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Investigación en Electrónica de Potencia y Microredes Universidad de Chile

Roberto Cárdenas Dobson
Profesor Titular (Full Professor)
Departamento de Ingeniería Eléctrica
Universidad de Chile
Página Personal

die magíster doctorado | Ingeniería Eléctrica

www.die.uchile.cl

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Introducción al DIE

Mejor Departamento en Ingenieria Eléctrica y Electrónica de Latinoamérica, de acuerdo al Shanghai World University Ranking.

Ver Ranking

die

Cuerpo Académico (pre pandemia)

- 23 académicos de jornada completa distribuidos en cinco áreas.
- 6 profesores extranjeros.

FACULTAD DE CIENCIAS FÍSICAS Y MATEMÁTICAS UNIVERSIDAD DE CHILE

Alta Diversidad en la Formación de los Académicos

Roberto Cárdenas
Ph.D.
University of Nottingham, UK

Rodrigo Moreno
Ph.D.
Imperial collegue of London, UK

Sandra Céspedes
Ph.D.
University of Waterloo

Patricio Mena
Ph. D.
Universidad de Groningen, Holanda

Rodrigo Palma
Dr. Ing.
University of Dortmund, Alemania

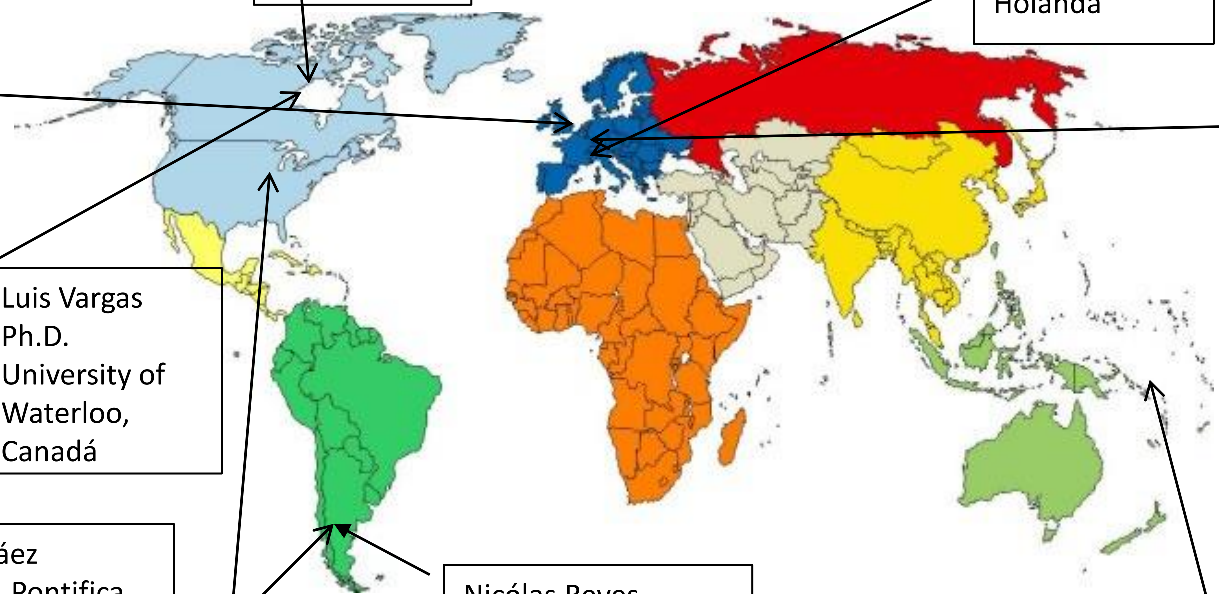
Martin Adams
Ph. D.
University of Oxford, UK

Ernest Michael
Dr. Rer. Nat.
University of Cologne, Alemania

Néstor Becerra-Yoma
Ph.D. University of Edinburgh, UK.

Luis Vargas
Ph.D.
University of Waterloo, Canadá

Javier Ruiz del Solar
Dr. Ing. TU Berlín, Alemania



Claudia Rahmann
Dr. Ing. RWTH Aachen University.

Doris Sáez
Dr. Ing., Pontifica Universidad Católica de Chile

Nicólas Reyes
Dr. Ing., Universidad de Chile

Claudio Estévez
Ph.D Georgia Institute of Technology, USA

Marcos Díaz
Ph.D. Boston University

Manuel Duarte
Ph.D. Yale University, USA

Claudio Held
Ph. D., Rensselaer Polytechnic Institute, USA

Marcos Orchard
Ph.D. Georgia Institute of Technology, USA

Claudio Pérez
Ph.D. Ohio State University, USA

Jorge Silva
Ph.D. University of Southern California, USA

Patricio Mendoza
Ph.D. University of Wisconsin Madinson

Pablo Estévez
Dr. Ing. University of Tokyo, Japón

Cesar Azurdia
Dr. Ing. Kyung Hee University, Korea

Áreas de especialización

- **Sistemas de Control. (mi grupo)**
- Energía & Sistemas de Potencia.
- Señales & Sistemas de Comunicación.
- Robótica & Sistemas Inteligentes.
- Instrumentación Astronómica.




Grupo de Control

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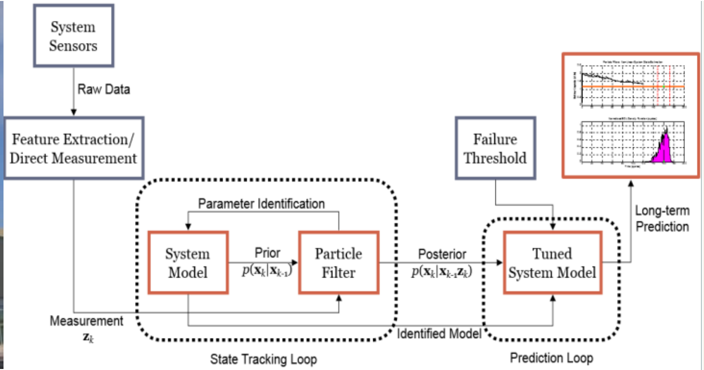
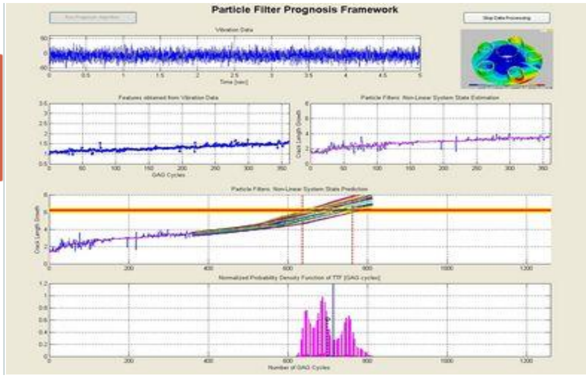
Sistemas de Control.

- Sistemas dinámicos
- Sensores virtuales
- Diagnóstico de fallas
- Control adaptativo
- Lógica difusa y redes neuronales
- Algoritmos evolutivos

- Industria del vino
- Instrumentación médica
- Baterías de litio
- Vehículos autónomos
- Sistemas de transporte.
- Control de Máquinas
- Microredes





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¿Quiénes Somos?

- Roberto Cárdenas Dobson, Prof. Titular, Ph.D. in Electrical and Electronic Engineering, U de Nottingham 1996. Áreas de trabajo, Electrónica de Potencia y control digital de máquinas eléctricas.
- Doris Sáez Hueichipan, Prof. Titular, Doctora en Ciencias de la Ingeniería, PUC, 2000. Áreas de trabajo, Control predictivo y control difuso.
- Marcos Orchard Concha, Prof. Titular, Ph.D. in Electrical and Computer Engineering, The Georgia Institute of Technology, 2007. Áreas de trabajo Detección de fallas y predicción de eventos catastróficos.
- Jorge Silva Sánchez, Prof. Asociado, Ph.D. University of Southern California, 2008. Proc. Estadístico de señales, estimación y decisión.
- Constanza Ahumada Sanhueza, Prof. Asistente, Ph.D. in Electrical and Electronic Engineering, University of Nottingham, 2018. Área de trabajo Control de interacciones electromecánicas.

Productividad

- El índice H (WoS) del grupo es de 60 con variaciones entre 35 y 14.
- Dos académicos en al 2% superior a nivel mundial de acuerdo al ranking de la Universidad de Stanford.
- El grupo ha ganado 23 proyectos Fondecyt (contando solo PIs), 9 proyectos Fondef (director y director alterno) , tres proyectos Fondequips y participa en un Fondequip mayor.
- En los últimos 10 años hemos publicado 210 papers en revistas de la base WoS. Una buena parte de éstas son publicaciones de primer cuartil.
- Este año se adjudicó, como entidad asociada, un Fondequip mayor por 122 millones de pesos con el objetivo de investigar la descarbonización del sistema de potencia nacional.
- Participamos como investigadores asociados y titulares de proyectos basales como SERC, AC3E, Instituto de sistemas complejos, entre otros.

Colaboración Internacional

- Doctorados de doble grado con la Universidad de Nottingham UK. y la Universidad de Waterloo (Canadá). Cinco doctores ya graduados, y tres todavía cursando sus estudios en Nottingham. Total 8 hasta ahora.
- Existe un nuevo acuerdo de doctorado de doble grado que se está discutiendo con la Universidad Politécnica de Cataluña (Oriel Gomis).
- Colaboración internacional a nivel de proyectos, papers y estadías para alumnos y profesores, con la Universidad Tecnológica de Múnich (C. Hackl), Universidad de Newcastle UK (S. Mc Donald), Universidad de Edimburgo (M. Mueller), Universidad di Modena (S. Nuzzo), Universidad de Pisa (Luca Papini), Universidad de Waterloo (M. Kazerani), U de Toronto (J. Simpson), U de Aalborg (J. Guerrero), U de Oviedo (F. Briz), U. de Jaen (J de la Casa), Politécnico de Cataluña (O. Gomis), Politécnico de Milano, U de Ljubljana (I. Skjranc), Universidad de Sidney (R. Aguilera), etc.

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Formación de Capital Humano

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Formación de Capital Humano

- Contamos con 19 doctores ya graduados y llegamos a 22 si se cuentan los guiados y co-guiados. Dos más están a la espera del examen de grado.
- Tenemos 61 alumnos de magister guiados y llegamos a 75 si se cuentan los co-guiados.
- 106 alumnos de primer grado guiados. Llegamos a 172 contando los co-guiados.
- En la actualidad nuestro grupo tiene 11 alumnos de doctorado y 10 alumnos de magister. Estos se encuentran en distintas etapas de sus estudios.

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Doctores ya Graduados en el Grupo

(12-13 de ellos son profesores)

Graduado	Ocupación
Vanessa Quinteros (2019)	Profesora Asistente U. de Panamá (Claudio Estévez, co-guiada por Marcos Orchard)
Enrique Espina (2021) (*) (microredes)	Profesor Asistente USACH
Claudio Burgos (2019) (*) (microredes)	Profesor Asistente U de O'Higgins
Andrés Mora (2019) (*) (EP)	Profesor Asistente UTFSM sede Valparaíso
Mauricio Espinoza (2018) (*) (EP)	Profesor Asistente Universidad de Costa Rica.
Matías Diaz (2017) (*) (EP)	Profesor Asociado USACH.
David Acuña (2020)	Profesor Asistente PUC Santiago.
Aramis Pérez (2018)	Profesor Asociado Universidad de Costa Rica.
Jacqueline Llanos P. (2020)	Profesora Asistente Universidad de las Fuerzas Armadas ESPE, Ecuador
Luis Marín C. (2018)	Profesor Asistente Pontificia Universidad Javeriana, Bogotá, Colombia.
Carolina Ponce A. (2014)	Profesora Asistente, U. de la Serena

Doctores ya Graduados

(Post-docs y empresas nacionales e internacionales)

Graduados	Ocupación
Alfredo Núñez V. (2009)	Profesor Asociado, Intelligent Railway Infrastructure, TUDelft, Holanda
Felipe Donoso (2021) (*)(EP)	Siemens UK (Manchester)
Gina Sierra (2018)	SGT Inc. USA
Francisco Jaramillo (2018)	Postdoc U de Chile
Christopher Ley (2021)	Investigador AC3E
Juan Gomez Quinteros (2021)	Profesor Asistente Universidad Andrés Bello
Freddy Milla (2012)	Investigador CSIRO
Felipe Santibañez (2020)	ALGES/AMTC
Matias Urrutia (2022) (*) (EP)	Research Fellow, U de Nottingham, UK.
Alex Navas (2022)	Profesor Asistente Universidad Andrés Bello

Todos los graduados de nuestro grupo son contratados inmediatamente después de egresar (o antes) con muchos de ellos ejerciendo como profesores en Chile y el resto de Hispanoamérica.

Doctorandos Actuales

Electrónica de potencia y Microredes

Graduados	Ocupación
Yeiner Arias Esquivel	Profesor Asistente, Instituto Politécnico de Costa Rica.
Matias Uriarte	Profesor adjunto USACH
Felipe Herrera	Sin afiliación por ahora (originalmente de la Universidad de Talca)
Arturo Letelier	Sin afiliación (originalmente UTEM).

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Laboratorios

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Laboratorios del Grupo

(tenemos infraestructura de primer nivel que es utilizada por nuestros alumnos)

- Laboratorio de interacciones Electromecánicas. En este lugar se instalará el Equipamiento OPAL del Fondequip mayor (4to).
- Laboratorio de Control Avanzado.(3ro).
- Laboratorio de Electrónica de potencia y Accionamientos (-1). Este laboratorio fue financiado por un proyecto Fondequip. **(éste es uno de mis laboratorios)**
- Laboratorio de control de microredes (1ro. Electro-tecnologías). Este laboratorio fue financiado por dos proyectos Fondequips. **(Este es el otro laboratorio)**
- Laboratorio de Información y Decisión (5to piso).
- Laboratorio de prognosis y análisis de fallas (1ro Electro tecnologías)

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Power Electronic and Microgrids University of Chile

Roberto Cárdenas, Ph.D., Msc.
Full Professor
Página Personal
Department of Electrical Engineering
University of Chile

Universidad de Chile

Research Areas

- Microgrids
- LVRT control systems.
- 4-leg Converters.
- 3-leg and 4-leg NPC Converters.
- Multilevel converters
- Sensorless control methods for induction machines.
- 3-leg and 4-leg Matrix Converters.
- Variable speed generation.
- Hardware in the loop emulation.

I Have Chosen Two Fields

- MicroGrids, mainly our work with 4-leg converters.

- Multilevel Converters

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Lab of Control of Micro-Grids

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Triphase Microgrid

Power Electronics, Machines and Drives Laboratory .

Universidad de Chile

Research Using 4-Leg Converters in Microgrid Applications

Part of this work is realised using Triphase Converters

Part of this work is realised using Triphase Converters

Inside a triphase unit

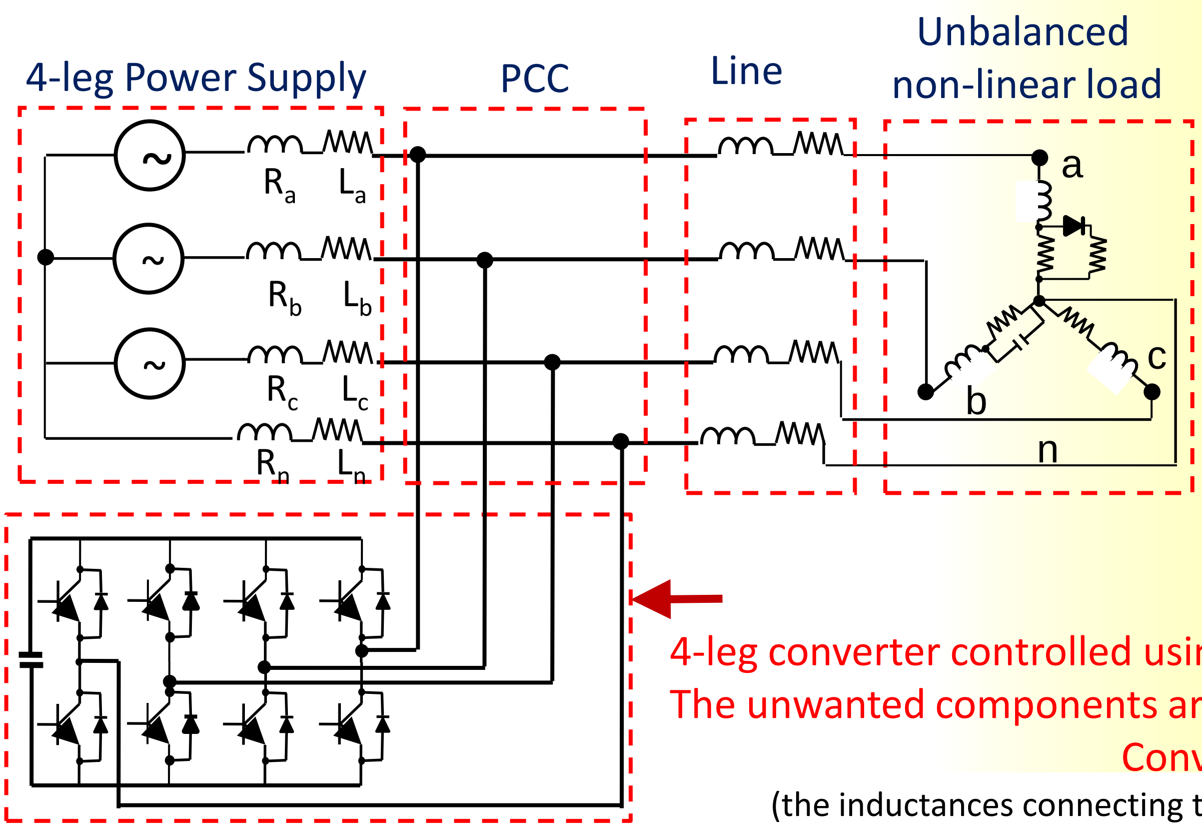
Converters loads

EXPERIMENTAL VALIDATION OF A 4-LEG ACTIVE FILTER

Based on the thesis work of Carlos Hernández (Msc. U Chile) and Carlos Burgos dual PhD. Uchile-U Notts.

C. Burgos, C. Hernandez, R. Cárdenas, D. Saez, M. Sumner, A. Costabeber, H. Morales, "Experimental Evaluation of a CPT-Based 4-leg Active Power Compensator for Distributed Generation", IEEE Journal of Emerging and Selected Topics in Power Electronics, (Special Issue on Distributed Generation), Vol. 2, no. 2, pp. 747-759, 2017

4-Leg Active Power Filter



4-leg converter controlled using a CPT-based algorithm
The unwanted components are supplied using this Converter

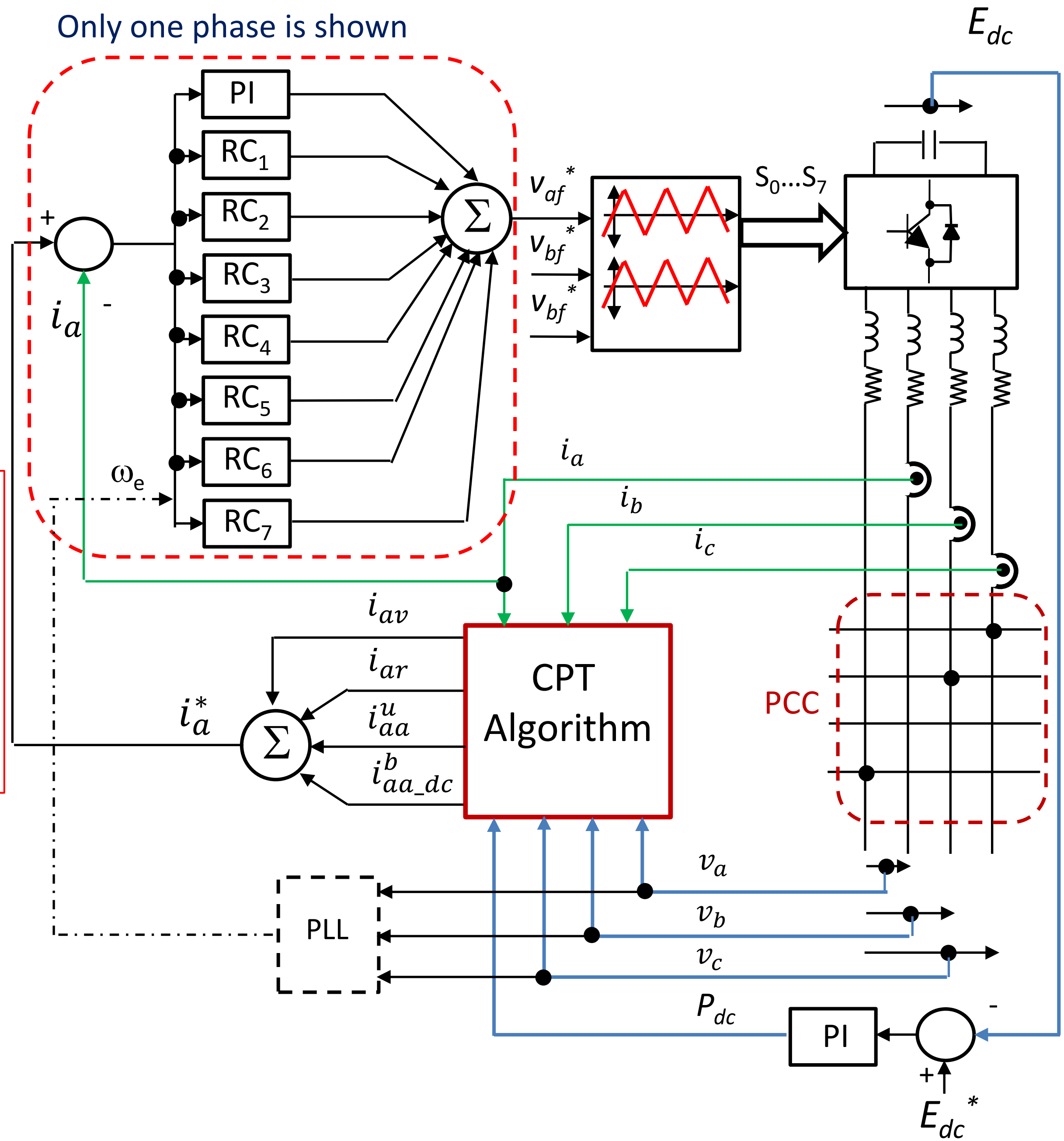
(the inductances connecting the power filter are not shown)

Control system implemented in the Dspace 1103 control Platforms.

It is based on one PI to eliminate DC signals and 7 resonant controllers.

The resonant controllers are self-tuned

i.e the resonant peak is tuned in real time.



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Experimental System

Programmable load

Dspace 1103

Ametek Power Supply

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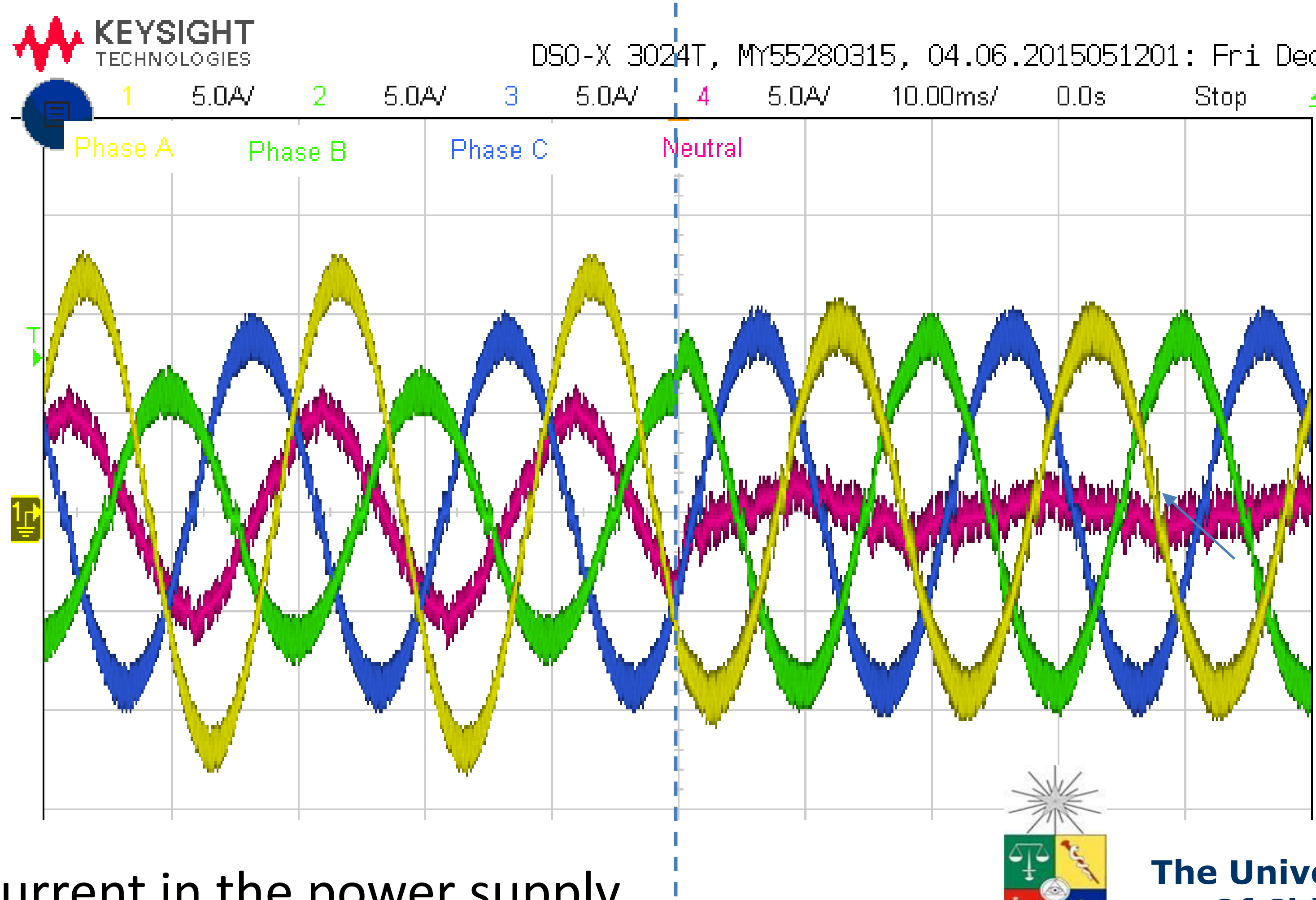
Unbalanced current operation

APF connection



Current in the power supply

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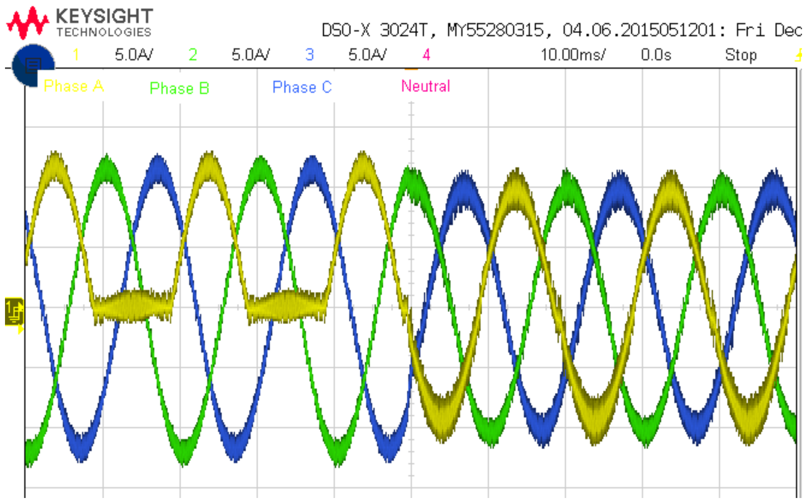
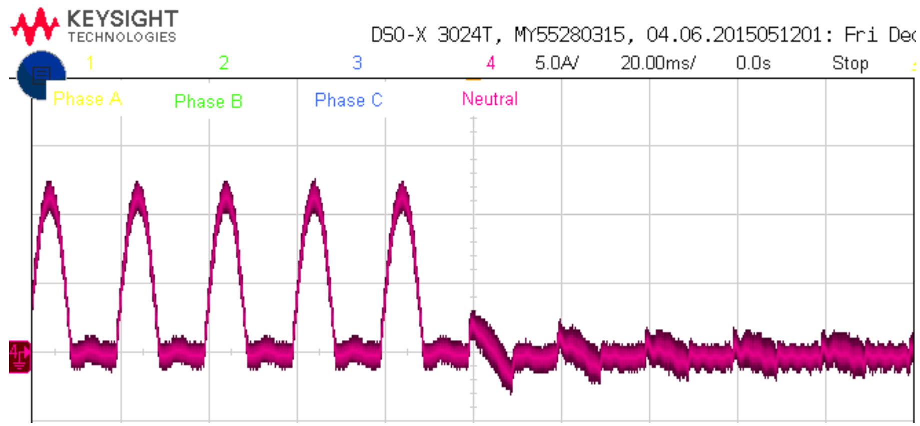
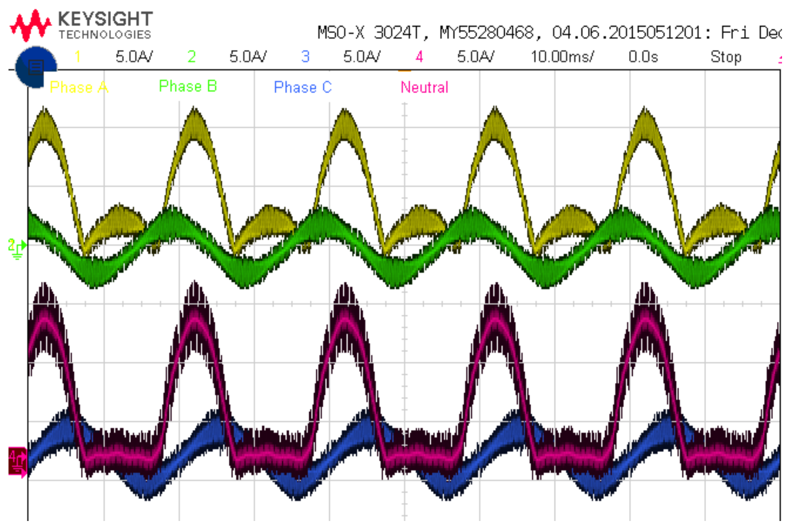
Non linear load



Power suppy

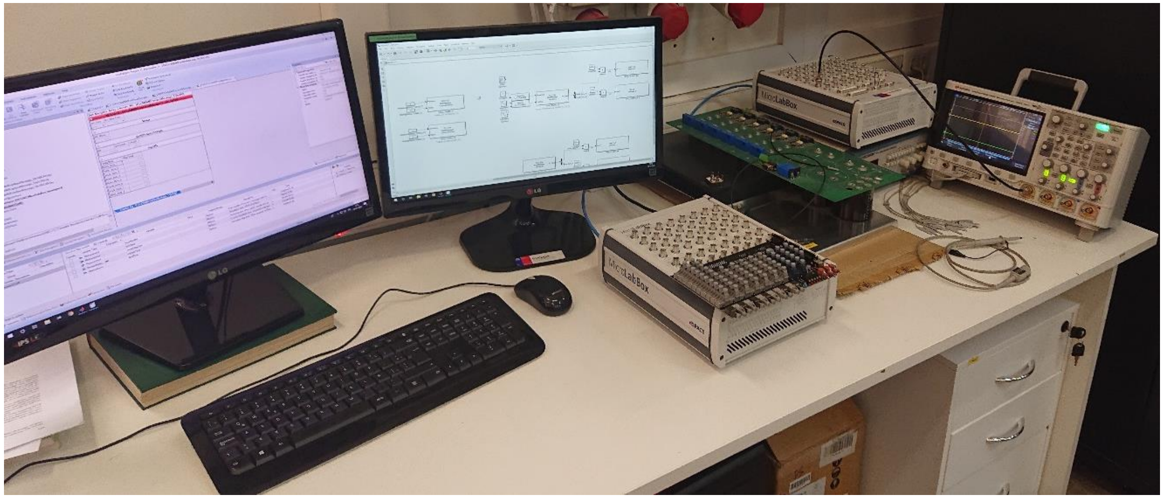


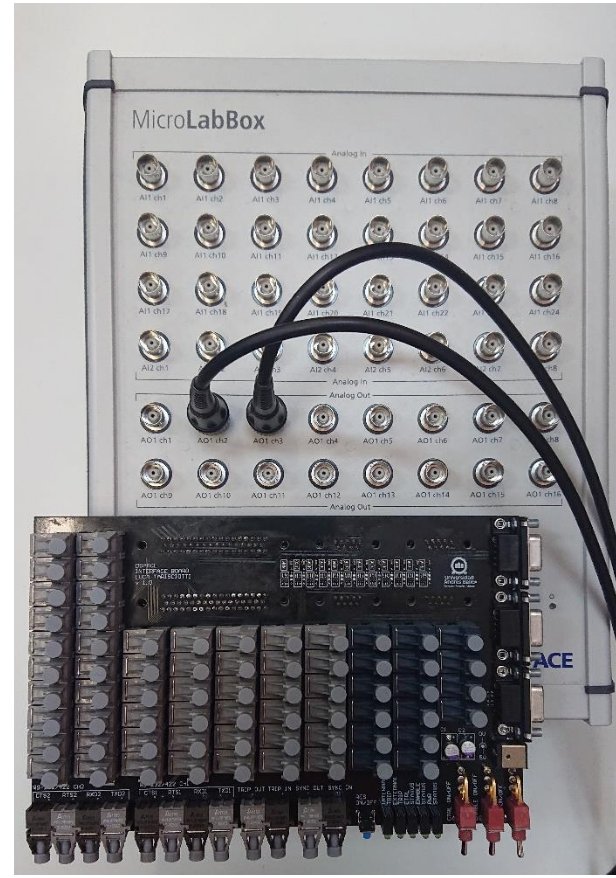
Neutral current power suppy



APF

Currently, we have more advanced DSpace platforms





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Variable speed Generation Feeding 4-leg microgrids

Partially Based on the work of Enrique Espina Ph.D. Uchile/ Waterloo.

R. Cardenas, E. Espina, J. Clare, P. Wheeler, "Self-Tuning Resonant Control of a Seven-Leg Back-to-Back Converter for Interfacing Variable-Speed Generators to Four-Wire Loads," IEEE Transactions on Industrial Electronics, , vol.62, no.7, pp.4618-4629, July 2015.(Special issue on Power Converters, Control, and Energy Management for Distributed Generation)

Research Goals

- To present a power converter topology for variable speed generation feeding unbalanced 4-wire loads.
- To investigate the resonant control systems required for the generator and load sides.
- To control the generator without using a position encoder (i.e. sensorless)

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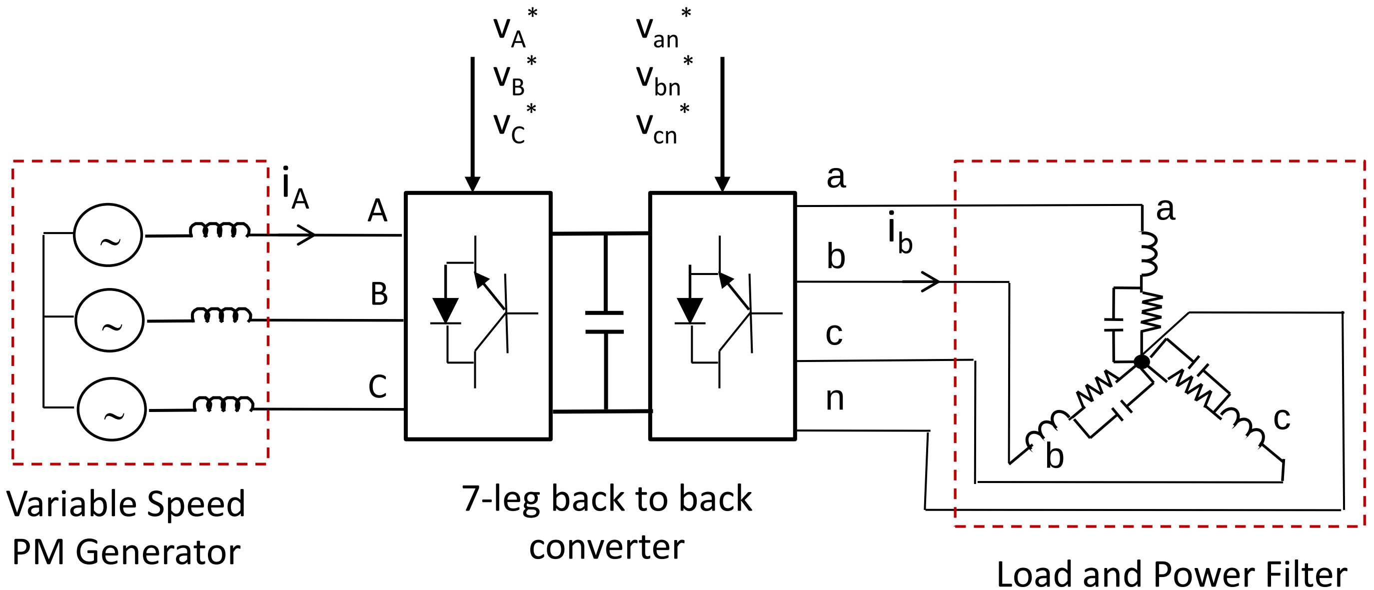
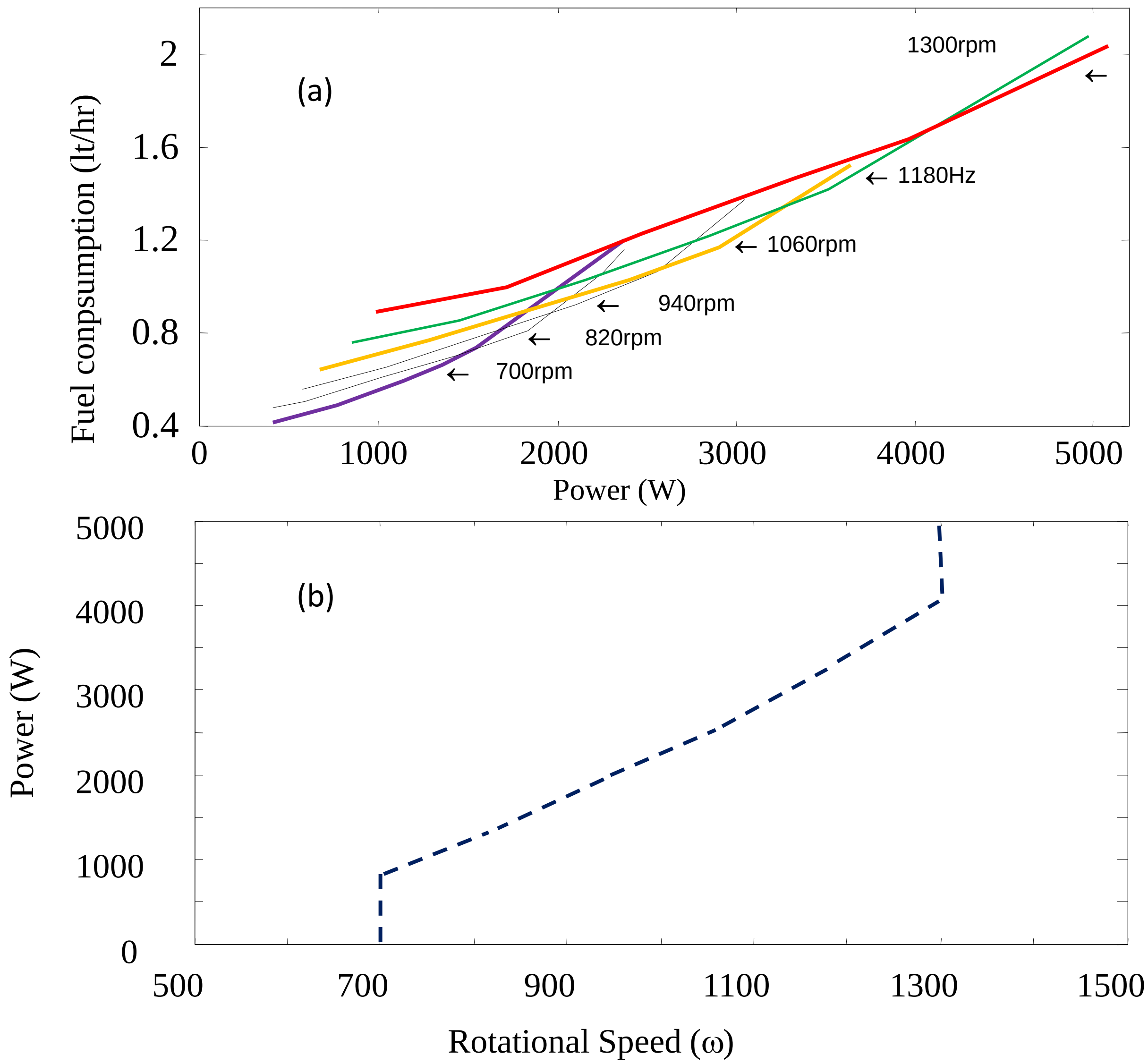
Proposed Power Converter Topology

- To operate variable speed generator, feeding unbalanced loads, power electronics is required.
- If a path for the circulation of zero sequence currents is a must, then a 4-leg front-end converter is a suitable option.



Example of Variable Speed Generation



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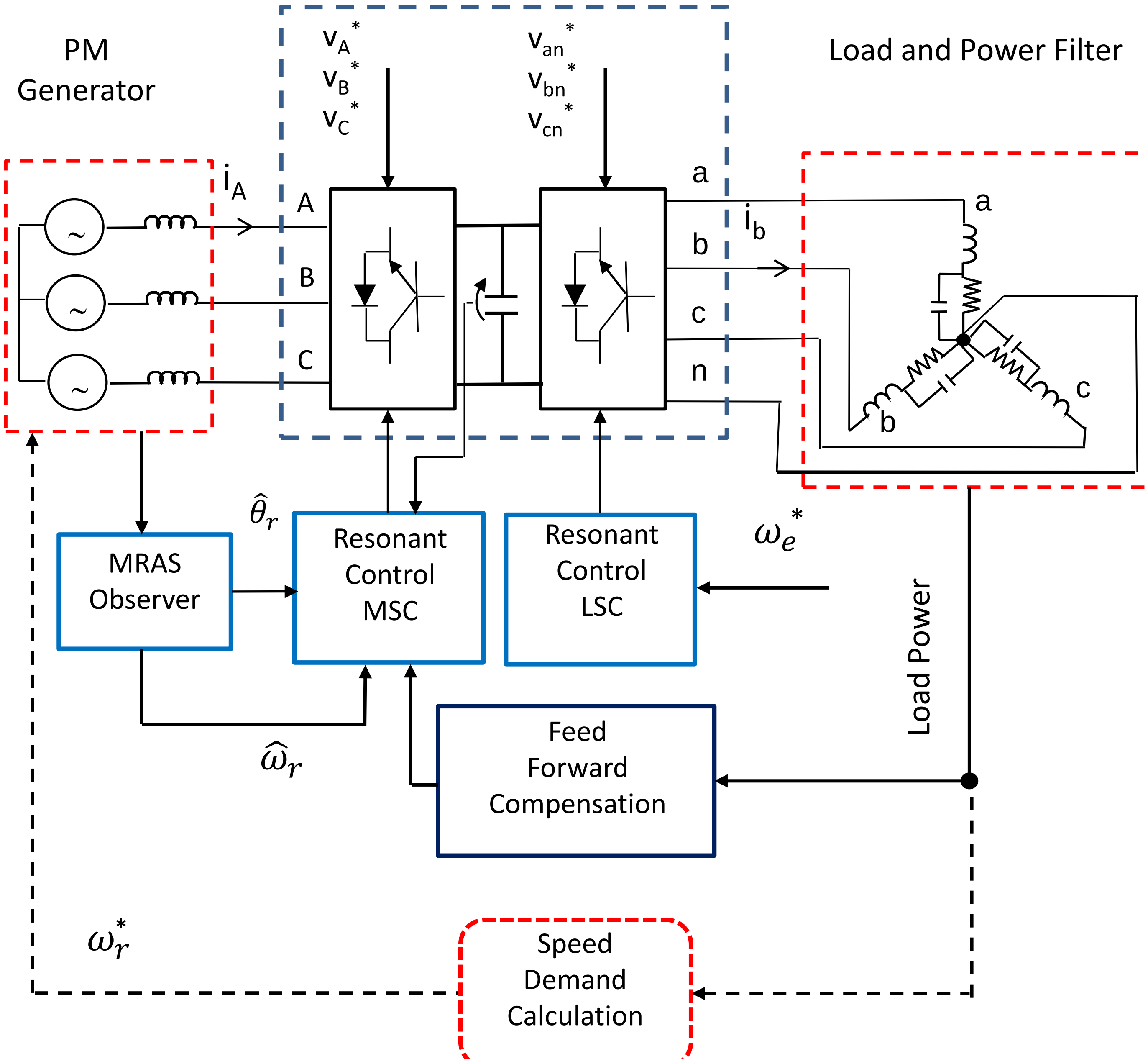

PM Generator
Load and Power Filter
v_A^*
v_B^*
v_C^*
v_{an}^*
v_{bn}^*
v_{cn}^*
i_A
A
B
C
a
b
c
n
i_b
a
b
c
$\hat{\theta}_r$
MRAS Observer
Resonant Control MSC
Resonant Control LSC
ω_e^*
Load Power
$\hat{\omega}_r$
Feed Forward Compensation
ω_r^*
Speed Demand Calculation

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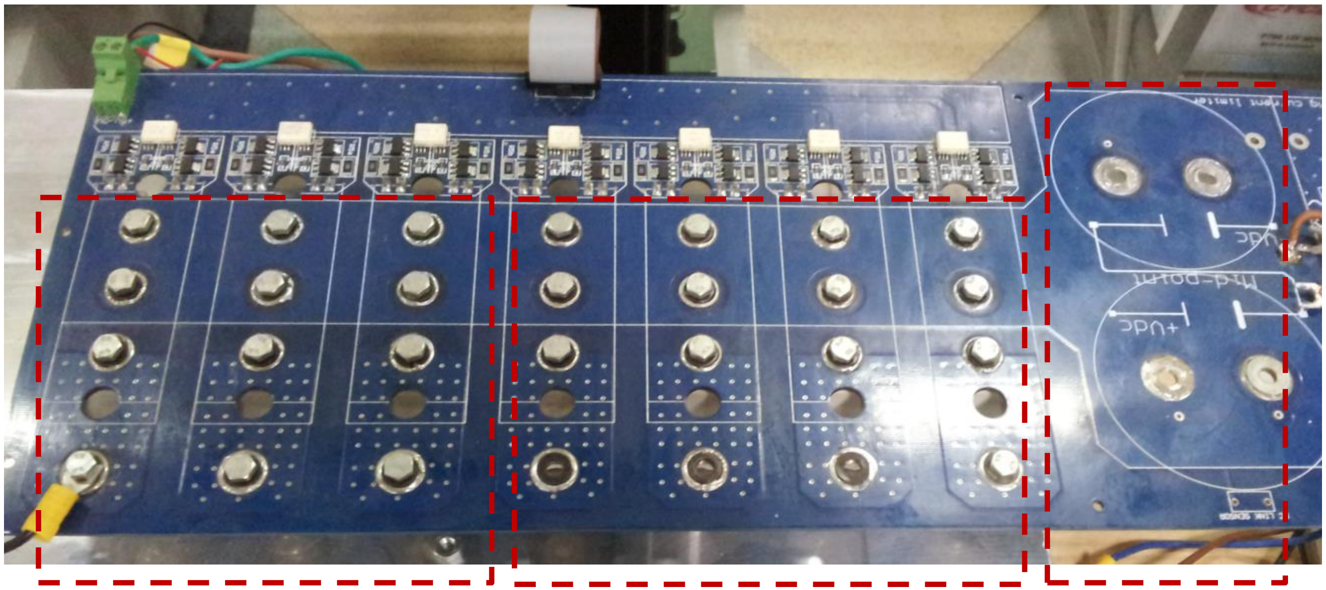
Experimental Work

Proposed Power Converter Topology



PWM Rectifier PWM Inverter DC Link

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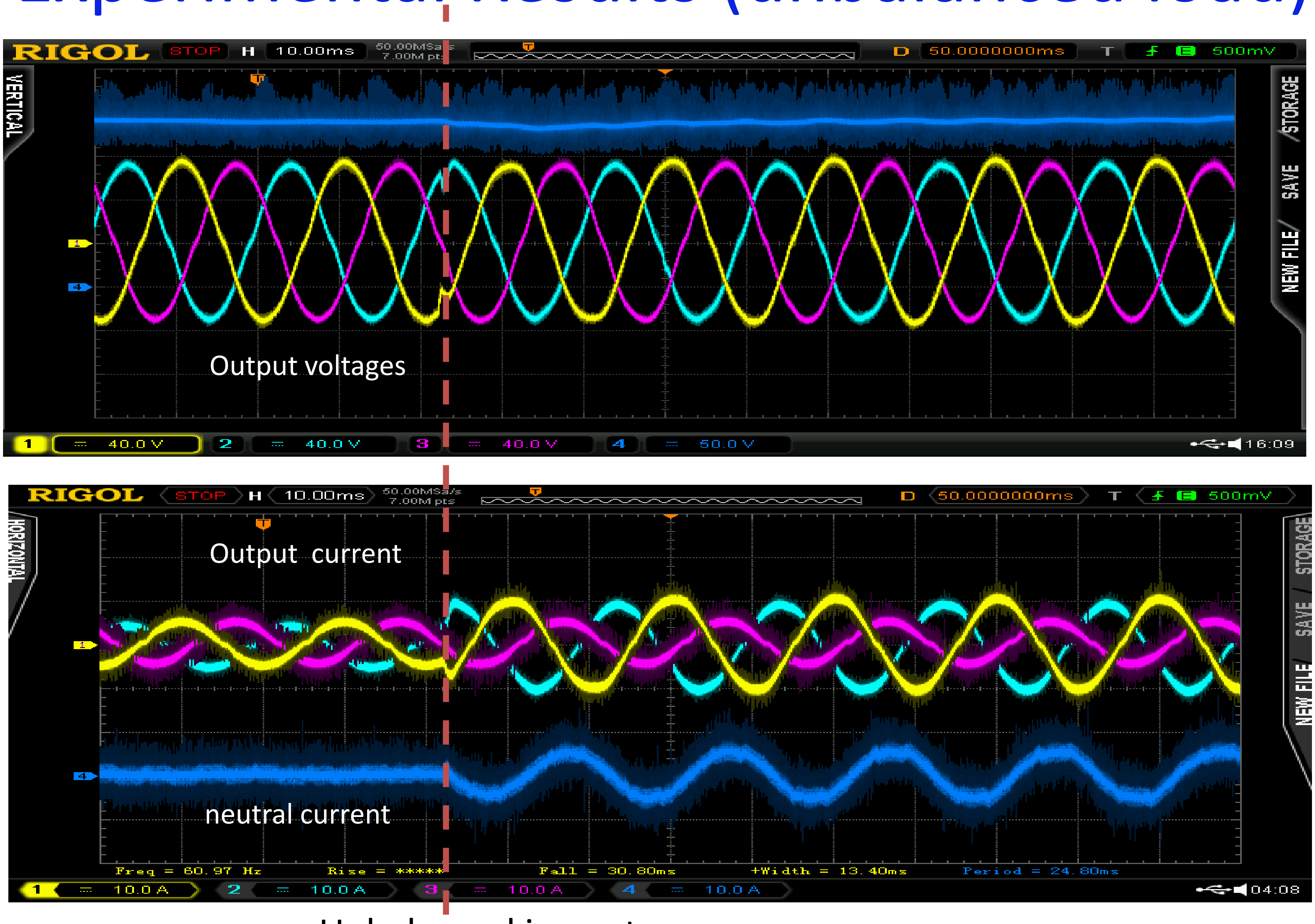
One of the first converters implemented by Enrique . Not very good, with some EMI problems but good enough to produce 5kW at the output.

Experimental Results (unbalanced load)



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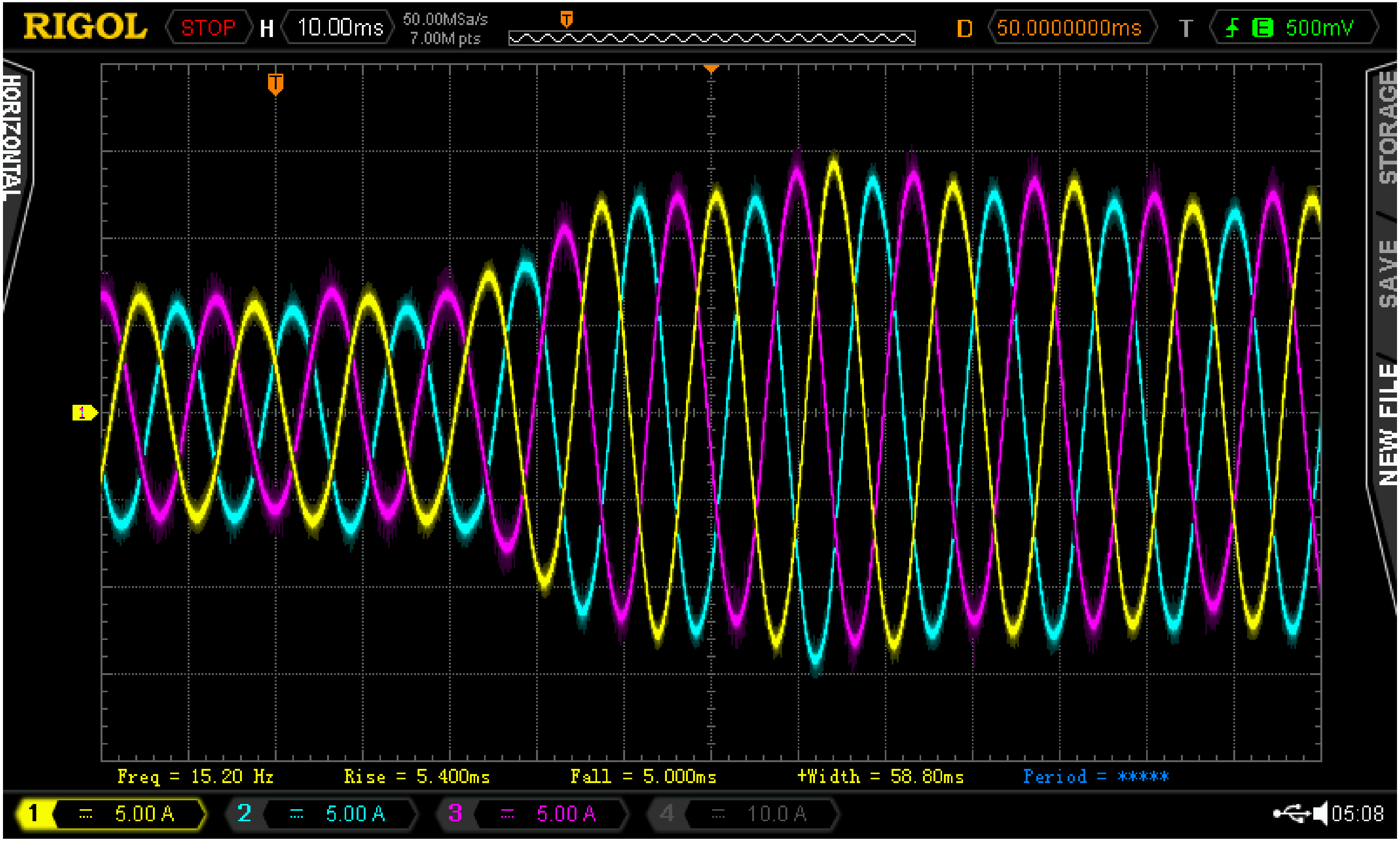
Input Currents



4-leg NPC Converter

Partially Based on the work of Felix Rojas at TUM

(Ph.D. Student at the time, now Assistant profesor at the PUC Santiago).

- F. Rojas, R. Cárdenas, R. Kennel, J. C. Clare and M. Díaz, "A Simplified Space-Vector Modulation Algorithm for Four-Leg NPC Converters," in *IEEE Transactions on Power Electronics*, vol. 32, no. 11, pp. 8371-8380, Nov. 2017.

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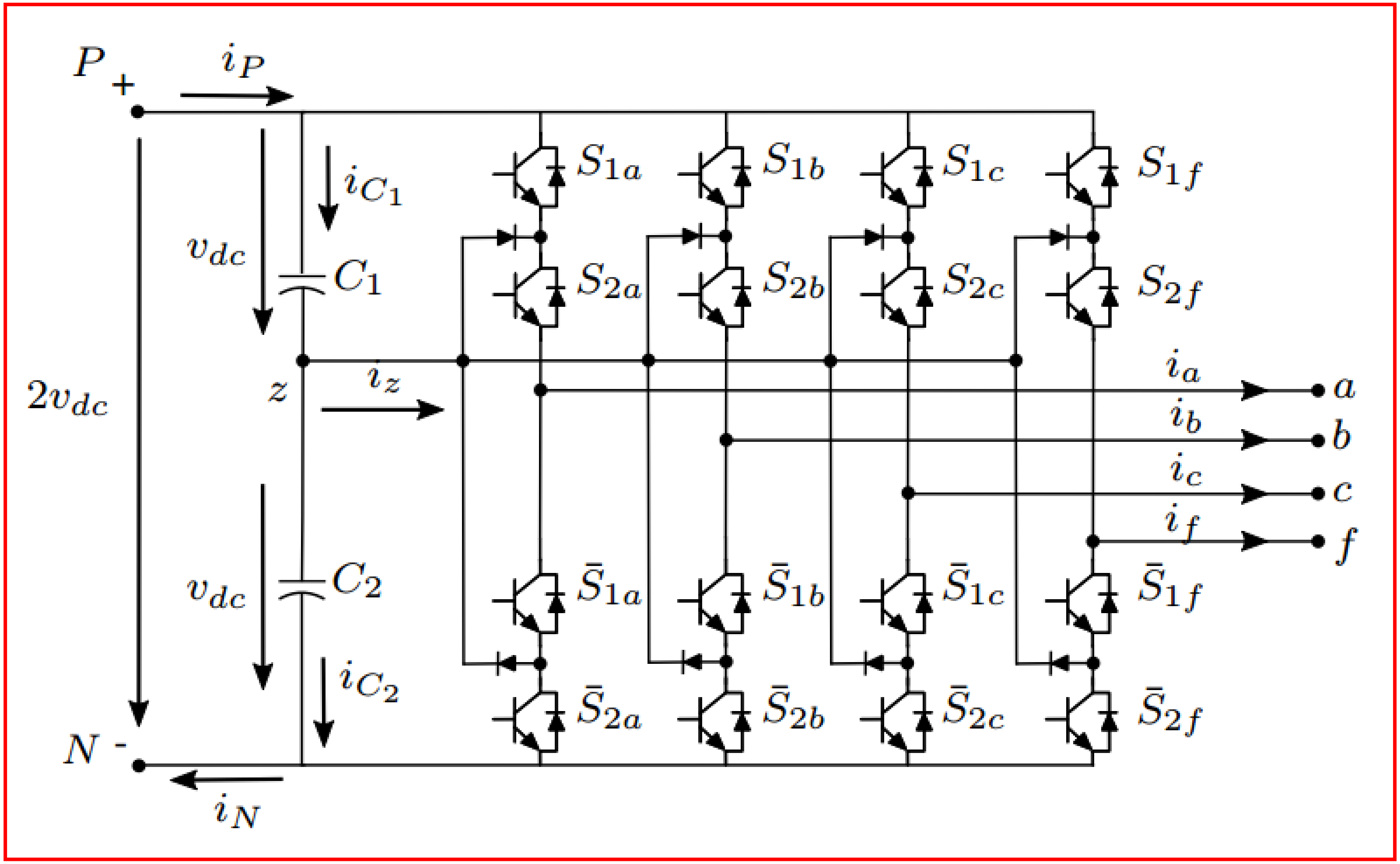
Research Goals

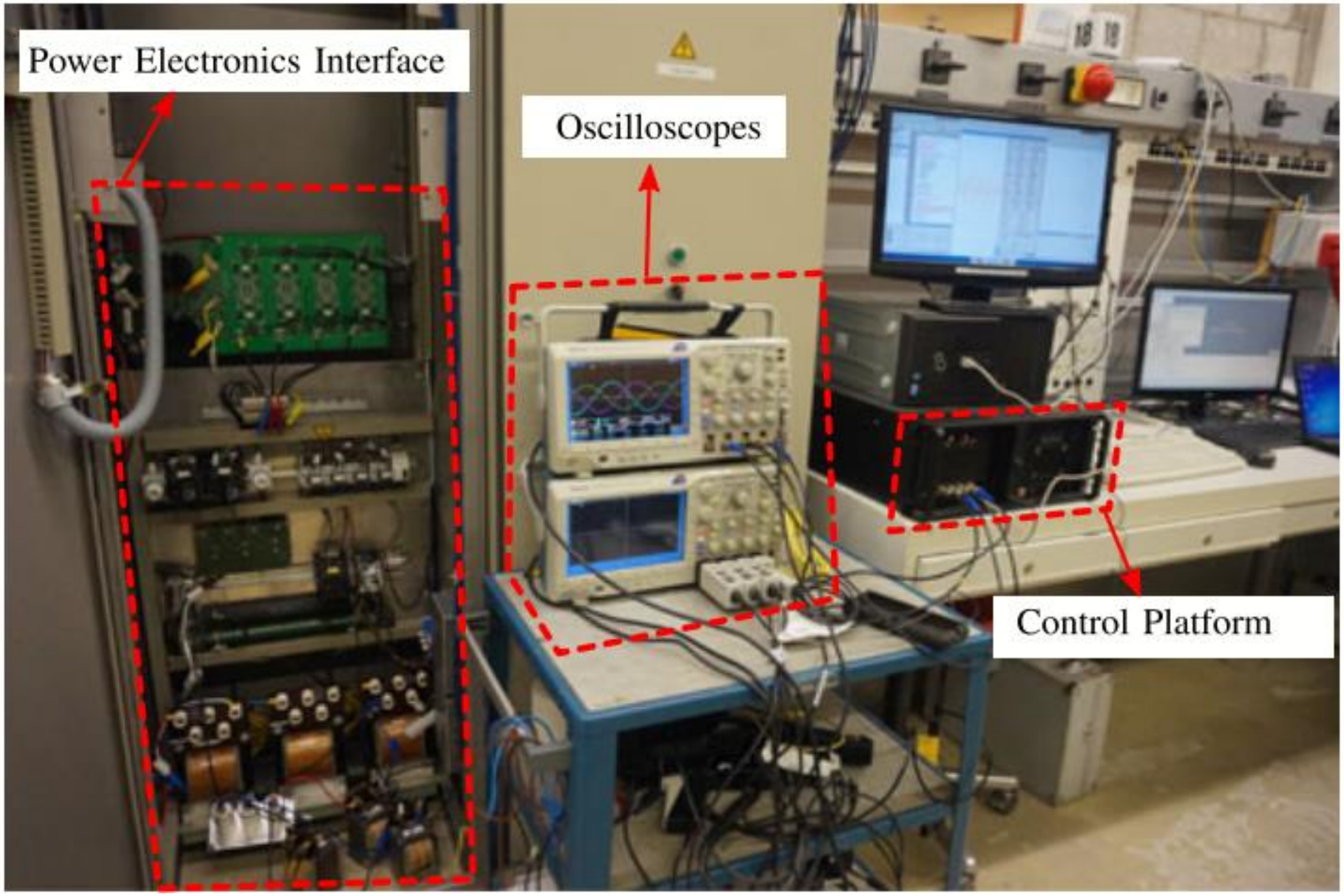
- To develop space vector modulation algorithms for the proposed converter.
- To implement a general purpose generation unit for aerospace applications (i.e. 400Hz or higher).
- To design control systems to eliminate harmonic distortion up to the 11th harmonic.

Implementation performed (mainly) at the Technical University of Munich.

NPC Power Converter



Experimental Work



Experimental results considering non-linear load and 400Hz output

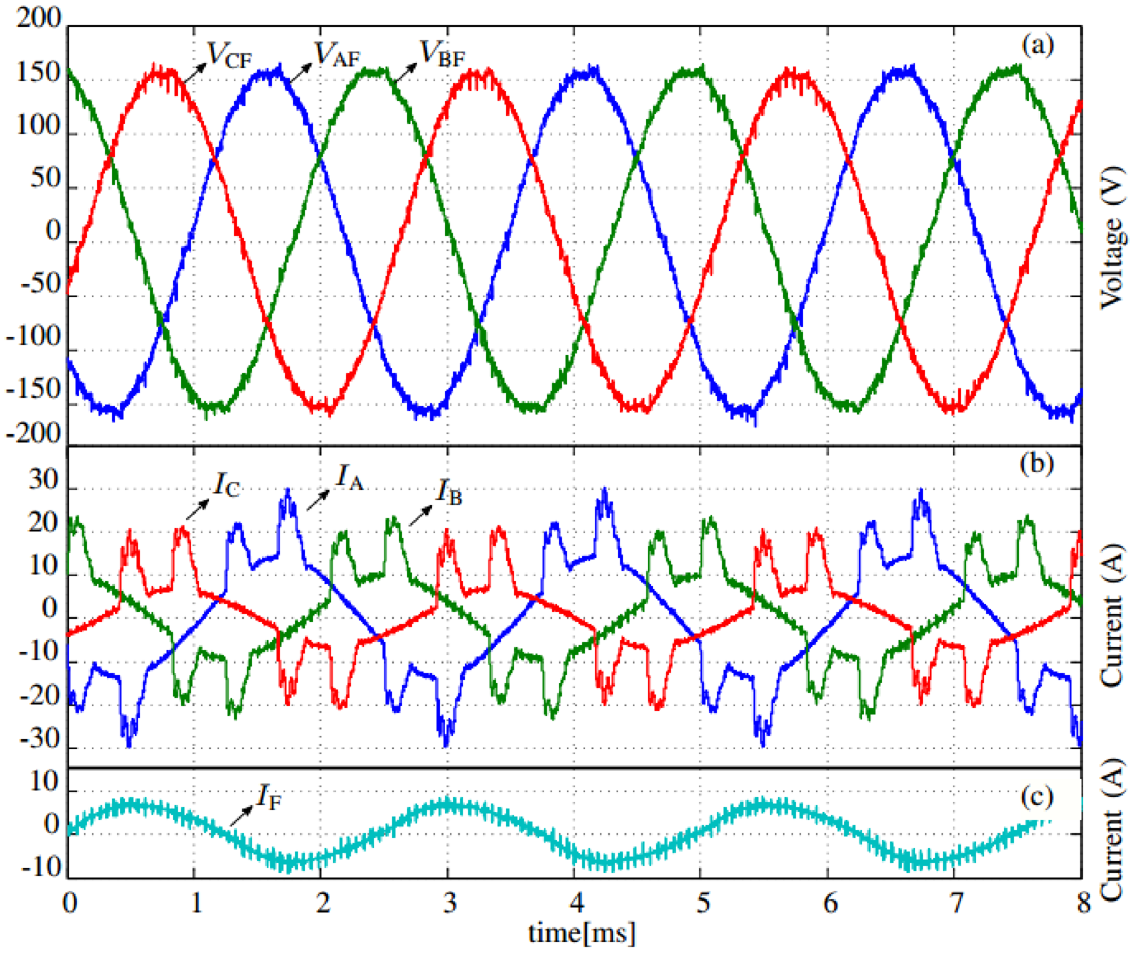


Fig. 8. Performance of the proposed GPU under a 2.8 kW linear-unbalanced load (Z_{a2}, Z_{b2}, Z_{c2}) and a 1.27 kW three-phase full wave diode bridge rectifier (57Ω and 220 uF). Sampling frequency of f_s=16.8 kHz.(a) output voltages V_{AF}, V_{BF}, V_{CF}, (b) line currents I_A, I_B, I_C and (c) neutral wire current I_F.

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MODULATED PREDICTIVE CONTROL OF AN NPC 3-LEG CONVERTER

Based on the work of Felipe Donoso, (ex Ph.D. student)
(Currently at Siemens UK)

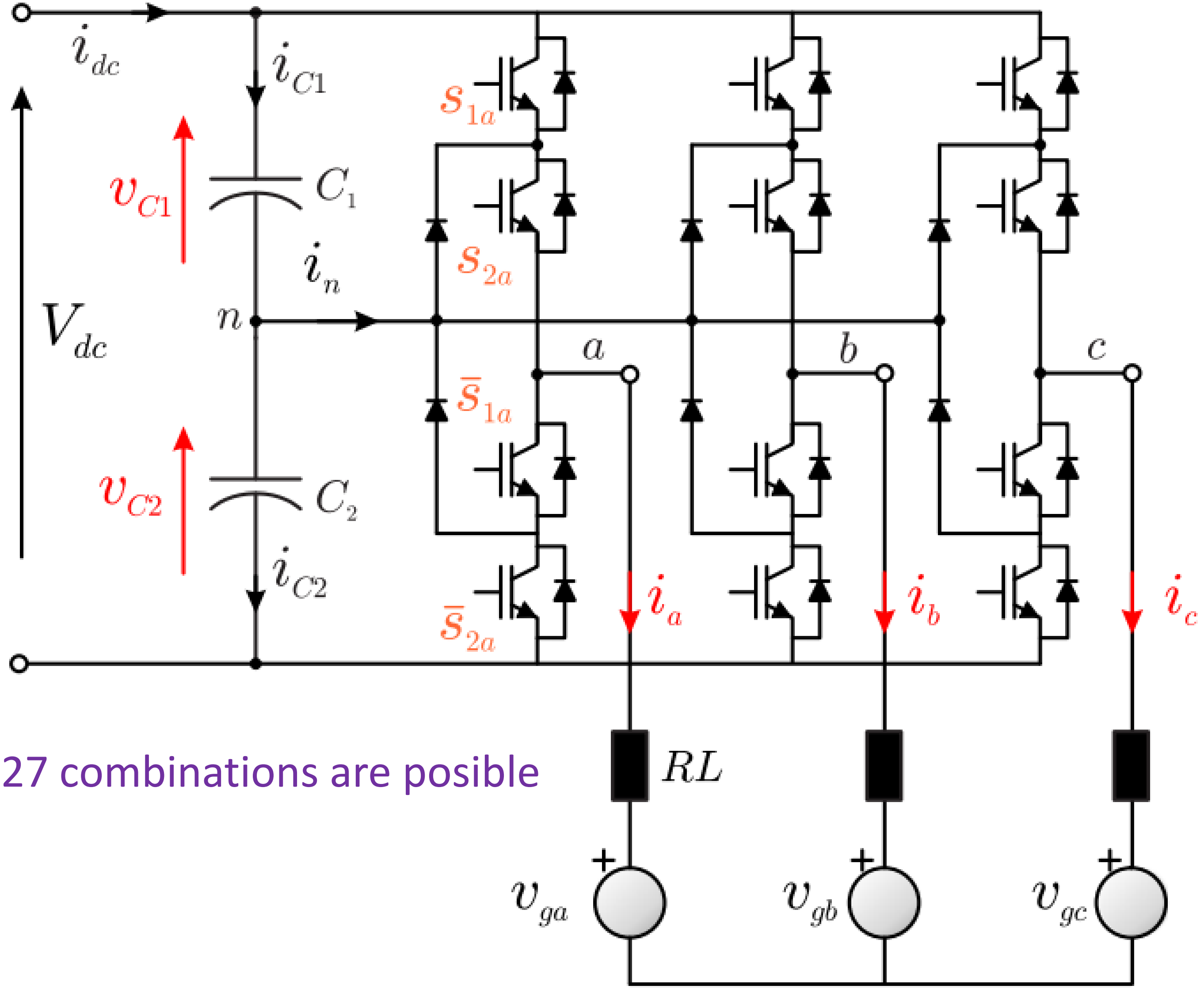
F. Donoso, A. Mora, R. Cárdenas, A. Angulo, D. Saez, M. Rivera, "Finite-Set Model Predictive Control Strategies for a 3L-NPC Inverter Operating with Fixed Switching Frequency", *IEEE Trans, on Industrial Electronics, Vol 65., Nr. 5, pp. 3954-3965, May 2018.*

**2018 Best paper award in the IEEE Transactions on Industrial Electronics.*

Research Goals

- Predictive control has some advantages, considering that a cost function with non-linear terms can be used.
- The most common methodology used is the Finite-Set model predictive control which has variable switching frequency.
- The modulated predictive control is proposed to obtain fixed switching frequency.

3-Leg NPC



27 combinations are posible

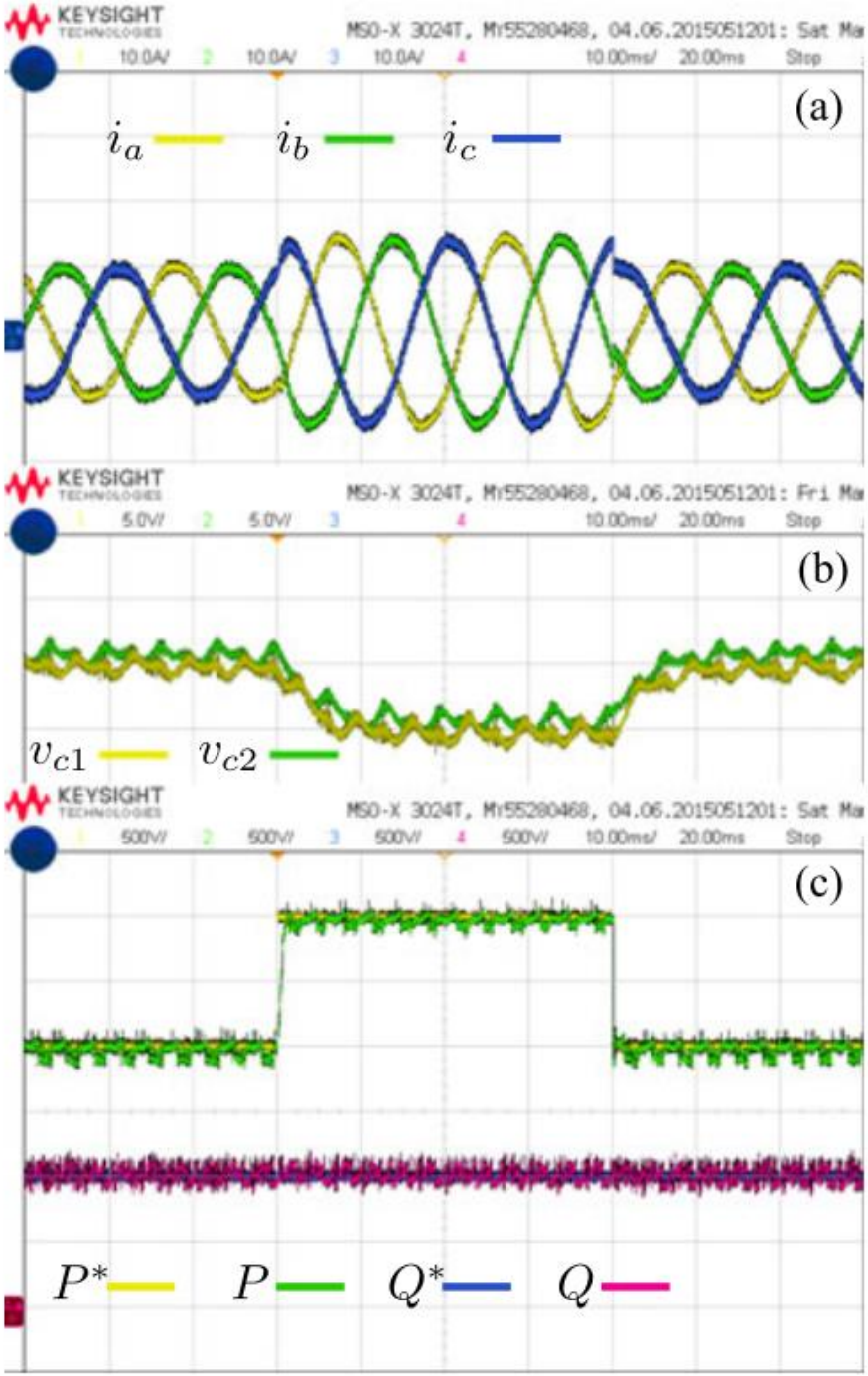
Cost Function

$$g_i(\boldsymbol{u}_i) = e_i^2(\boldsymbol{u}_i) = \left\| \boldsymbol{x}_{k+1}^* - \hat{\boldsymbol{x}}_{k+1} \right\|^2$$

Using conventional finite set model predictive control, the cost of each of the 27 vectors is evaluated using a model implemented in the DSP.

The vector which produces the lowest cost is used during a whole sampling period. However this approach produced a variable switching frequency if the same vector is repeated twice.

In modulated predictive control the region which produces the lowest cost is used. This enables fixed switching frequency.



Load Step Performance

Some research works in microgrids

(See https://sites.google.com/site/robertocardenasdobson/publicaciones)

- C. Burgos, **R. Cárdenas**, D. Sáez, A. Costabeber, M. Sumner, "A Control Algorithm Based on the Conservative Power Theory for Cooperative Sharing of Imbalances in Four-Wire Systems", *IEEE Trans. on Power Electronics,* Vol 34, Nr 6, pp. 5325-5339 June 2019.
- C. Burgos-Mellado, J. LLanos, **R. Cárdenas**, D. Sáez, D. Olivares, M. Sumner, A. Costabeber, "Distributed Control Strategy Based on a Consensus Algorithm and on the Conservative Power Theory for Imbalances and Harmonics Sharing in 4-Wire Microgrids", *IEEE Trans. on Smart Grid.*
- A. Mora, **R. Cardenas**, R. Aguilera, A. Angulo, F. Donoso, J. Rodriguez, "Computationally Efficient Cascaded Optimal Switching Sequence MPC for Grid-Connected Three-Level NPC Converters", *IEEE Trans. on Power Electronics,* Vol. 34, Nr. 12, pp. 12464-12475, December 2019.
- Enrique Espina, **Roberto Cárdenas-Dobson**, Mauricio Espinoza, Claudio Burgos, Doris Saez, "Cooperative Regulation of Imbalances in Three-Phase Four-Wire Microgrids Using Single-Phase Droop Control and Secondary Control Algorithms", *IEEE Trans. on Power Electronics, Vol. 35, Nr. 2, pp. 1978-1992,* 10.1109/TPEL.2019.2917653, February 2020.
- J. Gomez, D. Saez, J. Simpson-Porco, **R. Cárdenas**, "Distributed Predictive Control for Frequency and Voltage Regulation in Microgrids", *IEEE Trans. on Smart Grids*.

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Modular Multilevel Converters (power Electronic Lab)

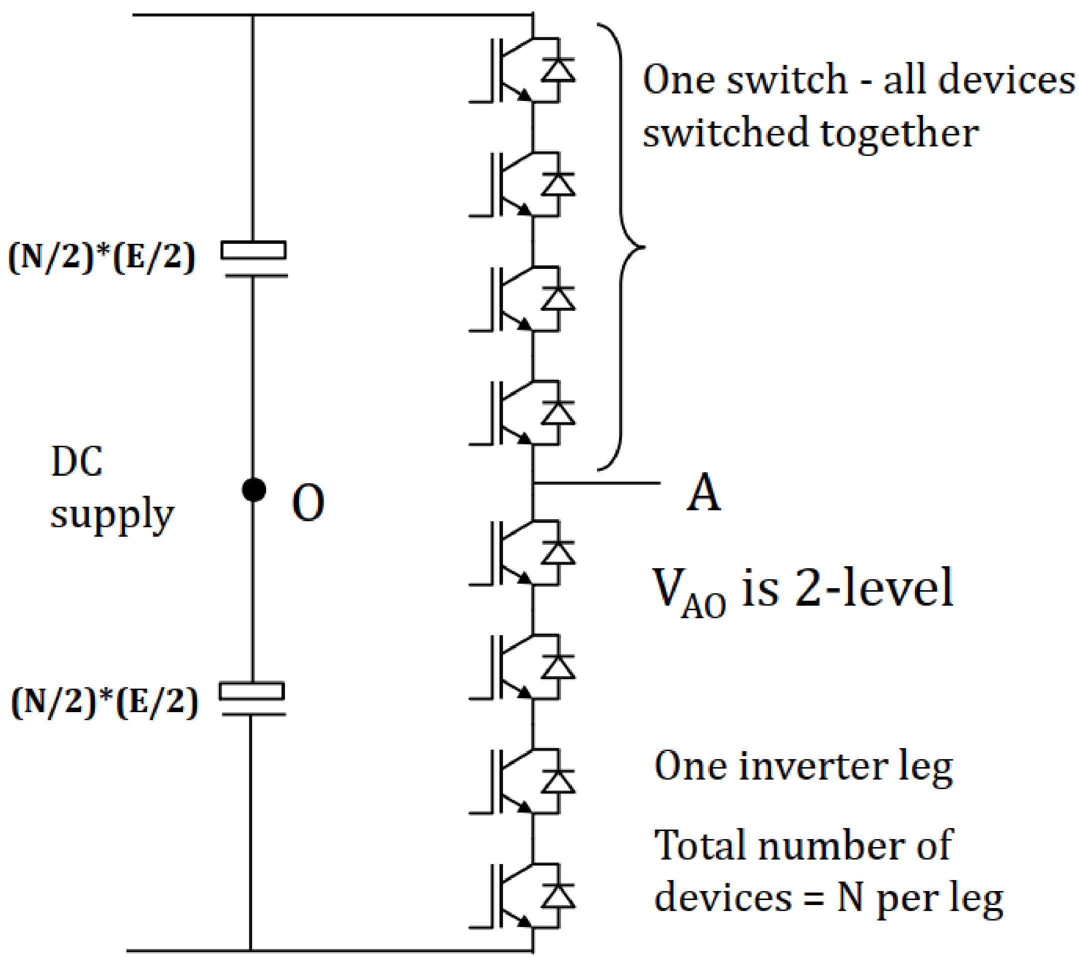
Control of the Modular Multilevel Converter for Drive Applications

Based on the work of Mauricio Espinoza B.,
Phd student from 2014 to 2018
(Associate profesor in Costa Rica)

- M. Espinoza , R. Cárdenas, J. Clare, D. Soto-Sanchez, M. Diaz, E. Espina and C. M. Hackl, "An Integrated Converter and Machine Control System for MMC-Based High-Power Drives," in IEEE Transactions on Industrial Electronics, vol. 66, no. 3, pp. 2343-2354, March 2019. doi: 10.1109/TIE.2018.2801839

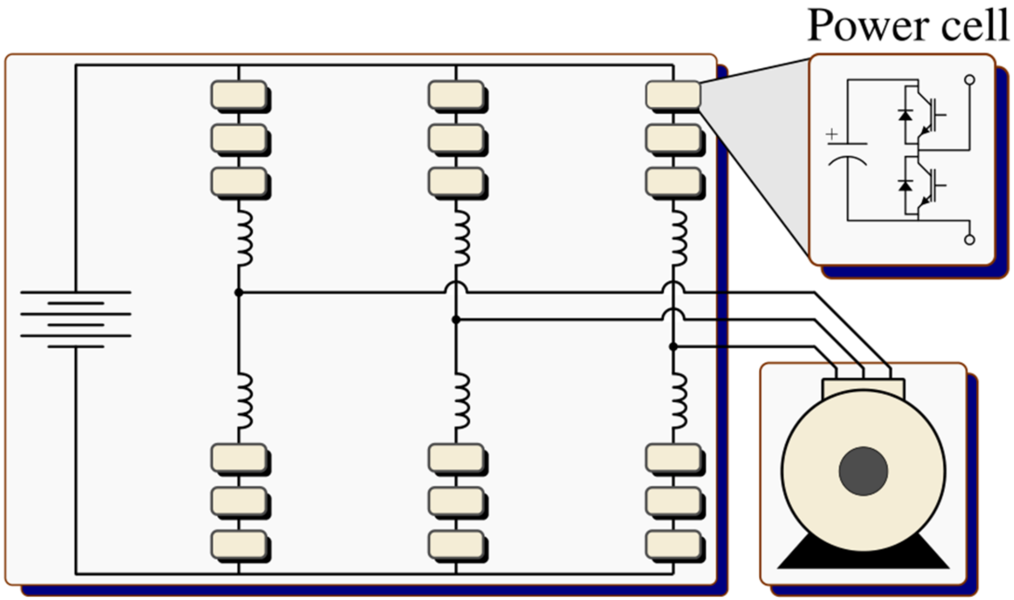
(joint collaboration with Jon Clare, U of Nottingham)

What can we do to supply high power high voltage?



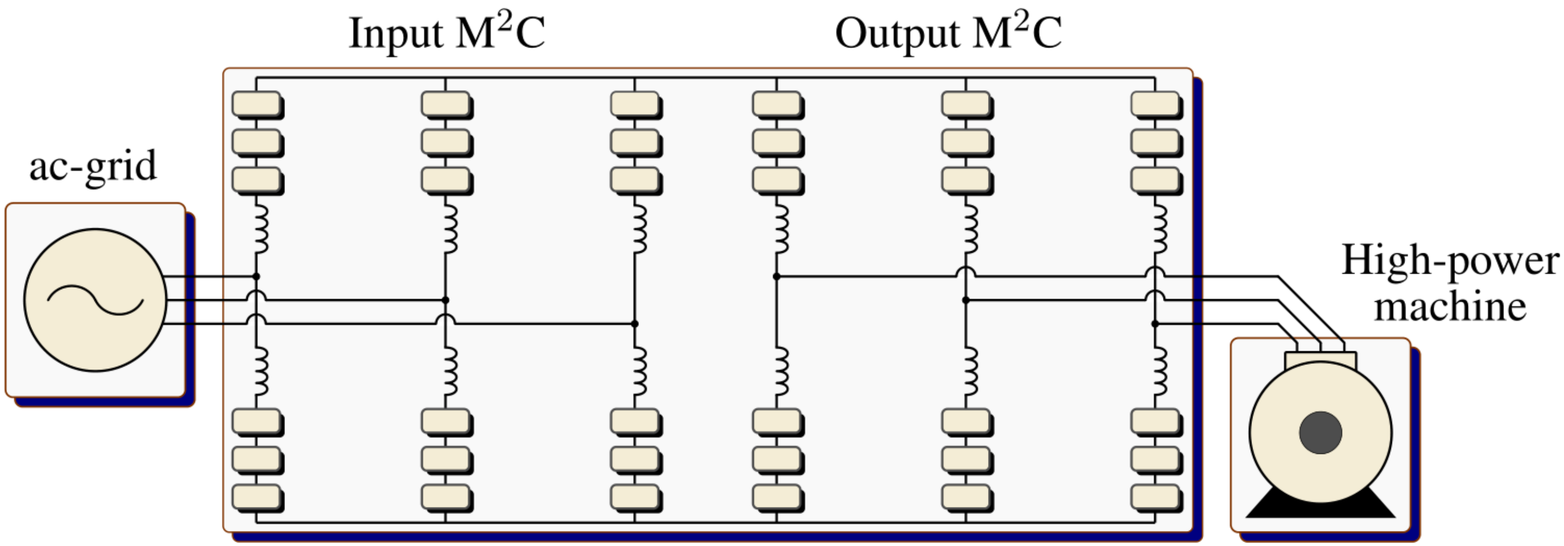
- First alternative to use switches in serial connection.
- Is not a very good idea!!

Topology of the Modular Multilevel Converter (M2C)



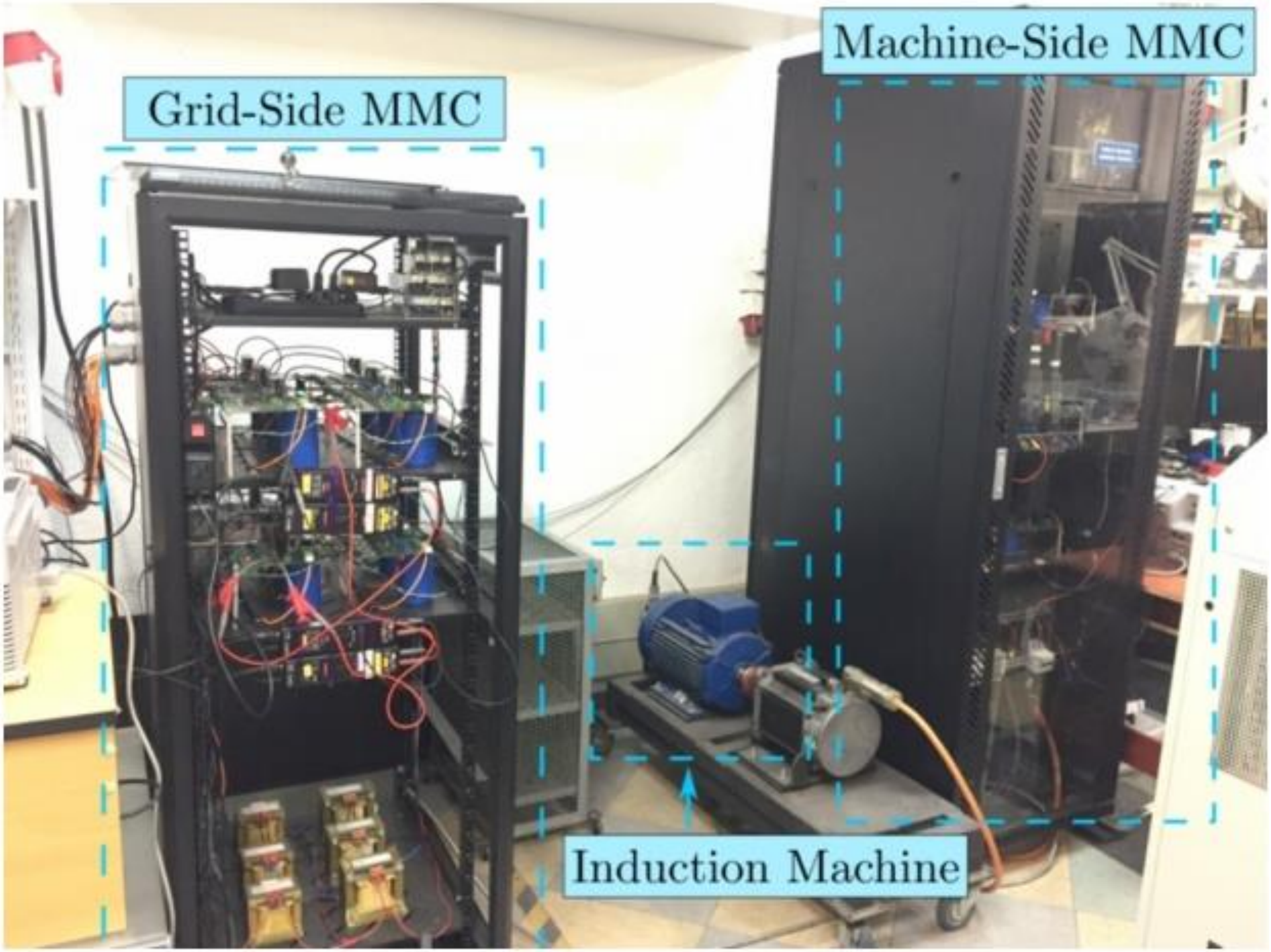
- Suitable for high-power/voltage drives.
- Good performance for drives operating with a quadratic torque-speed profile.
- Main control problem: to supply power to the machine maintaining the capacitor voltage fluctuations within an acceptable range (balanced operation).
- The most critical operating point: stand-still operation with high starting torque.

Topology of the M2C in Back to Back configuration



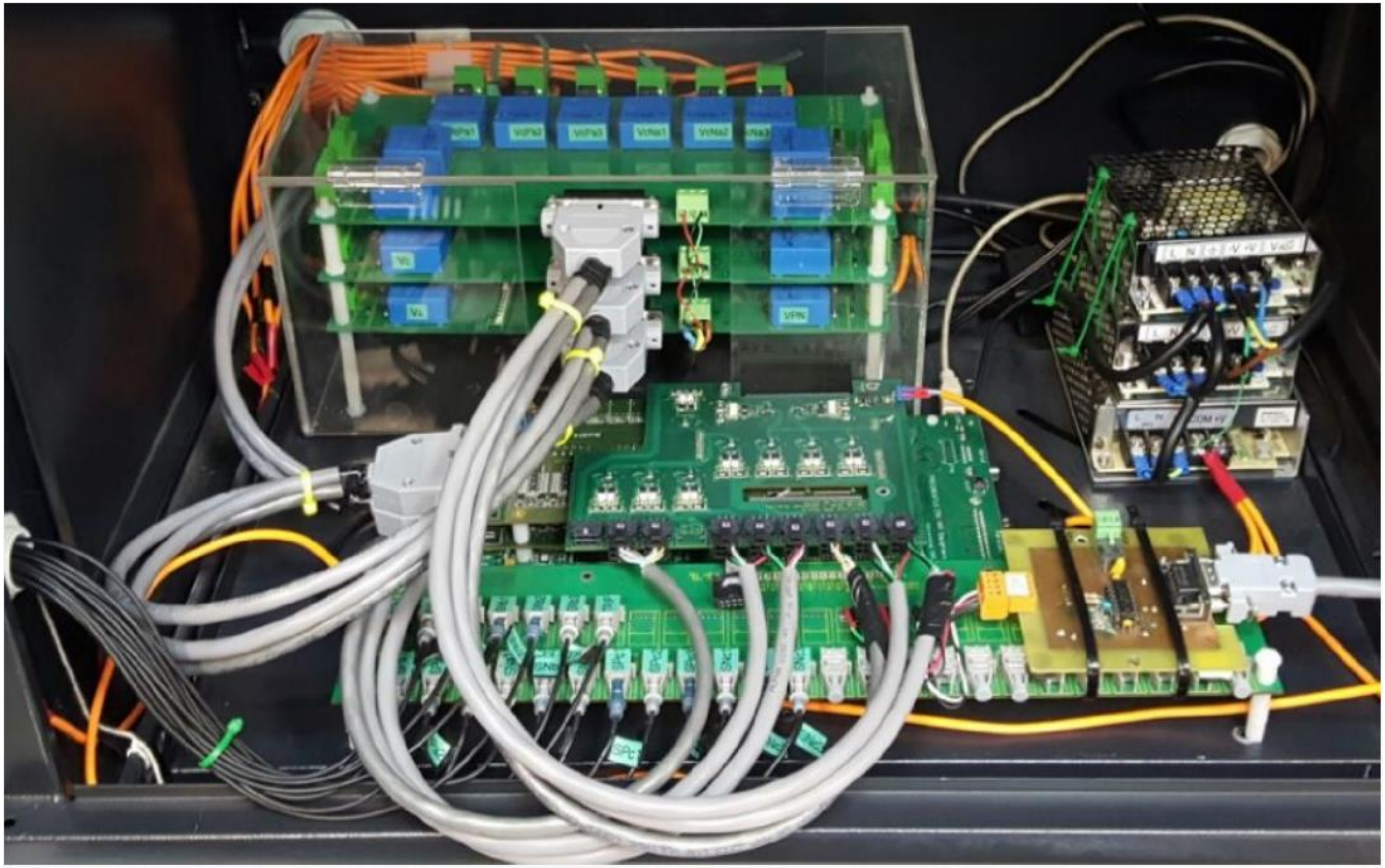
- Bidirectional power flow operation is feasible.
- The dc-port variables could be considered as degrees of freedom. For instance dc-link voltage variations and ac current components (superimposed in the dc-link current) can be considered.
- Low harmonic distortion in the grid and machine currents are achieved.

Experimental system description

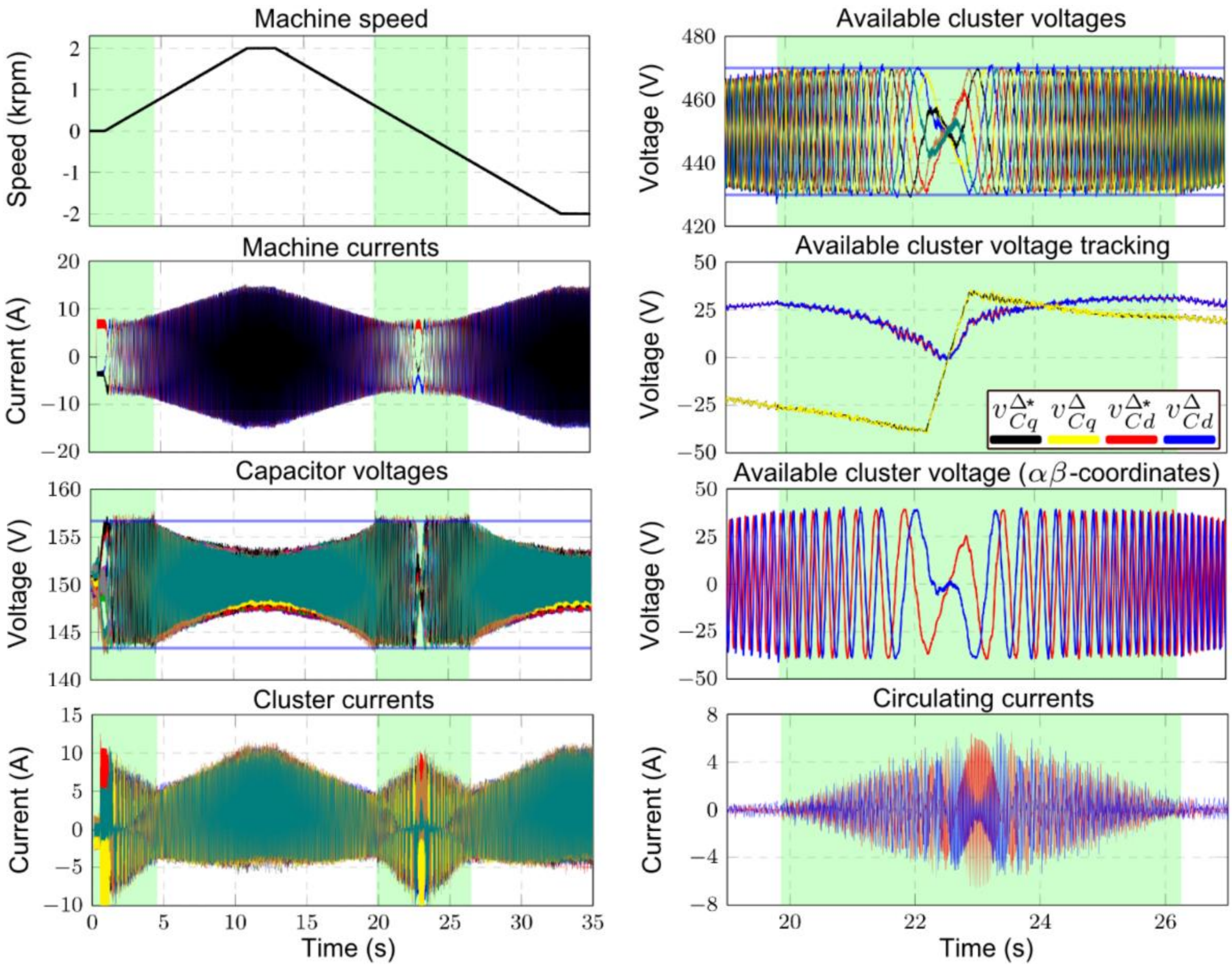


Machine-side control platform

- 2 FPGAs (U. Nottingham design).
- 1 extra measurement board.
- 19 voltage measurements.
- 6 current measurements.
- 19 optic-fibre pulses.
- 1 encoder adapter.
- 1 DSP.



Experimental system results (green area means LFM)



Proper voltage control

Seamless transition Between LFM and HFM

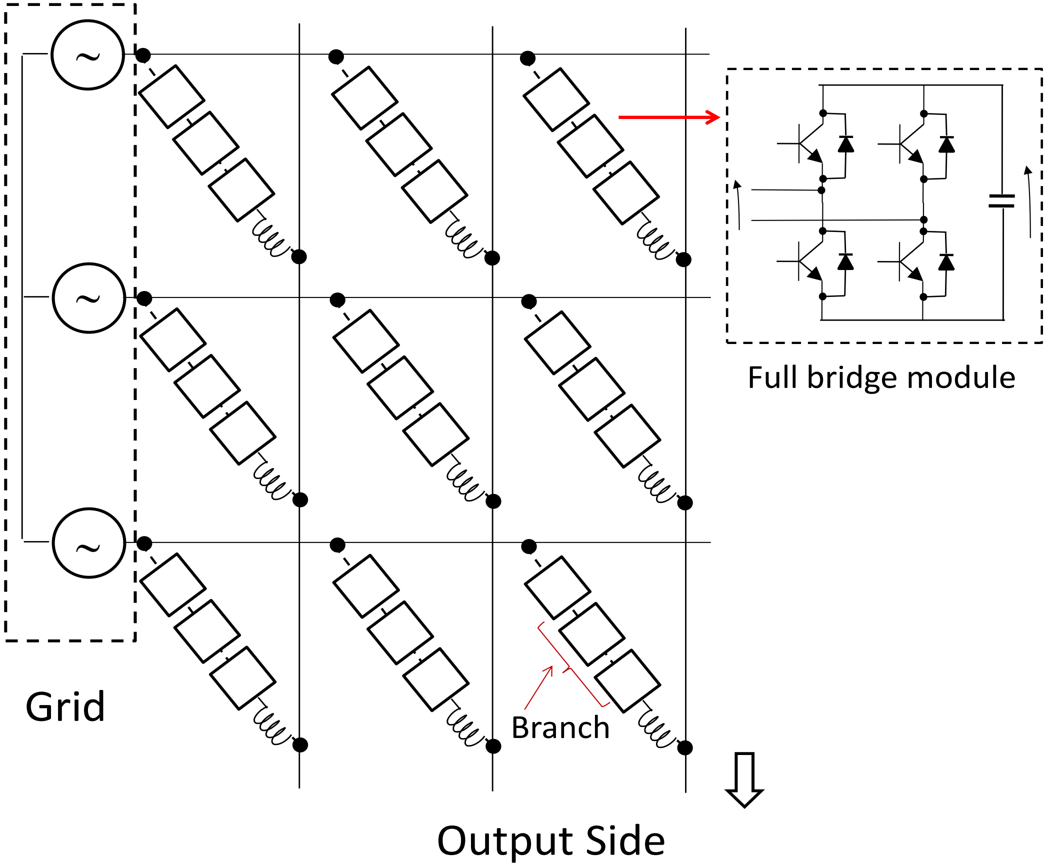
Modular Multilevel Matrix Converter

Partially Based on the work of Matías Díaz.,
Phd student from 2013 to 2017
(Associate Professor USACH)

- M. Diaz, R. Cardenas, M. Espinoza , F. Rojas, A. Mora, J. C. Clare, and P. Wheeler. "Control of Wind Energy Conversion Systems Based on the Modular Multilevel Matrix Converter." IEEE Transactions on Industrial Electronics, 64(11):8799-8810, Nov 2017. ISSN 0278-0046. doi: 10.1109/TIE.2017.2733467

Modular Multilever Matrix Converter

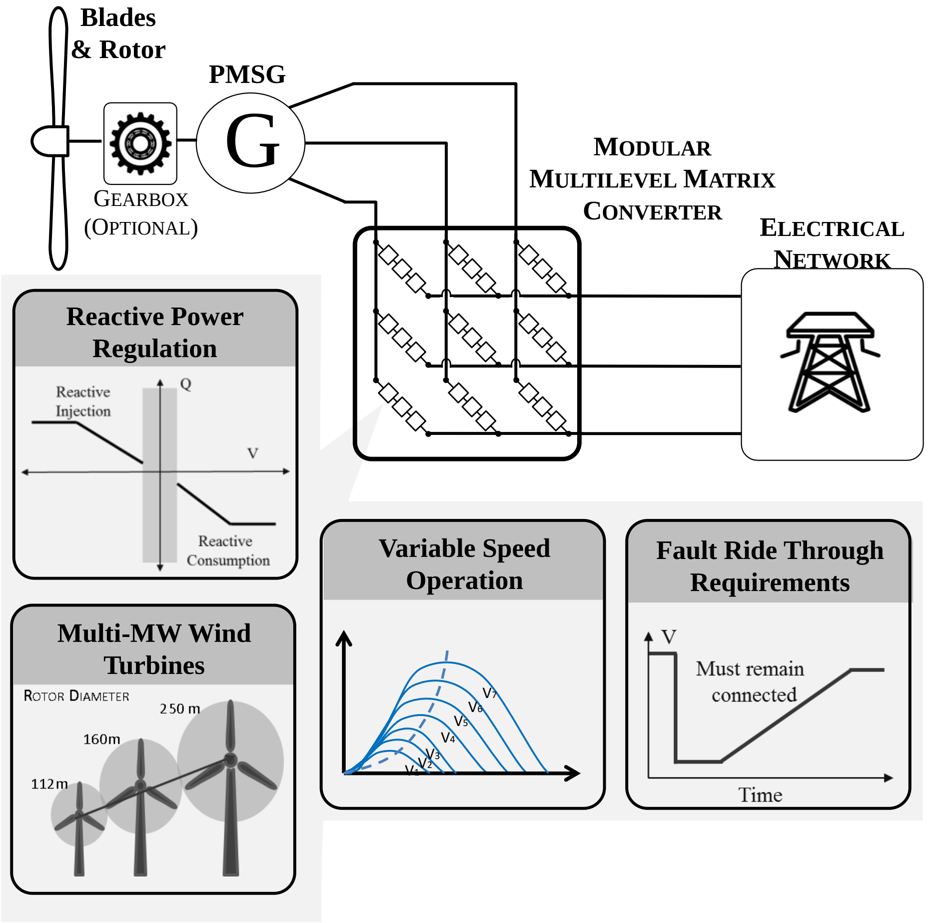
(joint collaboration with Jon Clare, Patrick Wheeler U of Nottingham)



To be connected to an induction machine

Wind Energy Applications

The Modular Multilevel Matrix Converter could be used for interfacing Multi-MW Wind Turbines:

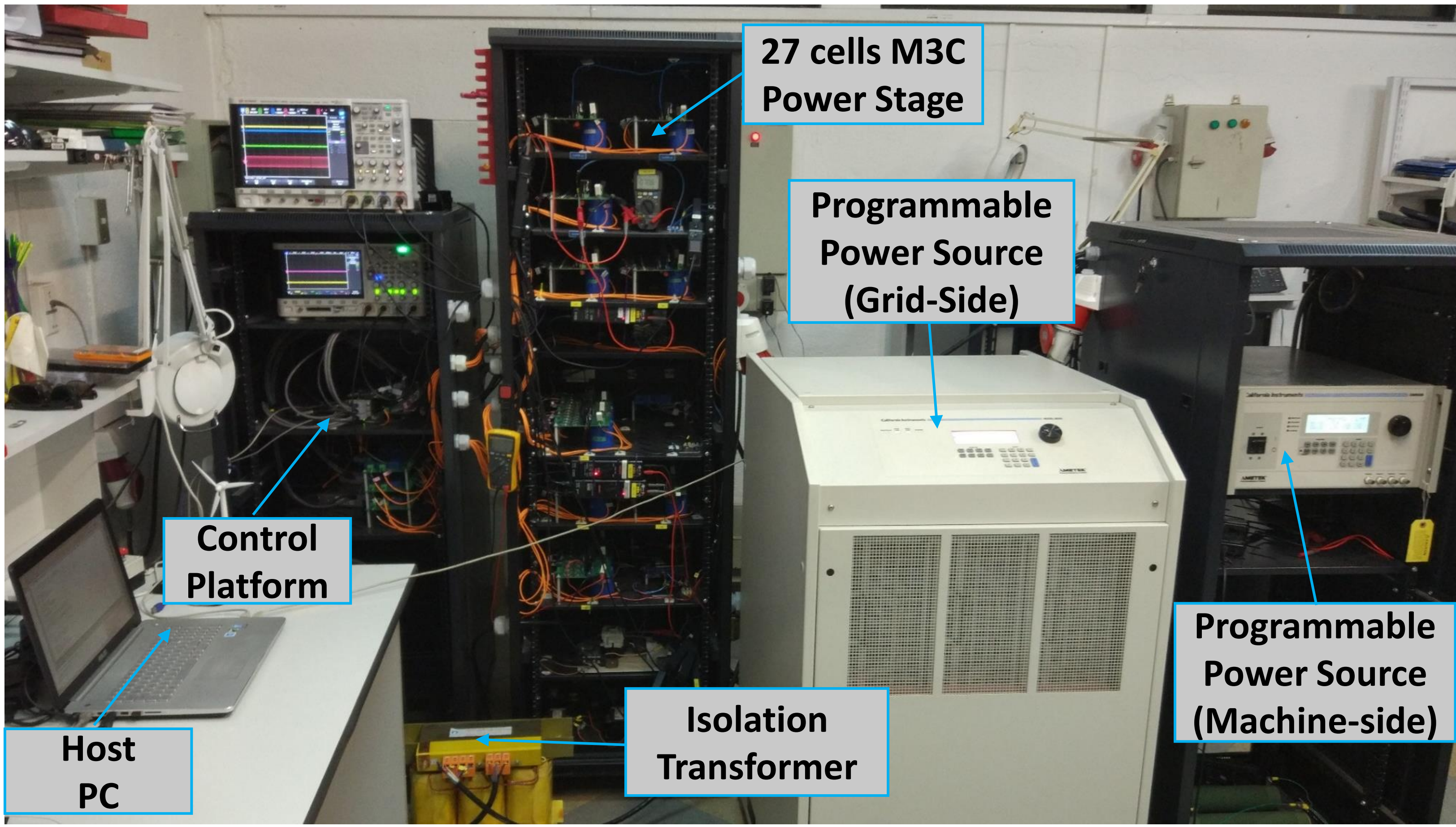


Features:

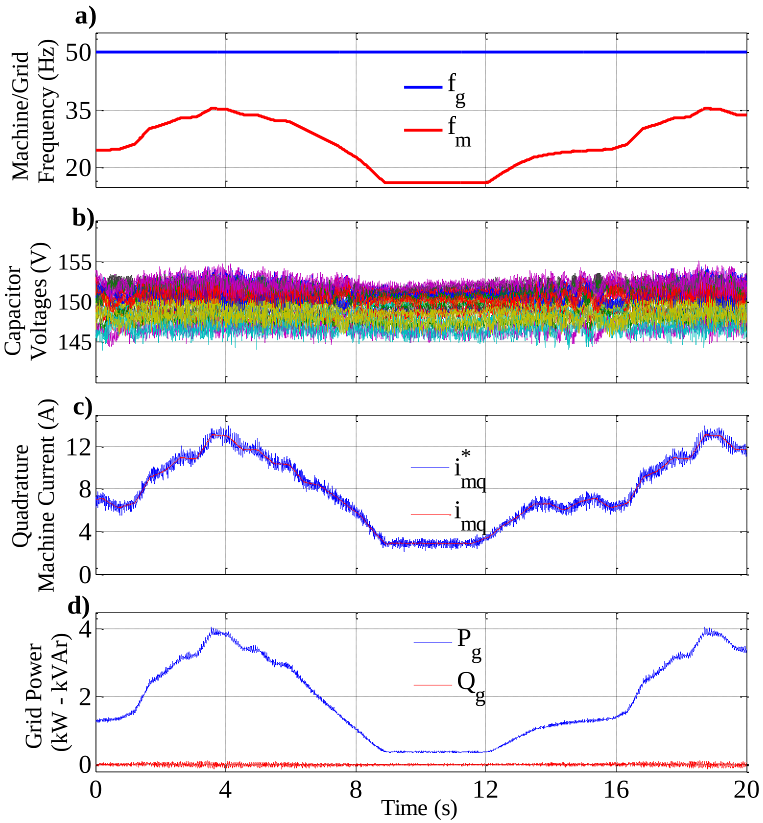
- ✓ Decoupled input-output regulation
- ✓ Variable speed operation
- ✓ Grid Code compliance (LVRT)

Universidad de Chile

Experimental Prototype:

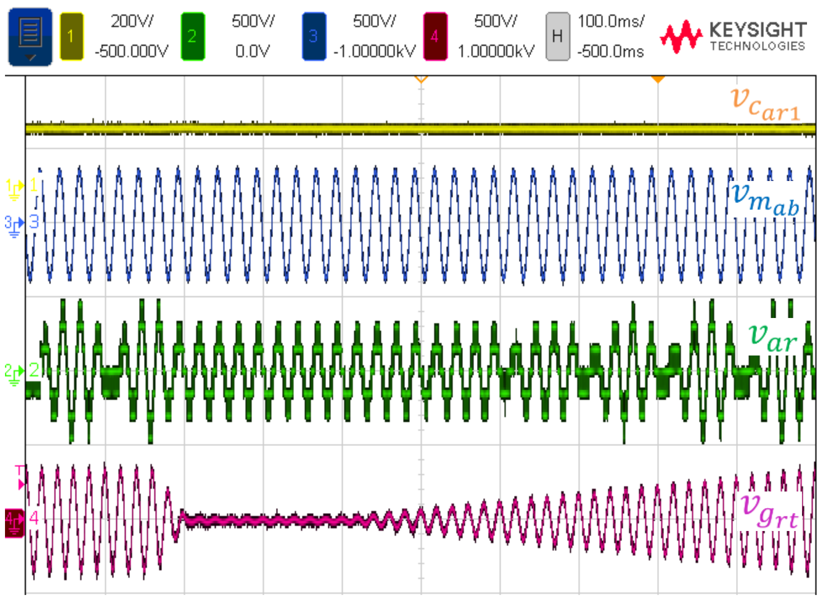


Experimental Results



Experimental Results for Variable Speed Operation. (a) Grid and Generator Frequencies. (b) 27-Cells Capacitor Voltages. (c) Tracking of quadrature input current. (d) Active and Reactive Power supplied to the grid

ZVRT Test



Voltages: Capacitor v_{car^1}, Input v_{mab}, Cluster v_{ar}, Output v_{grt}

Some research work in multilevel converters

(See https://sites.google.com/site/robertocardenasdobson/publicaciones)

- M. Espinoza, **R. Cárdenas**, J. Clare, D. Soto, M. Diaz, E. Espina, C. Hack, "An Integrated Converter and Machine Control System for MMC-Based High Power Drives", *IEEE Transactions on Industrial Electronics*, Vol. 66, Nr. 3, pp. 2343-2354, March 2019.
- A. Mora, M. Urrutia, A. Angulo, **R. Cárdenas**, M. Espinoza, M. Díaz, P. Lezana, "Model-Predictive-Control-Based Capacitor Voltage Balancing Strategies for Modular Multilevel Converters", *IEEE Transactions on Industrial Electronics*, Vol. 66, Nr. 3, pp. 2432 - 2443, March 2019.
- M. Díaz, **R. Cárdenas**, M. Espinoza, C. Hack, J. Clare, P. Wheeler, F. Rojas, "Vector Control of a Modular Multilevel Matrix Converter Operating in the Full Output-Frequency Range", *IEEE Transactions on Industrial Electronics,* Vol. 66, Nr. 7, pp. 5102-5114, July 2019.
- F. Donoso, **R. Cardenas**, M. Espinoza, J. Clare, A. Mora, A. Watson, "A Nested Closed-Loop Control for the balance of the Cell Capacitor Voltages in a Hybrid MMC", Submitted for publication to the *IEEE Transactions on Power Electronics.*
- L. Tarisciotti, A. Costabeber, **R. Cárdenas**, "Modular Multilever Converter based topology for High Speed, Low Voltage electric drives", submitted for publication to the *IEEE Journal of Emerging and Selected Topics in Industrial Electronics*, SS on Enabling Technologies for Transportation Electrification.

Thank you for your attention