# HARMONY Symposium 2015
# - Welcome & Overview

**Frede Blaabjerg, Professor**
**Department of Energy Technology**
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AALBORG UNIVERSITY
DENMARK

# Aalborg University - Denmark



**Inaugurated in 1974**
**20,000 students**
**2,000 faculty**

**PBL-Aalborg Model**
(Project-organised and problem-based)

AALBORG UNIVERSITET

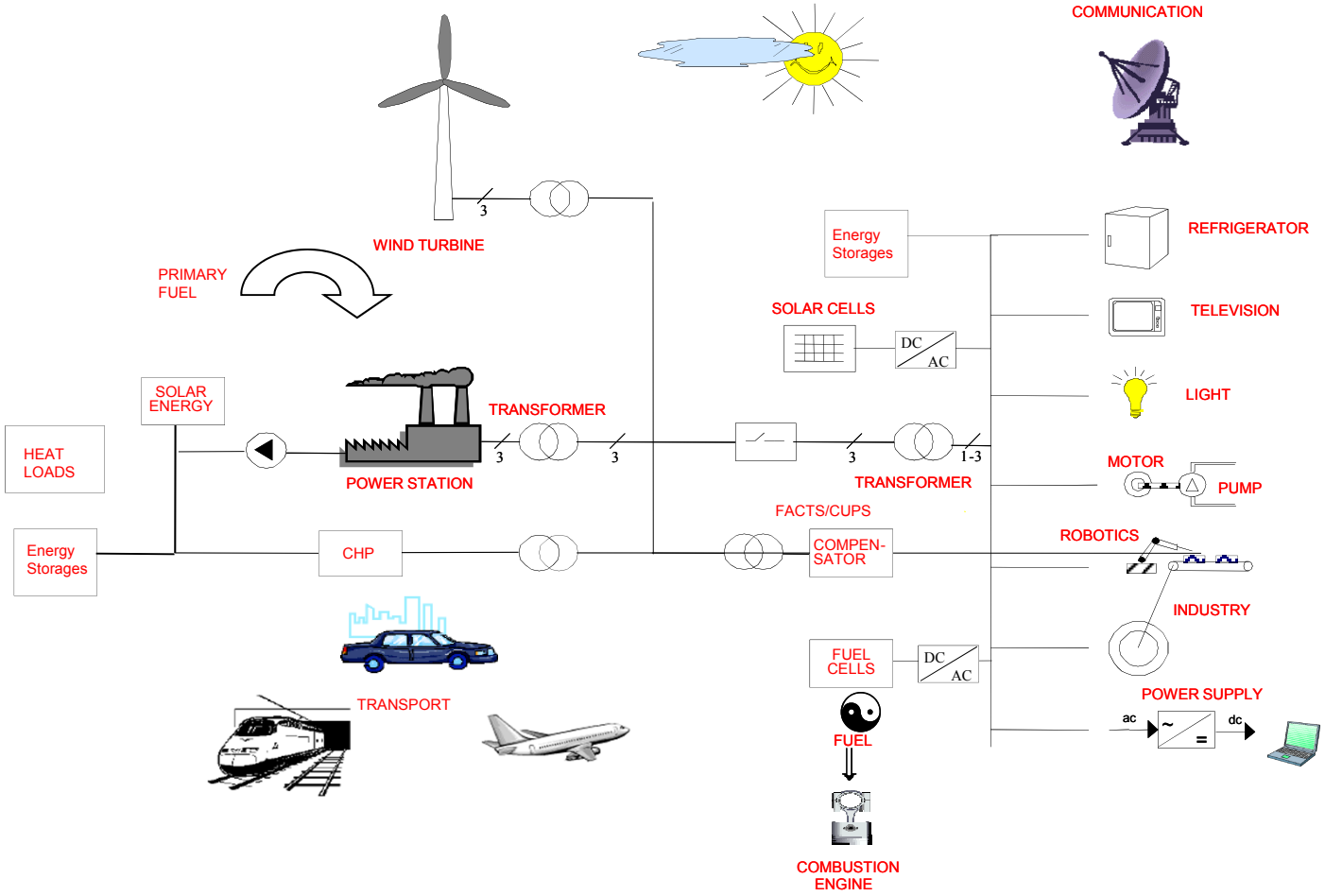
# Aalborg University - Campus





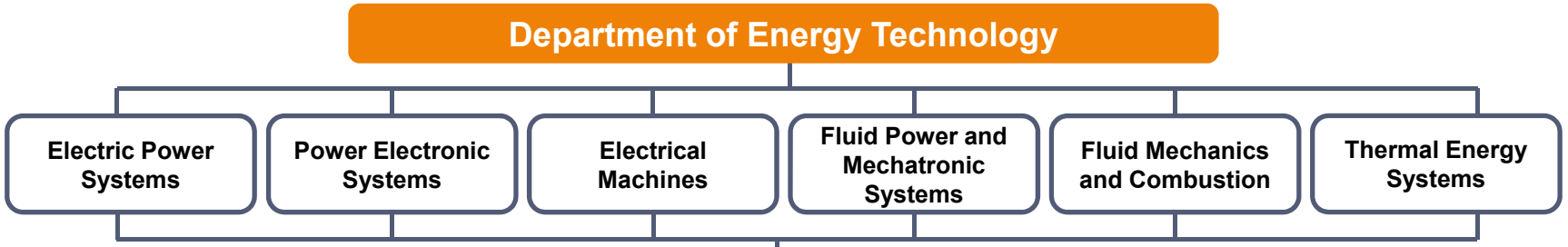
# Aalborg University - Campus

# Department of Energy Technology




**Energy** production - distribution - consumption - control

# Department of Energy Technology




**Strategic Networks**

- EMSD
- CEES
- ECPE
- VE-NET
- DUWET
- WEST
- VPP
- REN-DK
- HUB NORTH
- Energy Sponsor Programme

- 60VIP
- 110 PhD
- 15+ Guest Researchers
- 10+ Research Assistants
- 22 TAP

**Multi-disciplinary Research Programmes**

- **Wind Turbine Systems**
- **Fluid Power in Wind and Wave Energy**
- **Biomass**
- **Photovoltaic Systems and Microgrids**
- **Modern Power Transmission Systems**
- **Smart Grids and Active Networks**
- **Fuel Cell and Battery Systems**
- **Automotive and Industrial Drives**
- **Efficient and Reliable Power Electronics**
- **Thermoelectrics**
- **Green Buildings**

**Lab. Facilities**

- Power Electronics Systems
- Drive Systems Tests
- Fluid Power
- Power Systems & RTDS
- Micro Grid
- High Voltage
- dSPACE
- PV Converter & Systems
- Laser Systems
- Fuel Cell Systems
- Battery Test
- EMC
- Vehicles Test Lab
- Biomass Conversion Facilities
- Proto Type Facilities

# HARMONY

## HARMONY

Harmonic Identification, Mitigation, and Control in Power Electronics Based Power Systems

## ERC Advanced Grant

Period: 01/02/2013 – 31/01/2018
Amount: 2.5 million Euros

European Research Council
Established by the European Commission
Supporting top researchers from anywhere in the world

## Principle Investigator

Professor Frede Blaabjerg
Department of Energy Technology
Aalborg University, Denmark

Department of ENERGY TECHNOLOGY
Aalborg University

## Website

www.harmony.et.aau.dk

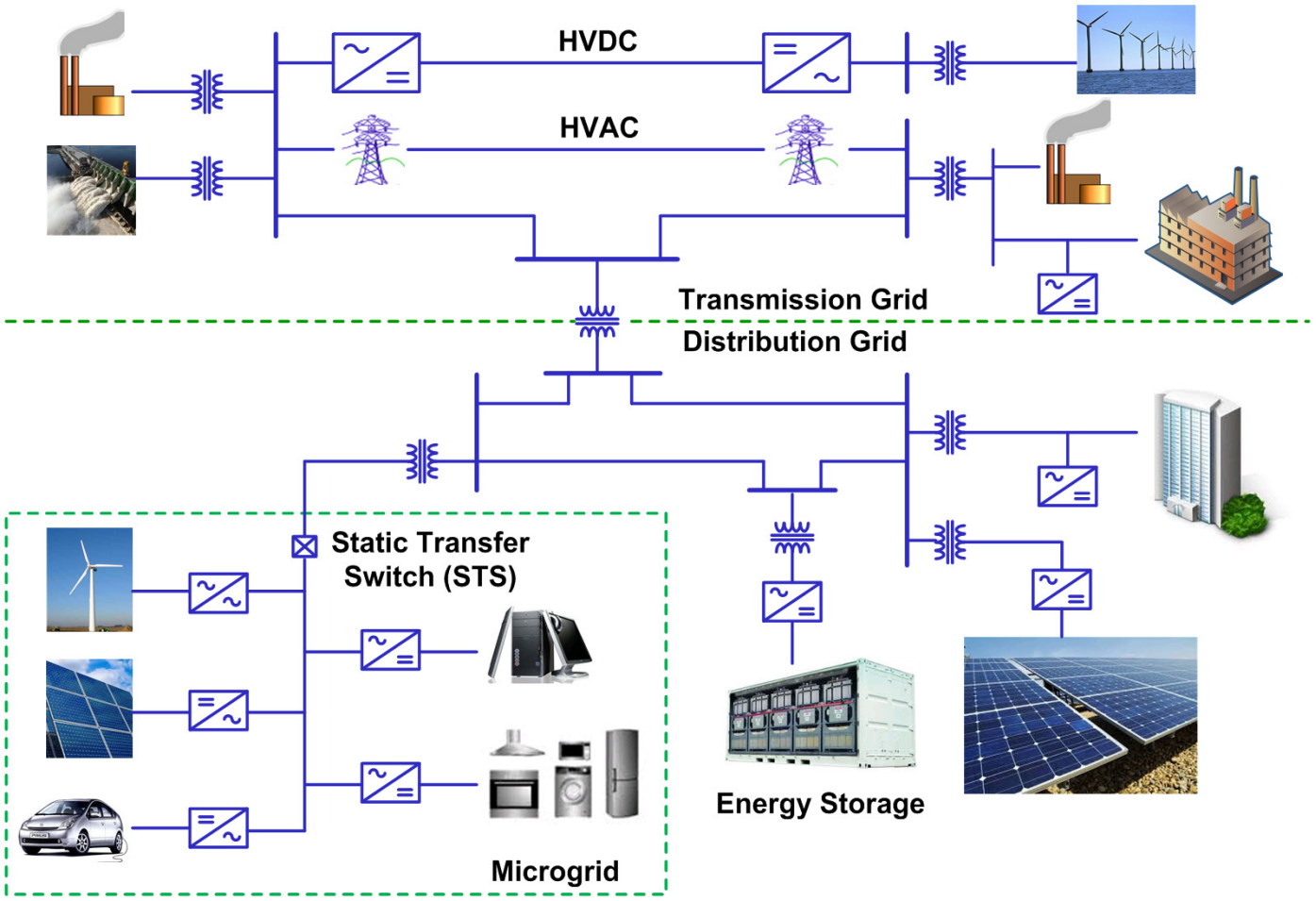
# Background

## Power Electronics Enabling Sustainable and Smart Power Grids

Source: IKEA

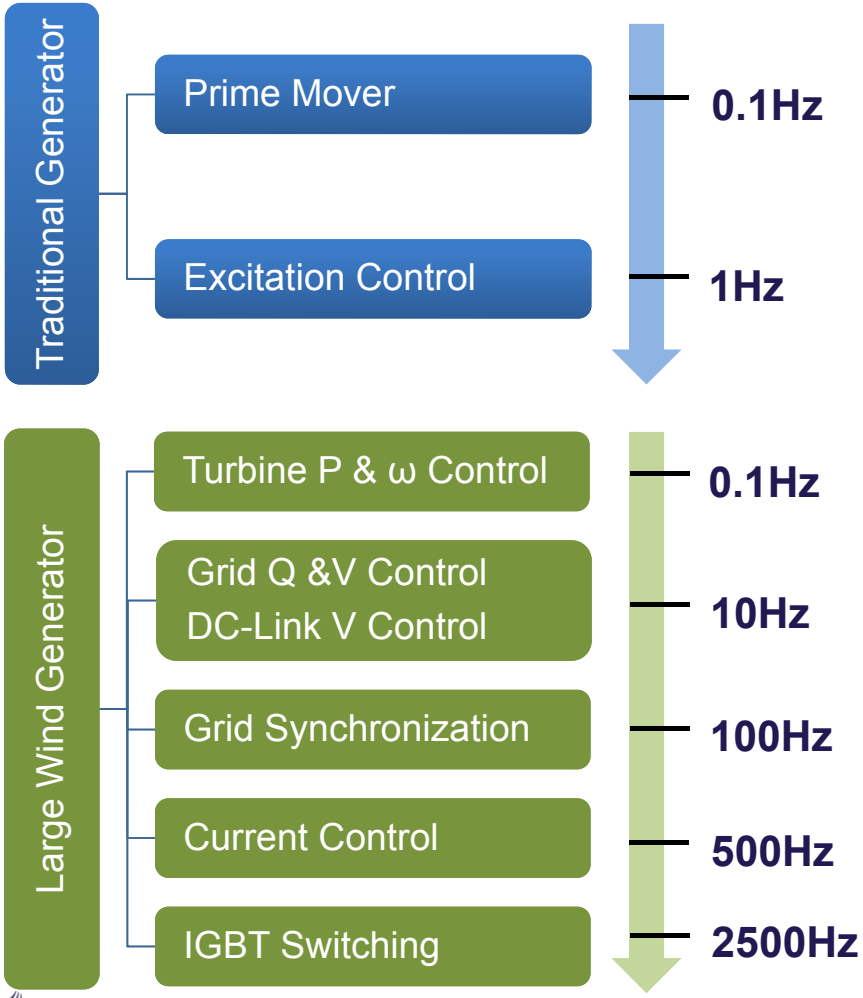
# Background

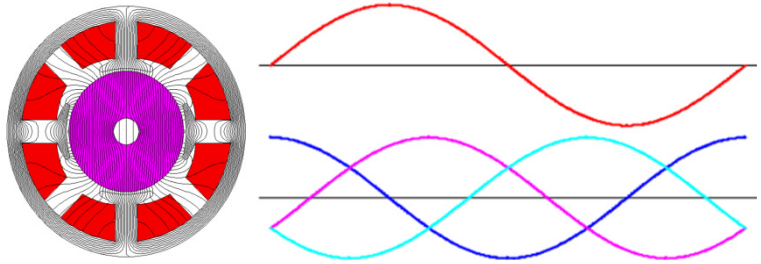
## Evolving Power Electronics Based Power Systems



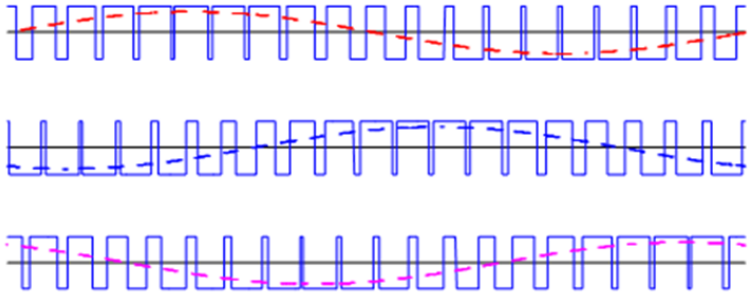
# Challenges

## Increasing Wideband Harmonics and Dynamic Interactions

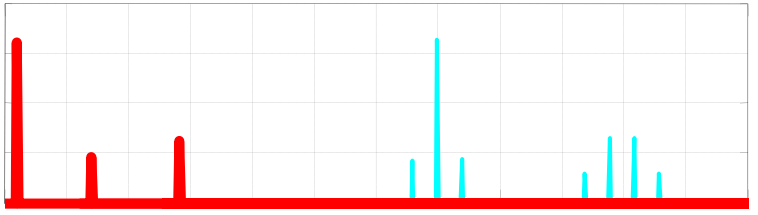


Traditional Generator Output Voltage



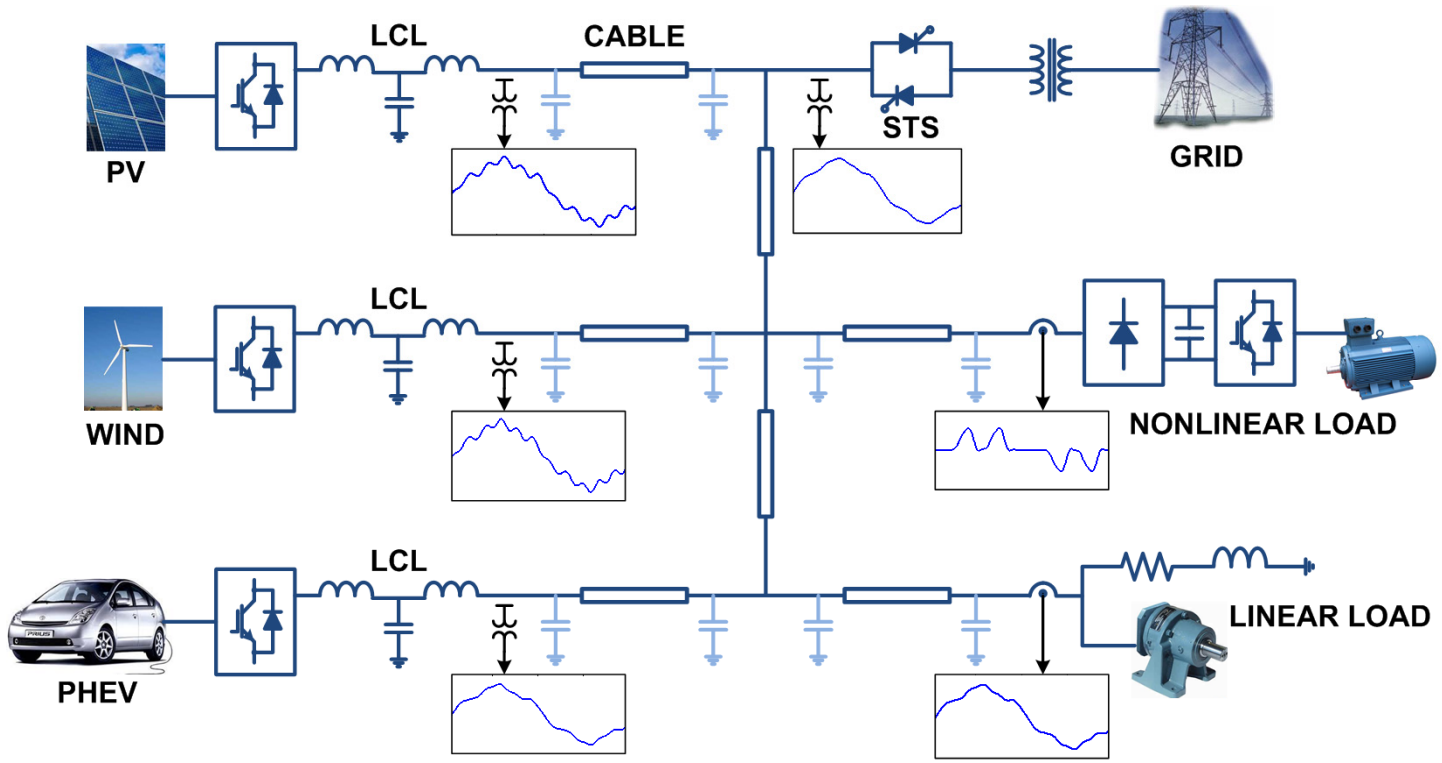
Wind Generator Output Voltage



Harmonic Spectrum

# Challenges

## Harmonic Coupling and Controller Interaction

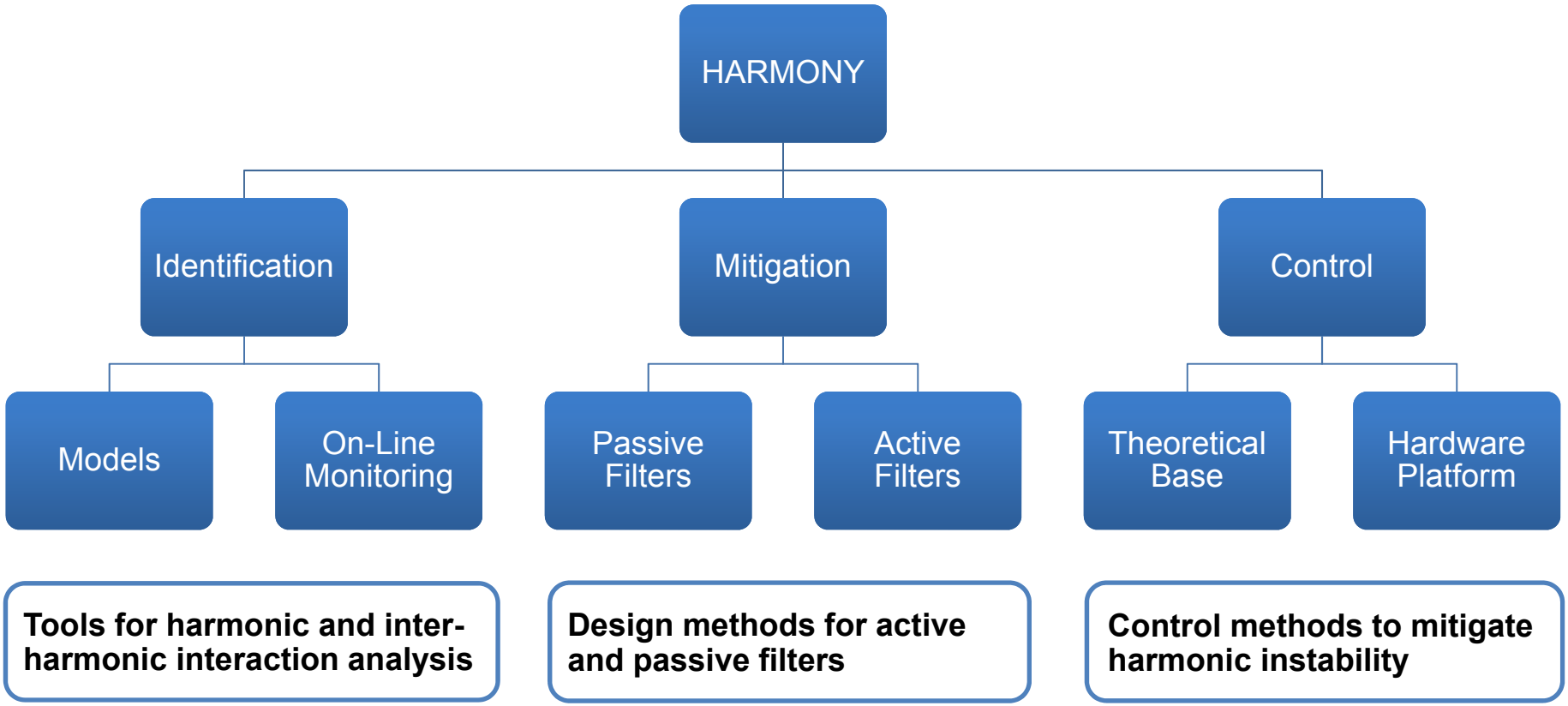



- Nonlinear characteristic of passive components under square wave condition
- More resonances in converter-filters and cables
- Interactions of harmonic and inter-harmonic components

# Objectives

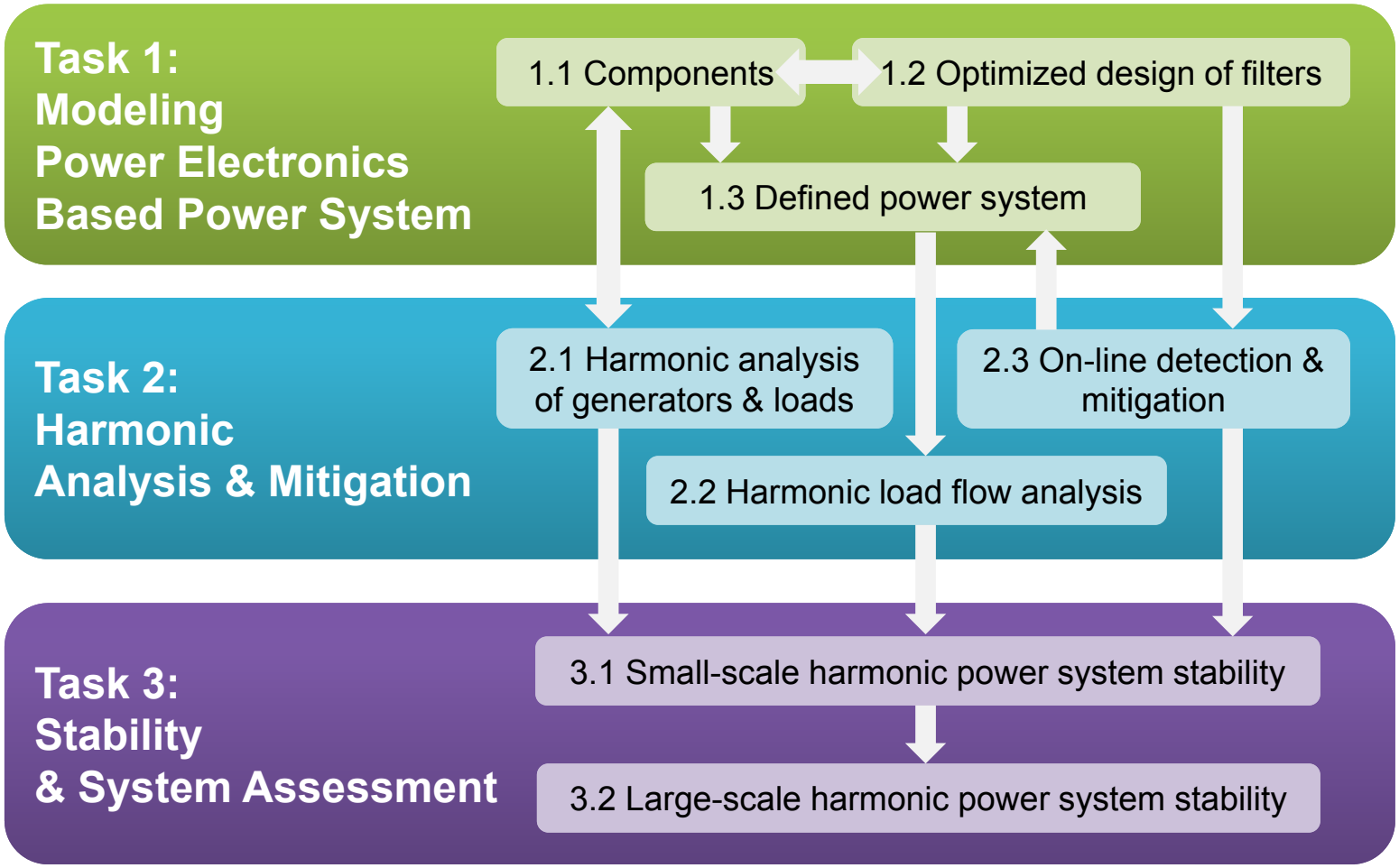
## Research Vision

- **Harmonious Power System without unexpected harmonics and instabilities**



# Implementation

## Research Plan



# Team Members

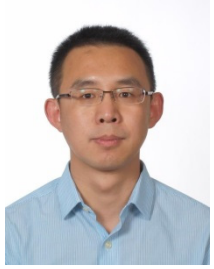
## Key Members

**Frede Blaabjerg**

**(Principle Investigator)**

**Claus Leth Bak**

**Poh Chiang Loh**



**Xiongfei Wang**

## PhD Students

Remus Beres

Changwoo Yoon

Jun Bum Kwon

Zhen Xin

Haofeng Bai

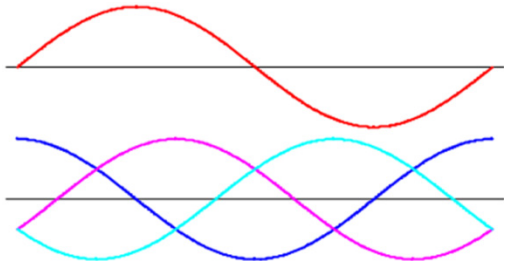
Minghui Lu

Esmaeil Ebrah.

Mohammadkazem B. D.

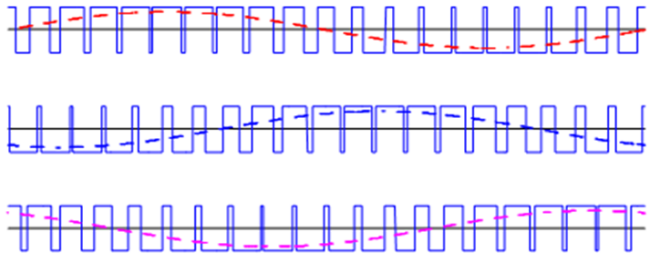
# Modeling Power System Components

## Wideband Model under Square Wave Conditions



Sinusoidal

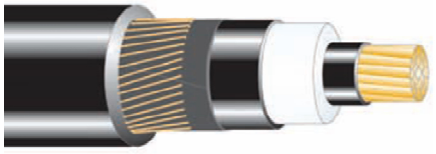
Power Electronics



Square

Passive Filters

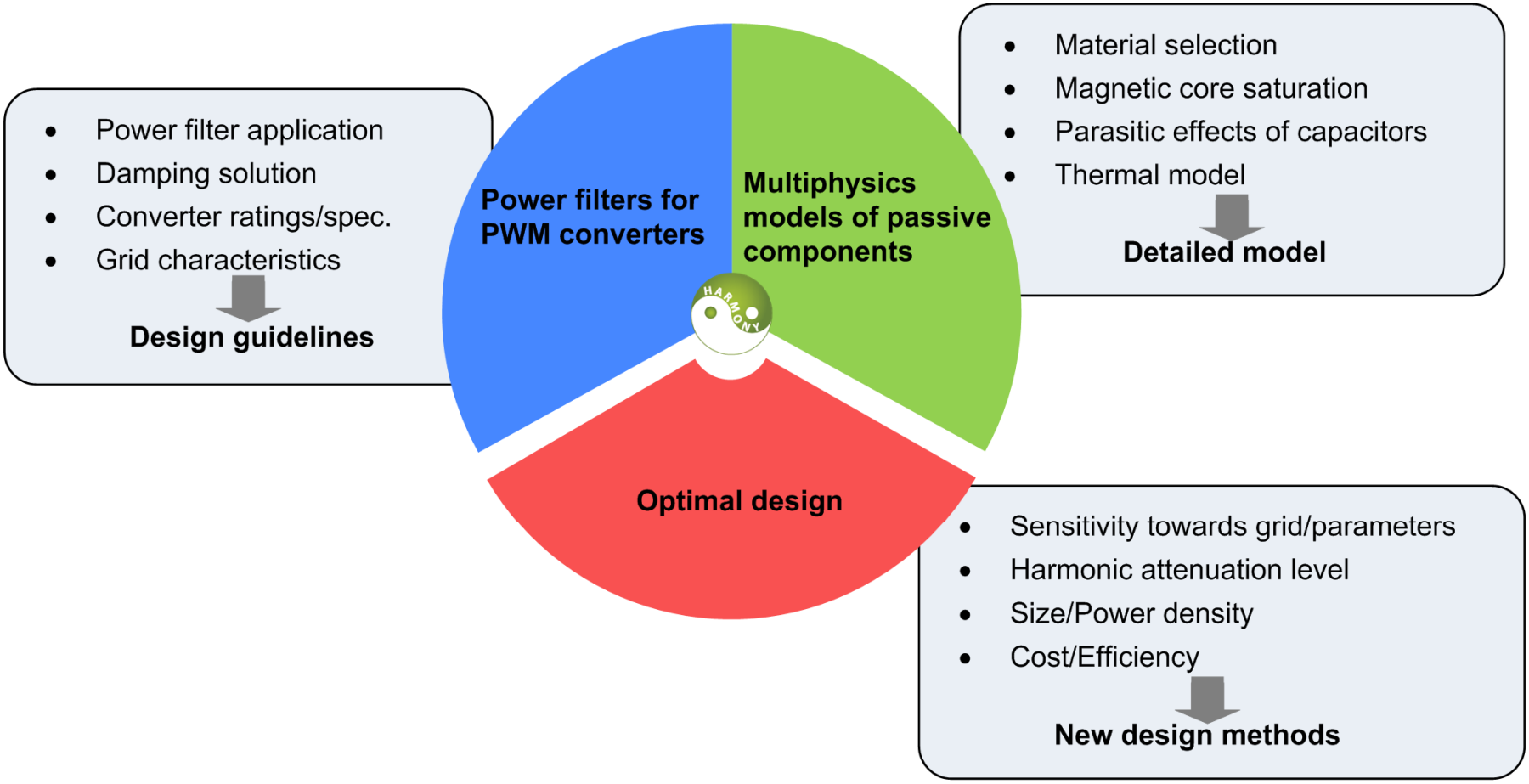
Transformers



Power Lines & Cables

# Optimized Design of Passive Filters

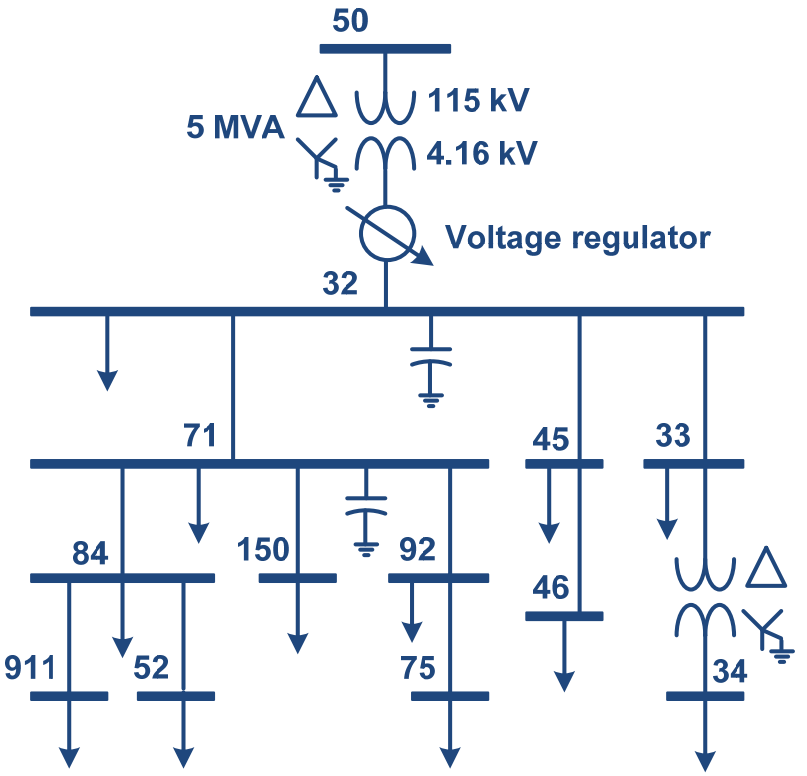
## Optimal Design for Stability and Power Loss



# Modeling Defined Power Systems

## Power Electronic Based Distribution Systems

- **Working with IEEE Task Force on Harmonics Modeling and Simulation**
- **Integration of power electronic based sources and loads**
  1. Distributed residential loads
  2. Integration of DG units
     - ✓ Photovolatic (PV)
     - ✓ Wind turbines (DFIG)
     - ✓ Vehicle to Grid (V2G)




**13-bus system**

# Harmonic State-Space Analysis

## Power Converters – Linear Time-Periodic (LTP) Systems

- Harmonic State-Space (HSS) model for harmonic interaction analysis




N. Wereley, “Analysis and control of linear periodically time varying systems,” Ph.D. dissertation, MIT, 1991.

# Harmonic State-Space Modeling

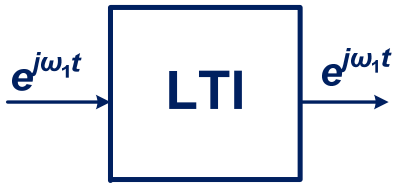
## Stability Analysis of Linear Time-Periodic System

- **Harmonic transfer functions (matrices)**

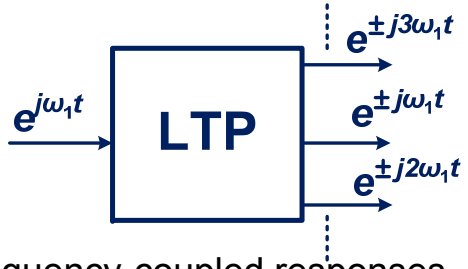
$$H(s) = \hat{C}\left((s + jn\omega_1)I - \hat{A}\right)^{-1}\hat{B} + \hat{D}$$

$$H(s) = \begin{bmatrix} \ddots & \vdots & \vdots & \vdots & \iddots \\ \dots & H_0(s - j\omega_1) & H_{-1}(s) & H_{-2}(s + j\omega_1) & \dots \\ \dots & H_1(s - j\omega_1) & H_0(s) & H_{-1}(s + j\omega_1) & \dots \\ \dots & H_2(s - j\omega_1) & H_1(s) & H_0(s + j\omega_1) & \dots \\ \iddots & \vdots & \vdots & \vdots & \ddots \end{bmatrix}$$

- **Frequency-coupled responses of LTP model**




Single frequency response

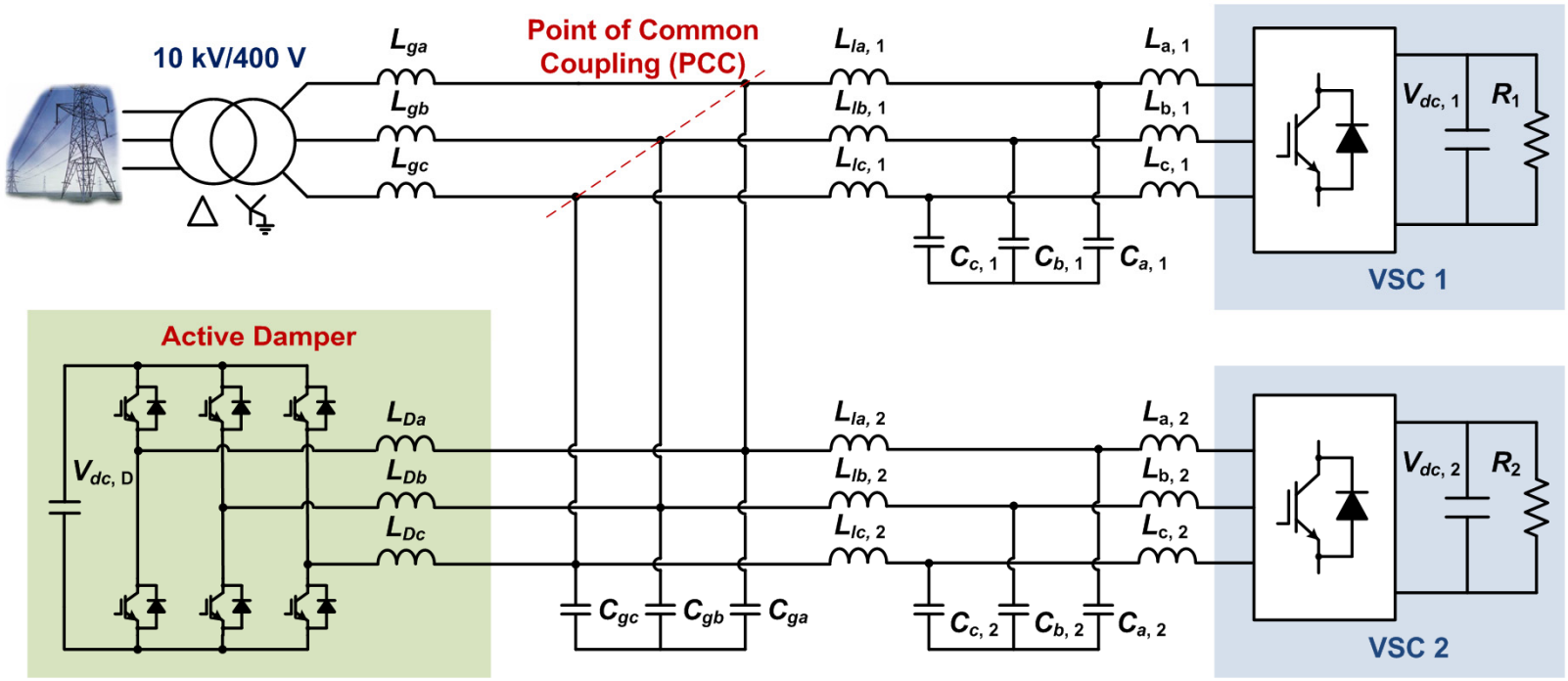



Frequency-coupled responses

# On-Line Detection and Mitigation

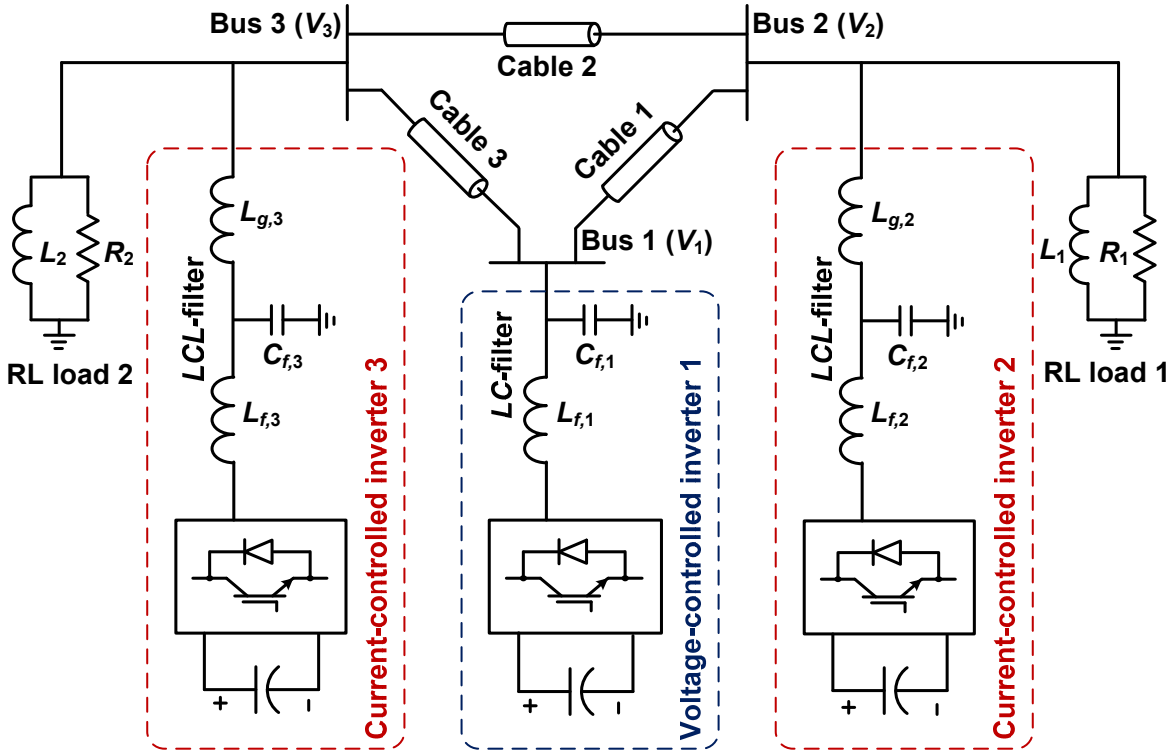
## Active Damper – Adaptively Reshaping Grid impedance

- Reduce electric coupling in paralleled VSCs at resonance frequency
- No low-order harmonic filtering – low-power, high-frequency, high-bandwidth



# System Stability Assessment

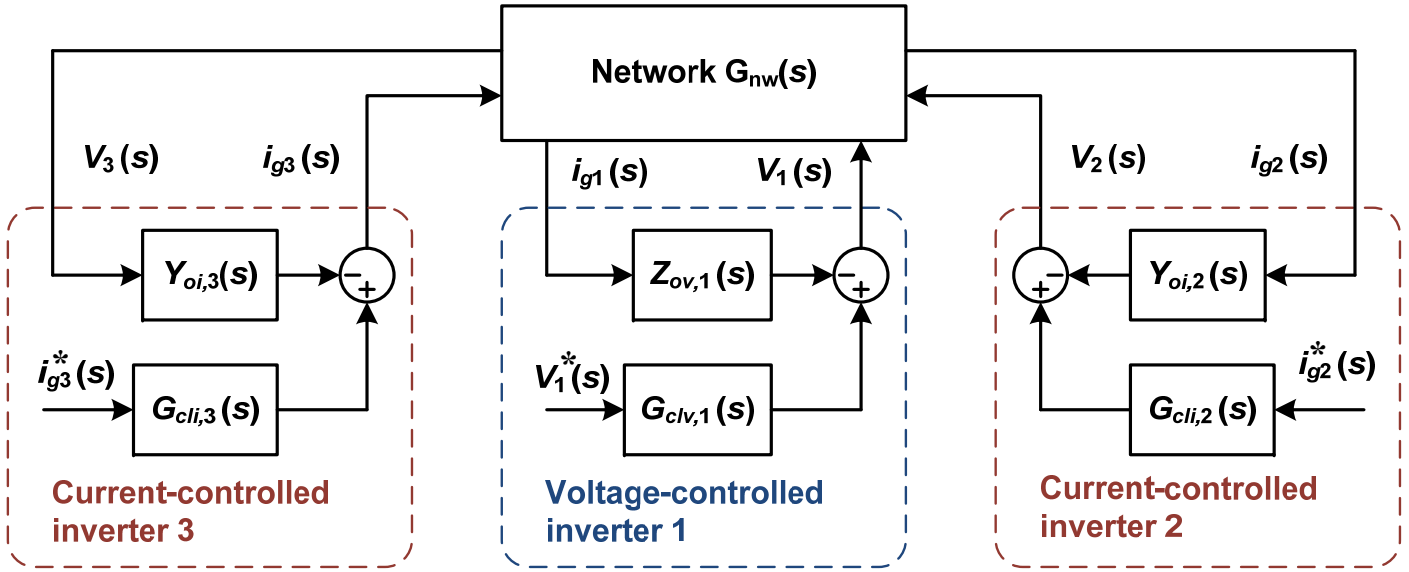
## Stability of AC Power-Electronic-Based System




- Voltage-controlled inverter: system voltage and frequency regulation
- Current-controlled inverter: unity power factor operation
- Harmonic instability due to current/voltage controller interactions of inverters

# System Stability Assessment

## Stability of AC Power-Electronic-Based System




- **Component Connection Method (CCM) – state-space matrix and eigenvalues**
  - ✓ Generalized to multi-bus power system
- **Impedance-based analytical approach – frequency-domain analysis**
  - ✓ Balanced three-phase system – SISO transfer functions
  - ✓ Generalized Nyquist stability criterion is required for MIMO systems

# Programme - Morning

**09:00 – 09:30** **Welcome and Overview of Harmony Project** - *by Prof. Frede Blaabjerg, Principle Investigator, Aalborg University, Denmark*

**09:30 – 10:00** **"D-Σ Digital Control for Improving Stability Margin under High Line Impedance"** - *by Prof. Tsai-Fu Wu, National Tsinghua University, Taiwan*

**10:00 – 10:30** **"Harmonic Assessment in a Modern Transmission Network"** - *by Christian Flytkjaer Jensen, Grid Analyst, Energinet.dk, Denmark*

**10:30 – 11:00** **Coffee Break**

**11:00 – 11:30** **"Harmonic Challenges and Mitigation in Large Offshore Wind Power Plants"** - *by Lukasz Kocewiak, Senior Power System Engineer, DONG Energy, Denmark*

**11:30 – 12:00** **"Harmonic Standards of the Present and the Future Electricity Networks"** - *by Firuz Zare, Lead Engineer, Danfoss Drives, Denmark*

**12:00 – 12:30** **"Stability Analysis and Active Stabilization of DC Distribution Systems"** - *by Mehdi zadeh, PhD Student, NTNU, Norway*

**12:30 – 13:30** **Lunch**

# Programme - Afternoon

**13:30 – 13:50** **"Harmonic Stability in Power Electronic Based Power Systems"** - *by Xiongfei Wang, Assistant Professor, Aalborg University, Denmark*

**13:50 – 14:10** **"High-Order Passive Filters for Grid-Connected Voltage-Source Converters: Topologies and Design Challenges"** - *by Remus Beres, PhD Student, Aalborg University, Denmark*

**14:10 – 14:30** **"Small Scale Harmonic Power System Stability"**- *by Changwoo Yoon, PhD Student, Aalborg University, Denmark*

**14:30 – 14:50** **"Harmonic State Space Modeling in Power Electronics"** - *by Jun Bum Kwon, PhD Student, Aalborg University, Denmark*

**14:50 – 15:10** **Coffee Break**

**15:10 – 15:30** **"Active Damper for Stabilizing Power-Electronic Based Systems"** - *by Haofeng Bai, PhD Student, Aalborg University, Denmark*

**15:30 – 15:50** **"Robust Active Damping Design for Grid-Current Feedback Control in Grid-Connected Converters"** - *by Zhen Xin, PhD Student, Aalborg University, Denmark*

**15:50 – 16:10** **"A Multi-Pulse Pattern Modulation Scheme for Harmonic Mitigation in Three-Phase Multi-Motor Drives Applications"** - *by Pooya Davari, Postdoc, Aalborg University, Denmark*

**16:10 – 17:10** **Panel Discussion and Lab Visit**