the World

Area: 756102,4 km²
PIB: 24.170 USD
Maule in Chile

Area
30269,1 km²

Population
1.042.898 hbt.
The University of Talca
Universidad de Talca

www.utalca.cl

5 Campuses
8 Faculties
~10000 Students
35 Undergraduate programs
37 Postgraduate programs

Mashhad – Iran
14-16 February 2017
Energy Conversion and Power Electronics Research Laboratory

- Started in 2012 – We are a very young group
- 5 Academics
  - Prof. Carlos Baier
  - Prof. Johan Guzmán
  - Prof. Javier Muñoz
  - Prof. Marco Rivera
  - Prof. Carlos Restrepo
- 2 Postdoc
- 6 Master students
- 1 PhD student
- More than 30 undergraduate students
- 7 labs with more than 300m2
Research Group

- LARI-AACA - Lab. of Intelligent Network Applications – Area of Alternating Current Applications (45 m²)
  Prof. Carlos Baier

- LARI-AACC - Lab. of Intelligent Network Applications – Area of Direct Current Applications (45 m²)
  Prof. Carlos Restrepo

- LEM-UTALCA - Lab. of Electrometallurgy of the University of Talca (30 m²)
  Prof. Johan Guzmán

- LERAE - Lab. of Renewable Energy and Electrical Conditioning (35 m²)
  Prof. Javier Muñoz

- LCEEP-01 - Energy Conversion and Power Electronics Laboratory (24,69 m²)
- LCEEP-02 - Energy Conversion and Power Electronics Laboratory (20,35 m²)
- LCEEP-03 - Energy Conversion and Power Electronics Laboratory (105,6 m²)
  Prof. Marco Rivera
Research Group – National and International Collaboration

- Ryerson University – Canada
- McGill University – USA
- North Arizona – USA
- Georgia Institute of Technology – USA
- Tecnológico de Monterrey – México
- Instituto Politécnico Nacional – México
- Universidad Nacional de Asunción – Paraguay
- Instituto Tecnológico de Buenos Aires – Argentina
- Universidad Nacional de La Plata - Argentina
- The University of Nottingham – UK
- Aalborg University – Denmark
- ETH Zurich – Switzerland
- The University of Newcastle – Australia
- The University of New South Wales – Australia
- University of Belgrade – Serbia
- Universidad de Concepción – Chile
- Universidad Federico Santa María – Chile
- Universidad de Chile – Chile
- Universidad de Santiago – Chile
- Universidad Católica de la Santísima Concepción – Chile
- Universidad Andrés Bello – Chile
- Universidad del Bío-Bío – Chile
- Universidad de Magallanes - Chile
- Universidad de la Frontera – Chile

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I am looking forward to cooperate with you.

Iran University of Science and Technology (IUST)
Prof. – Dr. Davood A. Khaburi

- 1 ISI Journal
- 5 Scopus conference

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- Universidad de la Frontera - Chile

😊 Almost 200 papers

😊 Different projects

- Fondecyt
- Conicyt
- Newton Picarte
- Local government
- More than USD 1.000.000
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😊 45 ISI Journals
😊 127 Conference

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Research Lines - Matrix Converters
Research Lines - Matrix Converters
Research Lines - Matrix Converters
Research Lines - Predictive Control in Power Converters and Drives

Electric power grid → Power system impedance ($Z_s$) → STATCOM based 7-level CHB → Shunt power filter → Loads ($Z_L$)

Cost function optimization $g(k+2)$ → $S_{opt}$

Current reference generator: $i_{abc}^L$, $i_{abc}^c$, $Q_c$ → Finite-state predictive model: $i_{abc}^c$, $i_{abc}^c$, $v_{abc}^c$
Research Lines - Predictive Control in Power Converters and Drives
Research Lines - Predictive Control in Power Converters and Drives

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Research Lines - Predictive Control in Power Converters and Drives
Current Research Projects

- Advanced vector control techniques for high accuracy and fast dynamic power response of wind turbine, REDES150034, Curtin University, Bentley, Australia.


- Optimal design of predictive controllers for power converters in renewable energy applications, REDES150053, The University of Newcastle, Australia.


Introduction
Introduction
The technological and economic development has lead to an increase in the energy demand.

**World energy consumption**

- **Fossil fuels**
  - Oil
  - Coal
  - Natural Gas
  - Hydro
  - Nuclear
  - Other Renewable

**Year**
- 1970
- 1980
- 1990
- 2000
- 2010

**Energy, 1000 TWh per year**
- 0
- 5
- 10
- 15
- 20
It is well known that energy resources based on fossil fuels is very limited. Chile has little natural gas and oil resources. The extraction costs of coal are high.
There is a huge social opposition to the electrical development, because the perception of the community to this development is associated with environmental deterioration and social cost.
Introduction

Almost 4200 kms.
Introduction

- Limited fossil fuel resources.
- High extraction costs of fossil fuels.
- Social opposition for energy development.

This has lead to higher generation costs and thus high electricity prices for the consumers, affecting the competitiveness of the country.
Introduction

“A safe and efficient energy development, with reasonable prices, that take advantage of the renewable resources in a sustainable and non-polluting way”.

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Introduction

Big earthquake 27 Feb. 2010 – 8.8° Richter
Big Storm 23-25 March 2015
Communication problems and thousands of people without electricity for several days

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14-16 February 2017
Introduction

Big earthquake 25 Dec. 2016 – 7.6° Richter
Big Fire Middle of Jan. 2017
Communication problems and thousands of people without electricity for several days
Introduction

Chilean energy program 2014-2018

Electrical Systems Interconnection
Introduction

Chilean energy program 2014-2018

Using non-conventional renewable energies
Introduction

Chilean energy program 2014-2018

Installations of micro-grids in isolated areas
Introduction

Norte Grande Interconnected System
Arica y Parinacota, Tarapacá, Antofagasta

4.183.86 MW (20.6%)

Central Interconnected System
Atacama, Coquimbo, Valparaíso
Región Metropolitana
Lib. B. O’Higgins, Maule, Bío bío
Araucanía, Los Ríos, Los Lagos

16.011.46 MW (78.7%)

Aysén System
Aysén

50 MW (0.3%)

Magallanes System
Magallanes

101.68 MW (0.5%)

Electrical Systems Interconnection
Introduction

Amanecer 100 MW, the biggest in Latin America

Canela 78 MW

Colbún Machicura 3848 MW

Solar
724 MW
100,000 MW

Wind
911 MW
40,000 MW

Hidro
6,544 MW
21,000 MW

Geothermal
0 MW
16,000 MW

Biomass
442 MW
14,000 MW

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Introduction

Huatacondo, the first microgrid in Chile

- 150 kW diesel generator
- 22 kW tracking solar PV system
- 3 kW wind turbine
- 170 kWh battery
- An energy management system

To improve the life quality of the population
Micro-grids
A micro-grid is a localized station with its own power resources, generation and loads.
Micro-grids involve multiple energy sources as a way of incorporating renewable energy, reducing costs and enhancing reliability.
Micro-grid system based on Solar/Thermal generation
Micro-grids involve multiple energy sources as a way of incorporating renewable energy, reducing costs and enhancing reliability.
Micro-grid system based on Wave/Ocean generation
Micro-grid system based on Hydro power generation

In this micro-hydropower system, water is diverter into the penstock. Some generators can be placed directly into the stream.
Micro-grids working in Islanded / Grid Connected mode
Power Converters in Micro-grids
Role of Power Converters

Power converters allow the integration to the electrical network of different kind of generation and distributions systems.
Power Converters used in Micro-Grid Applications

Two level Voltage Source Inverter

Three level Neutral Point Clamped Inverter
Power Converters used in Micro-Grid Applications

Cascade H-bridge

Modular Multilevel Converter
Power Converters used in Micro-Grid Applications

Most of power converters include storage elements

Two level Voltage Source Inverter

Three level Neutral Point Clamped Inverter
Power Converters used in Micro-Grid Applications

- Cascade H-bridge
- Modular Multilevel Converter

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Power Converters used in Micro-Grid Applications

- Simple and compact circuit.
- Directly connects the AC-source with any arbitrary AC-load.
- No need for storage elements.
- Suitable for applications where weight and size are important issues.
- Regenerative capacity.

Matrix Converter
Power Converters used in Micro-Grid Applications

YASKAWA

- A complete line of standard units for up to several megawatts and medium voltage using cascade connection.
- These units have rated power (voltages) of 9–114 kVA (200 and 400 V) for low-voltage MC and 200–6.000 kVA (3.3 and 6.6 kV) for medium voltage.

AC7 - Matrix Converter
Power Converters used in Micro-Grid Applications

- Military
- Aerospace
- Wind Generation Systems

- No deeply studied in applications for grid interconnection of micro-grids, generation systems and/or loads.

Matrix Converter
Power Converters used in Micro-Grid Applications

A modified matrix converter topology for grid integration of two AC sources to the utility grid.

Power Converters used in Micro-Grid Applications

- New multilevel topologies have appear in order to use the matrix converter in high power applications.

- A multimodular matrix converter for wind power generation applications. (Each cell is an H-bridge)

Power Converters used in Micro-Grid Applications

- The structure allows the use of low voltage power semiconductors

Universal and flexible model for grid interconnection

Why? ... Chilean architecture network in only one direction
Universal and flexible model for grid interconnection

Providing a more flexible and modular power electronics interface able to connect different kinds of sources and loads including medium voltage electrical networks, renewable energy sources and energy storage systems.
Universal and flexible model for grid interconnection

Providing a more flexible and modular power electronics interface able to connect different kind of sources and loads including medium voltage electrical networks, renewable energy sources and energy storage systems.
Universal and flexible model for grid interconnection

It requires a flexible power management control in order to ensure proper and secure operation of the networks.

Providing a more flexible and modular power electronics interface able to connect different kind of sources and loads including medium voltage electrical networks, renewable energy sources and energy storage systems.
The structure will allow the interconnection of different generation systems and loads with a multidirectional power flow capability.
Requirements for the future electricity network

- Galvanic Isolation

- Multi-directional power flow capability

- Flexibility and scalability

- Easy maintenance and low cost

- Compact power conversion and low weight

- High efficiency and reliability
MF/HF isolated AC/DC conversion solutions

Power converter configurations

AC/DC/MF/DC/AC
MF/HF isolated AC/DC conversion solutions

Power converter configurations

AC/DC/MF/DC/AC
MF/HF isolated AC/DC conversion solutions

AC/DC/MF/AC

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Another MF/HF isolated AC/AC conversion solutions

Power converter configurations

AC/MF/AC
- All the configurations are **modular structures**, allowing easy replacement of the cells in case of failure.

- All the configurations have **the same number of commutation devices**.

- All the configurations schemes are able to operate with **multi-directional power flow**.

- The third alternative does not include energy storage elements, **reducing the weight and size**. In addition, there is not need for DC-link controllers and **the potential for failure is reduced**.
### Universal and flexible model for grid interconnection

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Type of Isolated Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AC/DC/DC/AC (VSIBM)</td>
</tr>
<tr>
<td>Number of stages</td>
<td>3</td>
</tr>
<tr>
<td>Number of DC link</td>
<td>2</td>
</tr>
<tr>
<td>Converter cell size</td>
<td>Bigger than the other two</td>
</tr>
<tr>
<td>Modulation</td>
<td>Higher degree of ease</td>
</tr>
<tr>
<td></td>
<td>Easier than CBM &amp; Dual-CBM</td>
</tr>
<tr>
<td>Commutation</td>
<td>Easiest (Dead Time Method)</td>
</tr>
<tr>
<td>Conduction losses</td>
<td>Lower than CBM &amp; Dual-CBM</td>
</tr>
<tr>
<td></td>
<td>Lower than Dual-CBM</td>
</tr>
<tr>
<td>Weight of Converter Cell</td>
<td>Higher than CBM &amp; Dual-CBM</td>
</tr>
<tr>
<td>Core losses</td>
<td>3.9 W/kg</td>
</tr>
<tr>
<td>Ohmic losses</td>
<td>6 W/kg</td>
</tr>
<tr>
<td>Transformer Parameters</td>
<td>Rating</td>
</tr>
<tr>
<td></td>
<td>61.3 kVA</td>
</tr>
<tr>
<td></td>
<td>36.3 kVA</td>
</tr>
<tr>
<td></td>
<td>10 kVA</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
</tr>
<tr>
<td></td>
<td>Number of cores</td>
</tr>
<tr>
<td></td>
<td>Overall Efficiency</td>
</tr>
<tr>
<td></td>
<td>Overall Transformer Efficiency</td>
</tr>
</tbody>
</table>
Modulation of AC/MF/AC i.e. Dual-CBM configuration
Modulation of AC/MF/AC i.e. Dual-CBM configuration

When demanded frequency is equal to input frequency i.e. $f_i = f_o$
Modulation of AC/MF/AC i.e. Dual-CBM configuration

A case when demanded frequency is lesser than input frequency e.g. connecting 60Hz and 50Hz grids i.e. \( f_0 < f_i \)

- Low order Harmonics – Worst filtering requirements e.g. large & expensive filters.
- Bad Spectrum – Difficult to eliminate low order harmonics.
Modulation of AC/MF/AC i.e. Dual-CBM configuration

Drawbacks of AC/MF/AC Single-Phase Converter (Dual-CBM)

- It is not a viable solution for the applications requiring frequency regulation e.g. v/f control of drives.
- Its failure in the applications interconnecting two systems at different frequencies e.g. interconnection of 60Hz and 50Hz grid.

Reason of Drawbacks
- Converter has single phase input i.e. output is limited to single phase input (in terms of selection).
Modulation of AC/MF/AC i.e. Dual-CBM configuration

Drawbacks of AC/MF/AC Single-Phase Converter (Dual-CBM)

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- Converter has single phase input i.e. output is limited to single phase input (in terms of selection).

Possible Solution
- Increasing the input options of the converter i.e. utilizing the concept of matrix converters.
Evolution of a new AC/MF/AC topology

Modifications in the topology

- Utilizing 3-phase input. At any instant, three input options.

- Modularity, galvanic isolation, bi-directional power capability, etc.

A new 3-phase to 1-phase isolated AC/AC topology using three Dual CBMs
Evolution of a new AC/MF/AC topology

Input voltage ICBM

Input voltage OCBM

Input voltage OCBM

Input current ICBM

Input current OCBM

Input current OCBM

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Evolution of a new AC/MF/AC topology

Input frequency $f_i = 50$Hz

Output frequency $f_o = 40$Hz

Output frequency regulation at 40Hz regardless of the input frequency change, i.e. 50-86 Hz, applied at time=1s

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Extension to 3-phase to 3-phase isolated AC/AC topology

A new 3-phase to 3-phase isolated AC/AC topology

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Conclusions
Conclusions

• The growing technological development has increased the demand of more available energy.

• It is necessary a safe and efficient energy development, with reasonable prices, that take advantage of the renewable resources in a sustainable and non-polluting way.

• There are several power converter topologies for micro-grid applications.

• Potential of isolated AC/AC direct converter topologies has been discussed.

• Identification of problem in a single cell i.e. in a single phase to single phase topology.

• Modification of the topology comes at the cost of an increased number of switching devices while keeping modularity intact as well as bi-directional power flow.

• This new AC/AC isolated topology will have a wider range of applications e.g. grid applications, AC drives etc.
IMPORTANT DATES
May 31, 2017
Full paper submission

July 31, 2017
Notification of acceptance

August 30, 2017
Final paper submission
Thanks for your attention ...

Contact:
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IEEE Power Electronics Society
SOUTHERN POWER ELECTRONIC CONFERENCE

4-7 DECEMBER
2017 HOTEL PATAGÓNICO
PUERTO VARAS - CHILE