Chair of
Sustainable Electric Networks
and Sources of Energy (SENSE)

Microgrids Research at SENSE/TU Berlin: Overview with a Special Focus on Integration of Tidal Energy

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Jeju 2011 Symposium on Microgrids

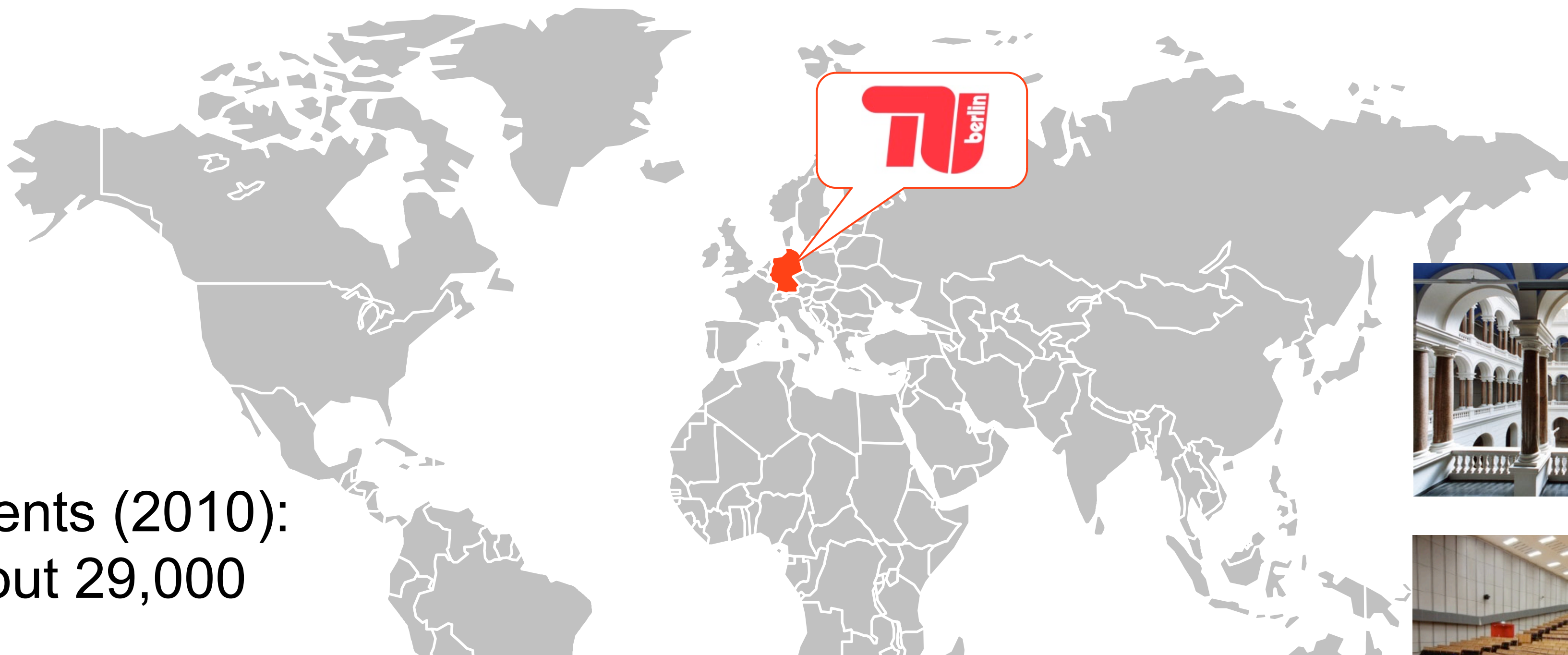
27 May 2011

Outline

1. **Introduction to TU Berlin: Overview and Research Rank**
2. **Introduction to SENSE: Research Overview**
3. **Selected Research with Relation to Microgrids**
   - MERGE
   - *E*-MERGE Laboratory
   - Control of Electric Vehicles for Improved Grid Security
   - Modeling of Next-generation Aircraft Power Systems
   - Benchmarking Technology
4. **Tidal Energy Conversion Systems for Microgrids**
   - Tidal Current Characteristics
   - Technology
   - Grid Connection

1. Introduction to Technische Universität Berlin

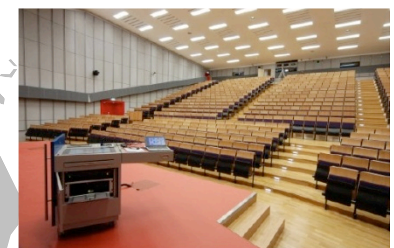
Overview



Students (2010):
about 29,000

Professors (2010):
320

Doctorates (2010):
376



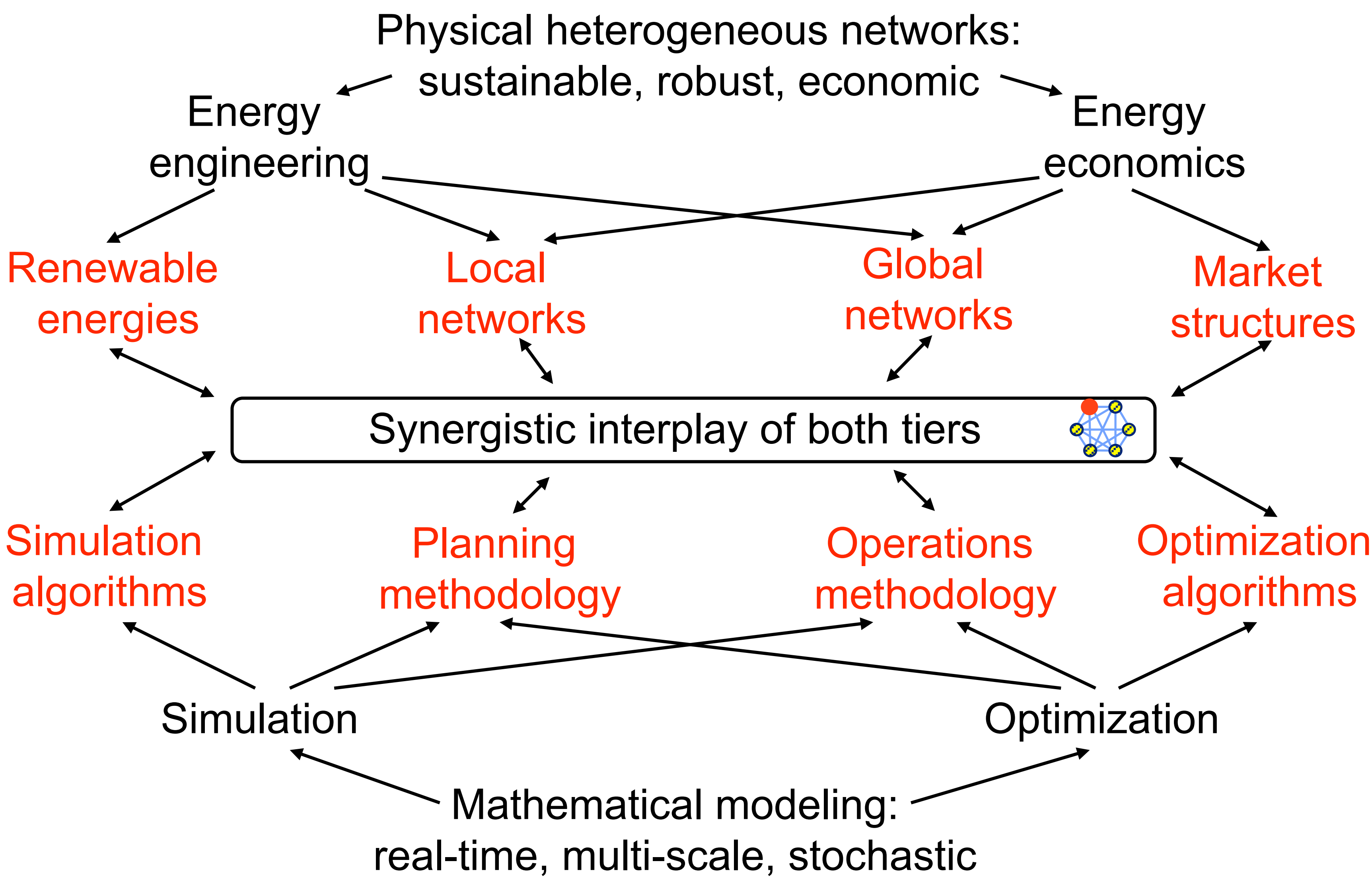
1. Introduction to Technische Universität Berlin
Research Rank of Electrical and Computer Engineering (ECE)

- Centre for Higher Education (CHE) Development published the results of the research assessment exercise for ECE Schools in 2008
- SENSE Chair is part of this top-ranked ECE School

University	Achieved top positions	Compared to 2004	Absolute				Relative			
			a	b	c	d	a	b	c	d
RWTH Aachen	6	++	●	●	●	●		●		●
TU Berlin	7	+	●	●	●	●	●	●	●	
TU Darmstadt	6	++	●	●		●	●	●		●
TU Dresden	6	++	●	●	●	●	●		●	
Uni Freiburg	5	+		●	●		●	●	●	
Uni Karlsruhe	6	++	●	●		●	●	●		●
TU München	6	++	●	●	●	●			●	●

a Third-party funds
b Publications
c Inventions
d Ph.D. graduates

2. Introduction to SENSE:
Research Overview

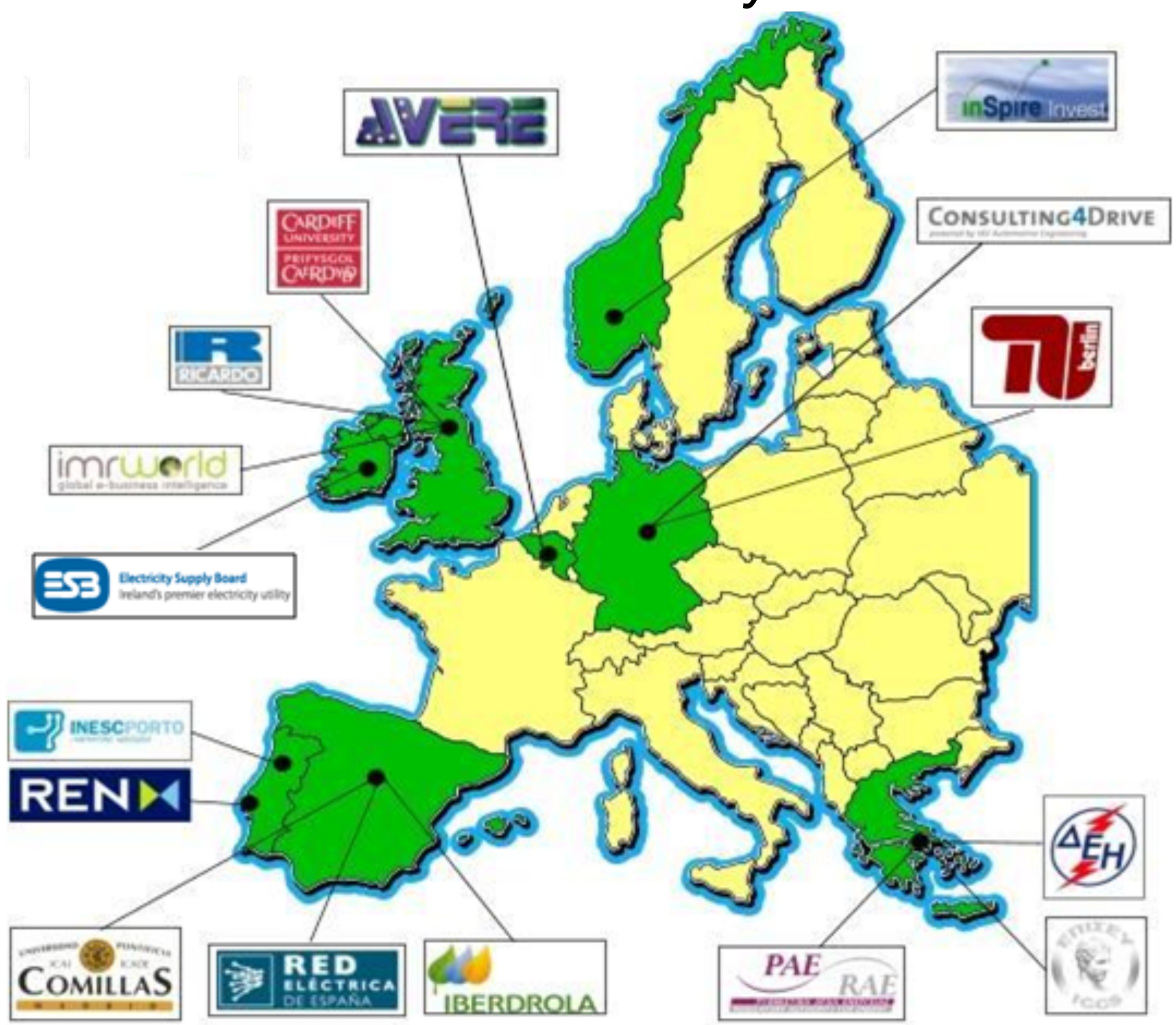


3. Selected Research: Selected Topics

- Selected sponsored research with microgrid relation at SENSE:
  - MERGE – Cooperation with European Union
  - *E-MERGE* Laboratory – Cooperation with German Federal Ministry of Economics and Technology
  - Control of Electric Vehicles for Improved Grid Security – Cooperation with industry
  - Modeling of Next-generation Aircraft Power Systems – Cooperation with industry
  - Benchmarking Technology – Cooperation with CIGRE
  - Tidal Energy Conversion – Cooperation with Reiner Lemoine Foundation

3. Selected Research:
MERGE – Partners

- *MERGE: Mobile Energy Resources in Grids of Electricity*
- Partners: see map
- Project coordinator:
  Prof. Nikos Hatziargyriou



3. Selected Research:
MERGE – Scope

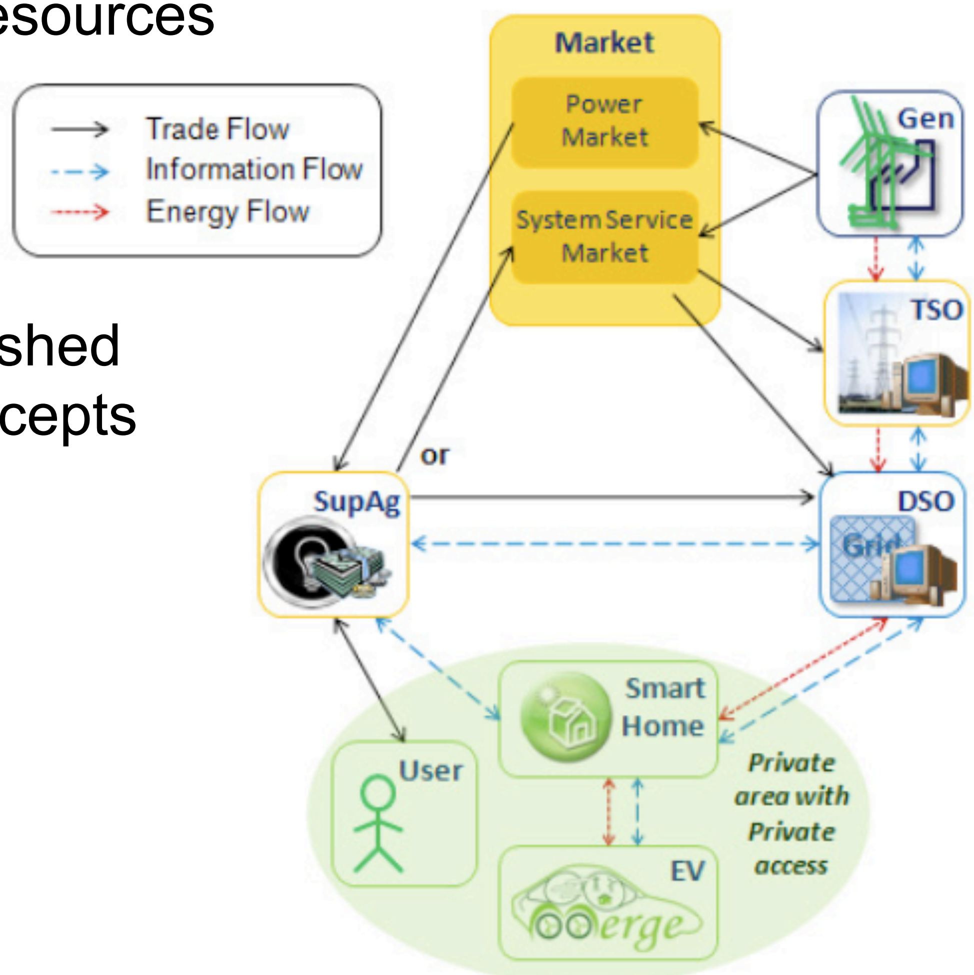
- MERGE offers novel methods of grid integration where electric vehicles are treated as valuable mobile energy resources

- Most suitable interactions between key actors were identified

- Interactions of MERGE are distinguished through extension of two known concepts from stationary to mobile resources:
  - Microgrid
  - Virtual Power Plant

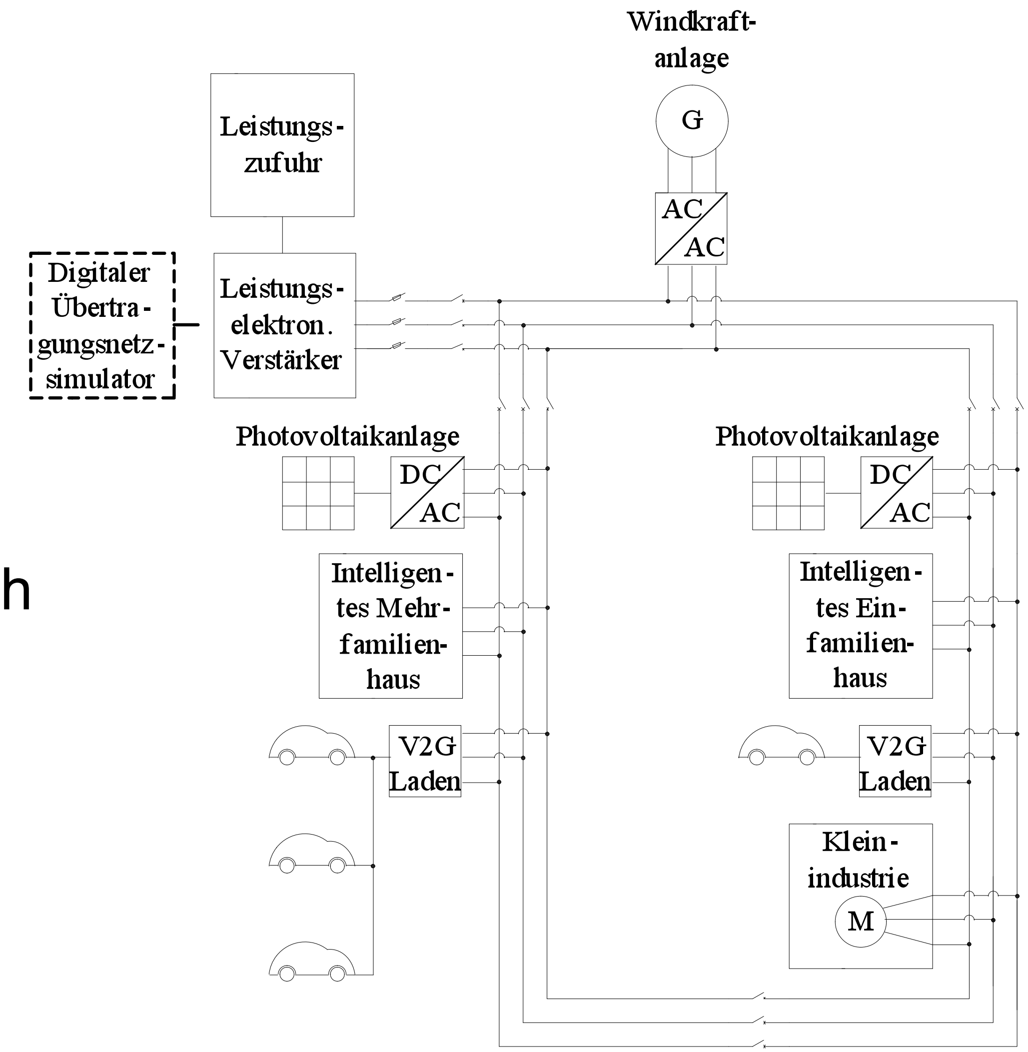
- More information available at

  www.ev-merge.eu



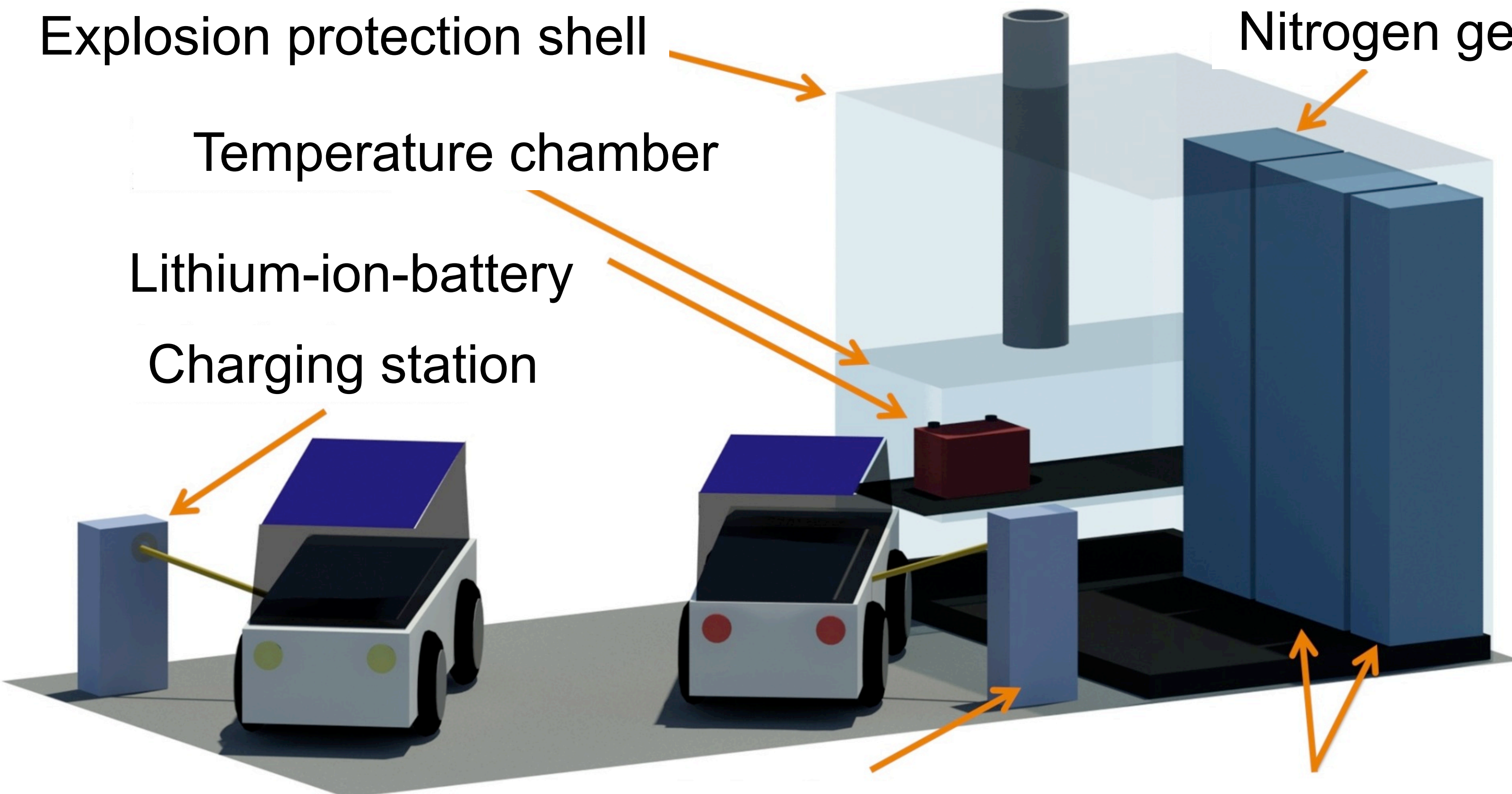
3. Selected Research:
E-MERGE Laboratory

- *E-MERGE: Electro-Mobile Energy Resources for Grids of Electricity*
- Partner: German Federal Ministry of Economics and Technology (BMWi)
- Complementary to e-mobility field tests
- Realization of physical microgrid with integrated e-mobility in 2011
- Research on security and stability



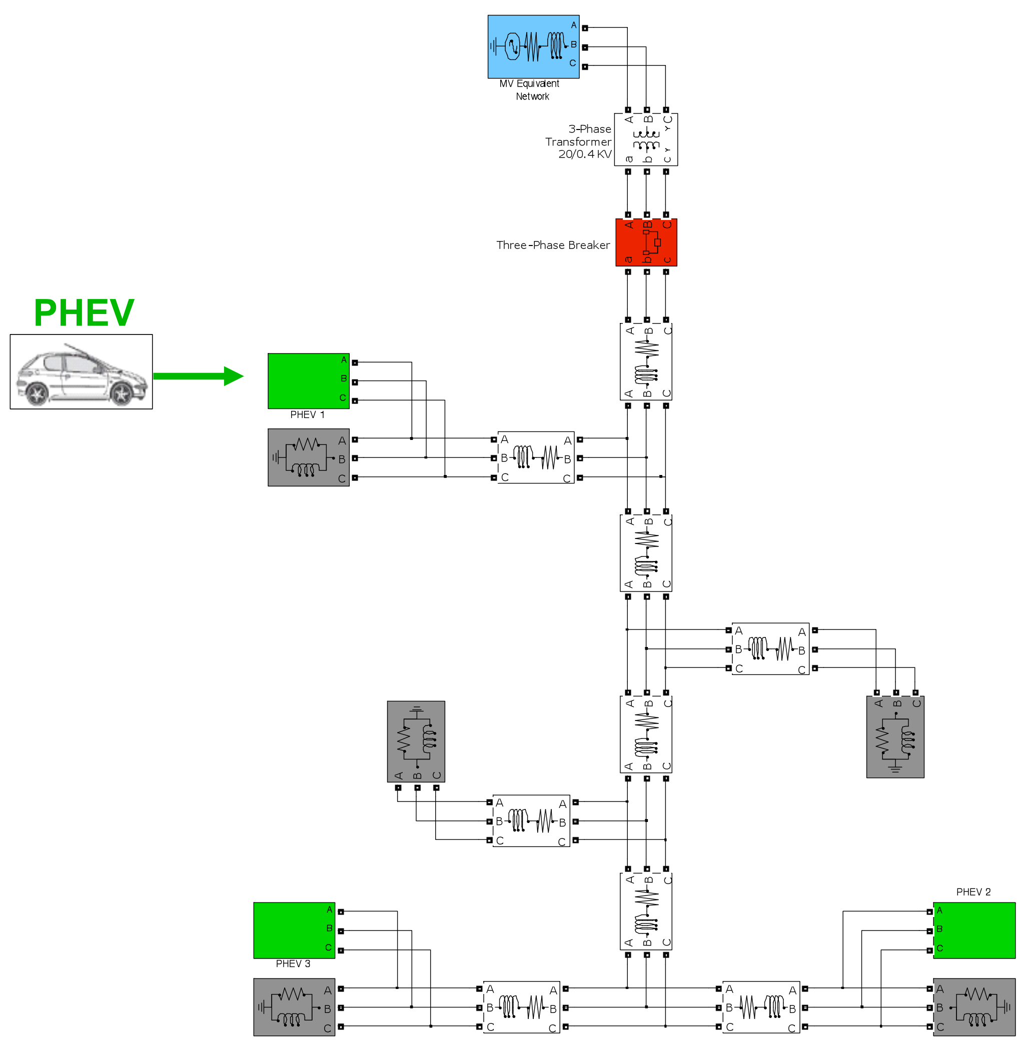
3. Selected Research:
E-MERGE Laboratory

- As part of the laboratory, battery testing is an important feature



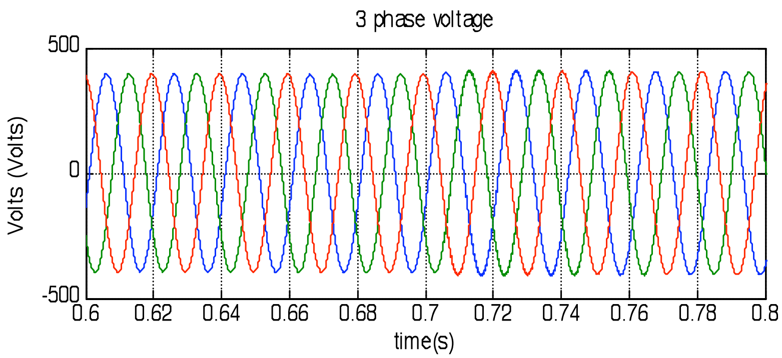
3. Selected Research:
Control of Electric Vehicles (EVs) for Improved Grid Security

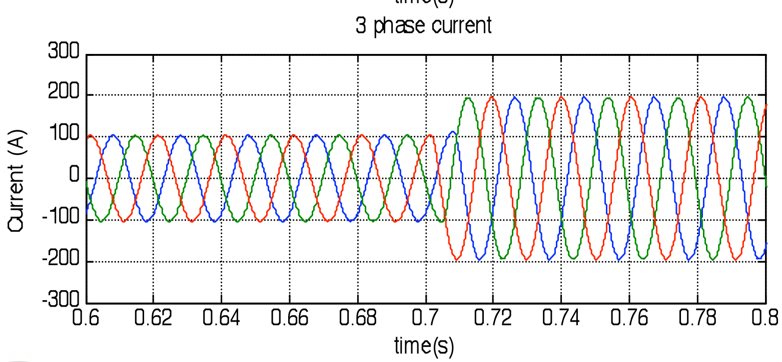
- Partner: industry
- EVs shown to support microgrid behavior in distribution networks
- Validation in MATLAB/Simulink using SimPowerSystems toolbox
- Blocks:
  - White: lines and transformers
  - Grey: loads
  - Blue: equivalent network
  - Green: plug-in hybrid electric vehicle (PHEV)
  - Red: switch

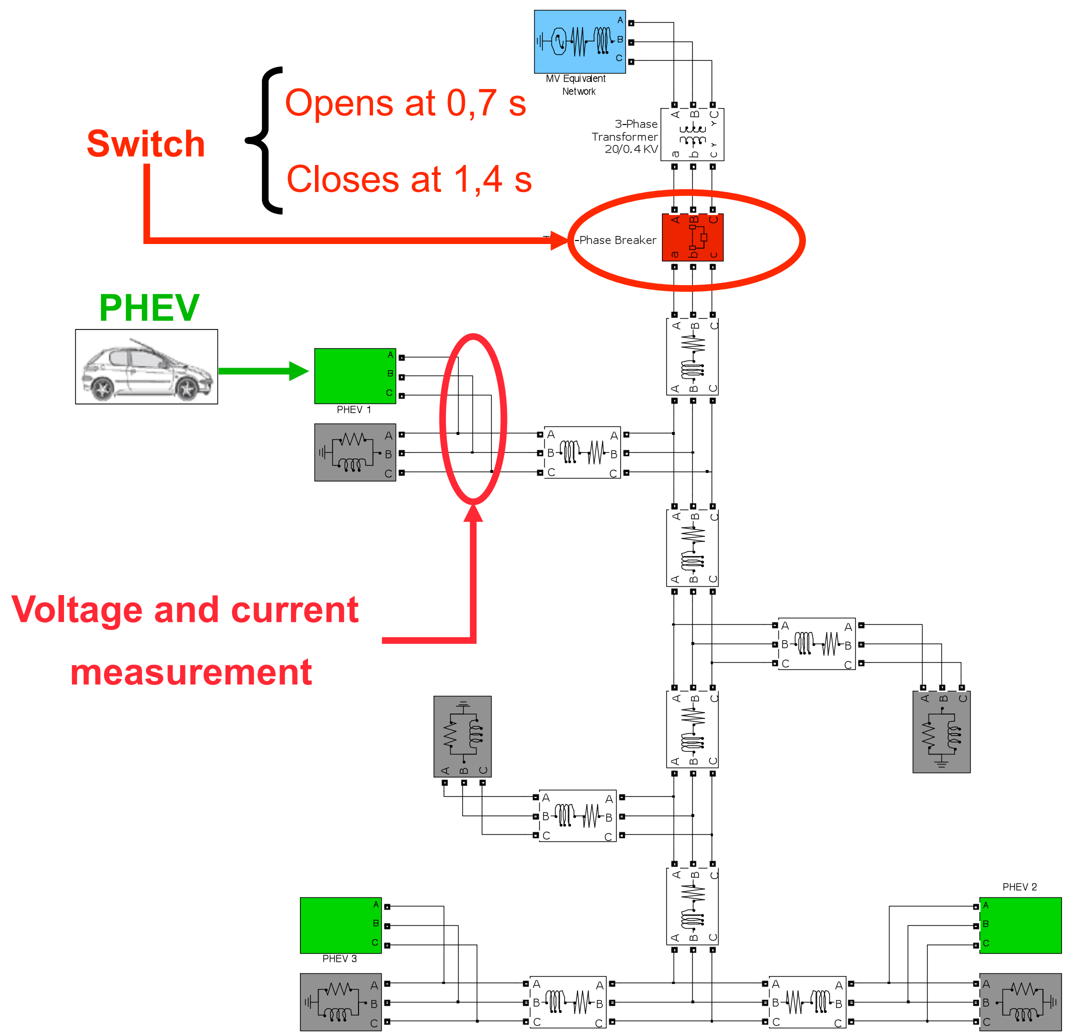


3. Selected Research:
Control of Electric Vehicles (EVs) for Improved Grid Security

- Result: PHEVs deliver power for microgrid support
- Voltage and current at PHEV terminals:



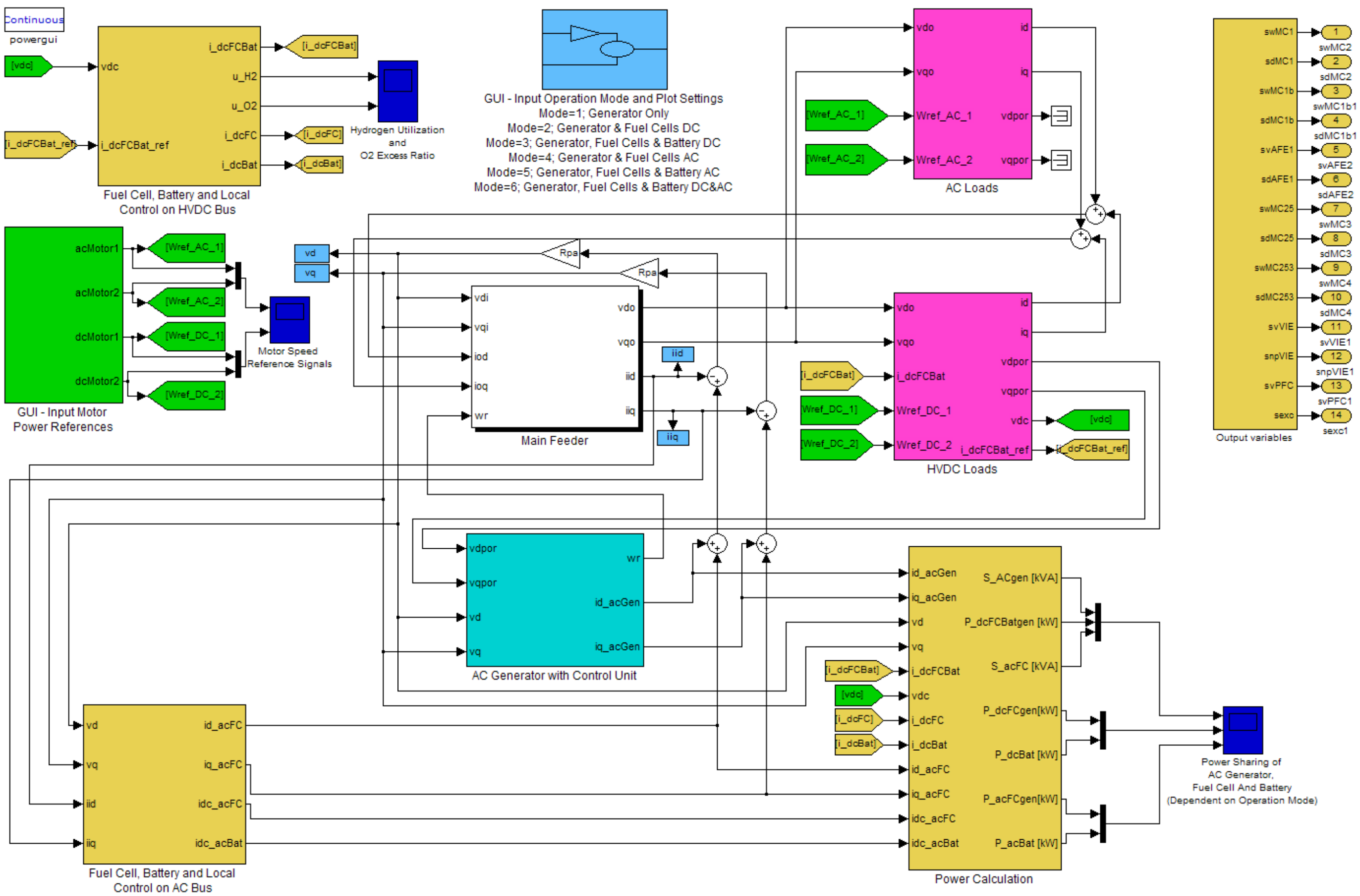




3. Selected Research:

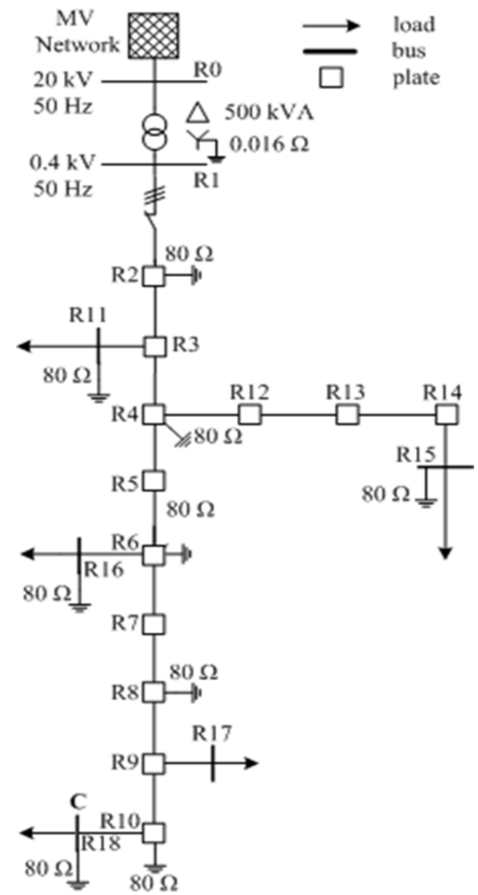
Modeling of Next-generation Aircraft Power Systems

- Partner: industry
- Microgrid experience can be helpful to aircraft power system design



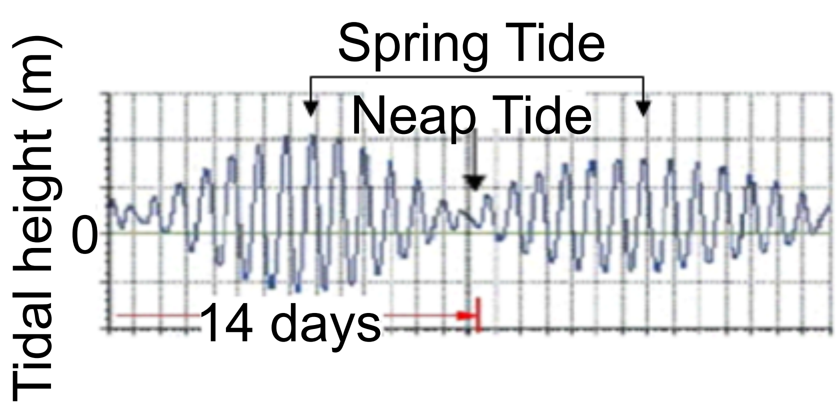
3. Selected Research: Benchmarking Technology

- Partner: CIGRE (Congrès International des Grands Reseaux Electriques)
- Need for having platform for testing technologies of distributed generation and microgrids was identified
- CIGRE Task Force C6.04.02 was founded
- Report on internationally recognized benchmark networks for performing the tests available in 2011

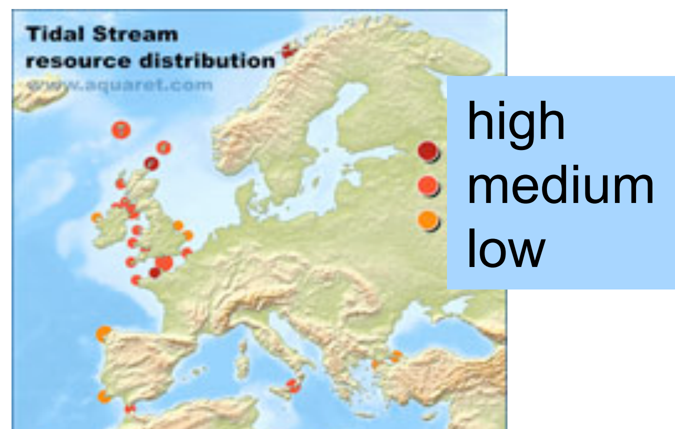


4. Tidal Energy Conversion Systems for Microgrids: Tidal Current Characteristics

- Partner: Reiner Lemoine Foundation
- Tidal energy conversion systems exploit kinetic energy of sea currents
- Tides vary sinusoidally; ebb and flood occur twice during a lunar day of about 25 hours
- Among others, a 14-days cycle exists with spring tides (maximum) and neap tides (minimum)



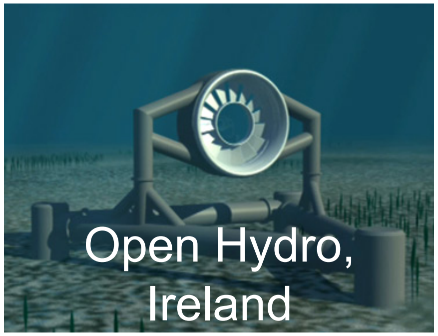
Source: www.epri.com



Source: www.emec.org.uk

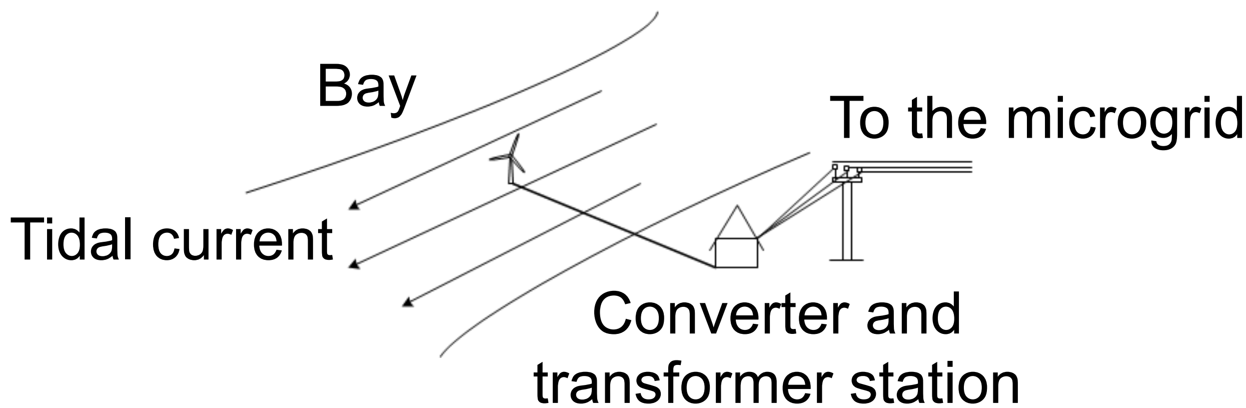
4. Tidal Energy Conversion Systems for Microgrids: Technology

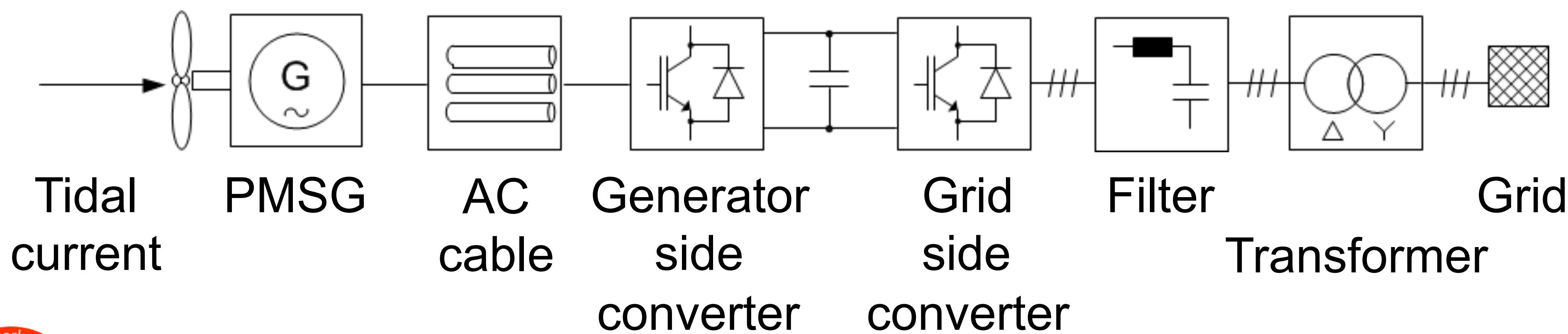
- Horizontal axis turbines are predominant
- Blade length up to 15 m — much smaller than wind turbine rotor blades due to high water density
- Duct concentrates the flow towards the rotor



4. Tidal Energy Conversion Systems for Microgrids:
Grid Connection – Structure

- Our research has centered on AC power transmission to shore
- Idea is here to put generator side converter on the shore instead of under water





4. Tidal Energy Conversion Systems for Microgrids:
Grid Connection – Cause of Traveling Waves

- High-frequency switching occurs at generator side converter
- Challenge as traveling waves on cable may cause overvoltage at generator
- Pulse rising time t_r at converter and traveling time over cable t_t are the influencing parameters
- Generator behaves close to open circuit, converter similar to short circuit
- Therefore, reflection coefficients Γ_{gen} and Γ_{con} can be approximated at generator and converter for first analysis as follows:

With $Z_{gen} \gg Z_c \gg Z_{con}$

$$\Gamma_{gen} = \frac{Z_{gen} - Z_c}{Z_{gen} + Z_c} \approx 1$$

$$\Gamma_{con} = \frac{Z_{con} - Z_c}{Z_{con} + Z_c} \approx -1$$

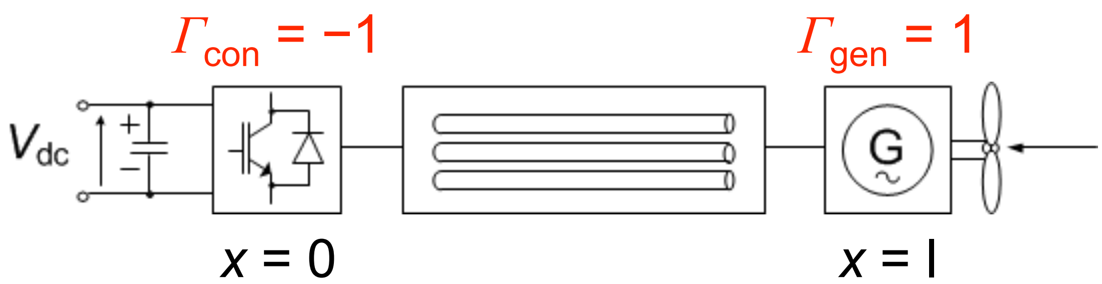
Z_{gen}: generator impedance

Z_{con}: converter impedance

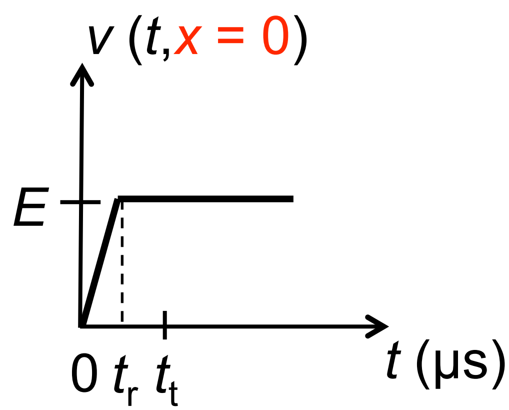
Z_c: characteristic cable impedance

4. Tidal Energy Conversion Systems for Microgrids: Grid Connection – Analysis Setup

- In order to analyze the traveling waves, the following setup is considered

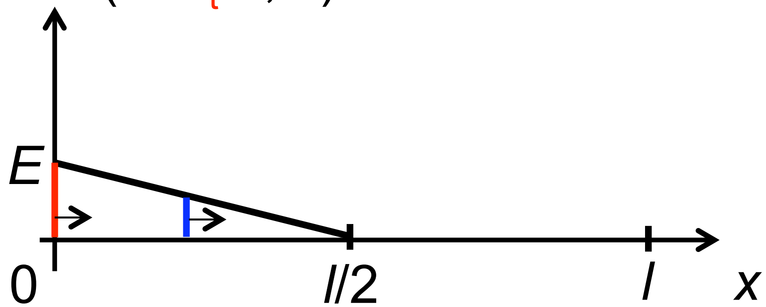


- Waves need traveling time t_t to move from one to the other end of cable
- The test function is a ramp with $t_r = t_t/2$ applied at location $x = 0$



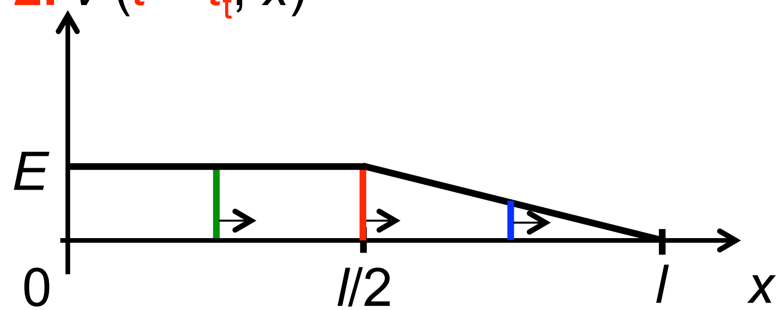
4. Tidal Energy Conversion Systems for Microgrids:
Grid Connection — Cable Voltage Profiles

1. $v\ (t = t_t/2,\ x)$



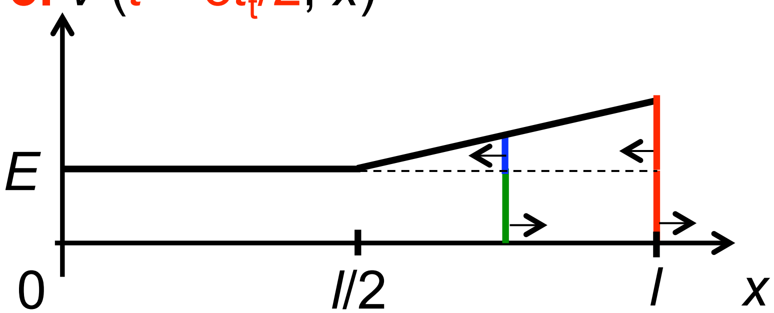
1. Pulse ramp stops rising at converter

2. $v\ (t = t_t,\ x)$



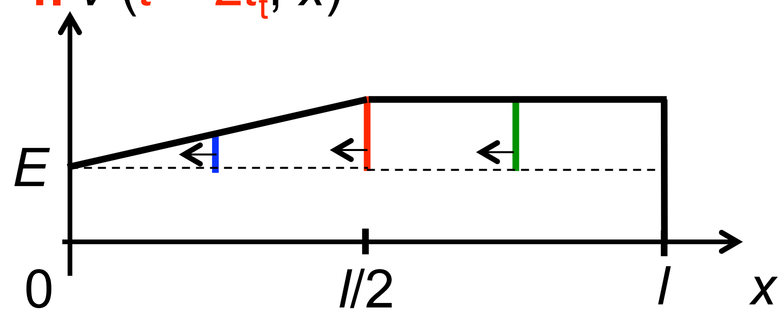
2. Start of ramp reaches generator

3. $v\ (t = 3t_t/2,\ x)$



3. End of ramp reaches generator,
voltage is doubled

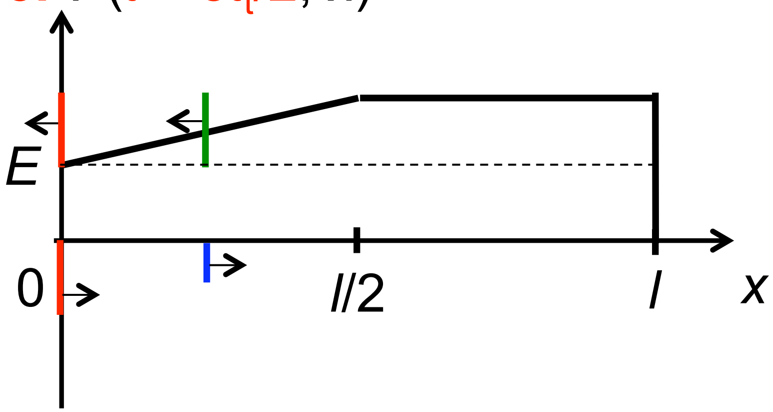
4. $v\ (t = 2t_t,\ x)$



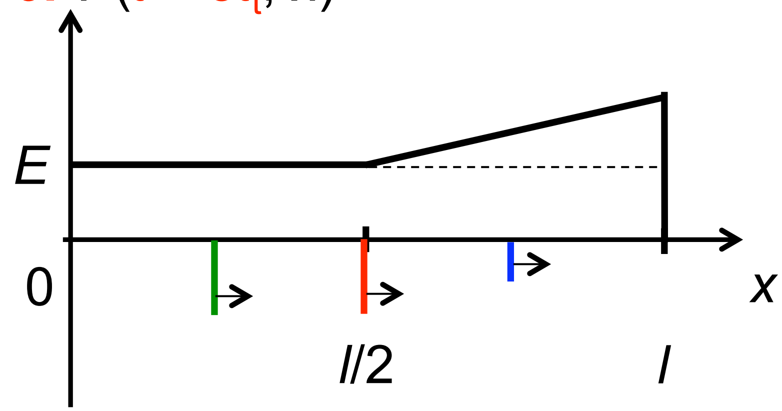
4. Start of ramp reaches converter after having traveled back to $x = 0$

4. Tidal Energy Conversion Systems for Microgrids:
Grid Connection — Cable Voltage Profiles

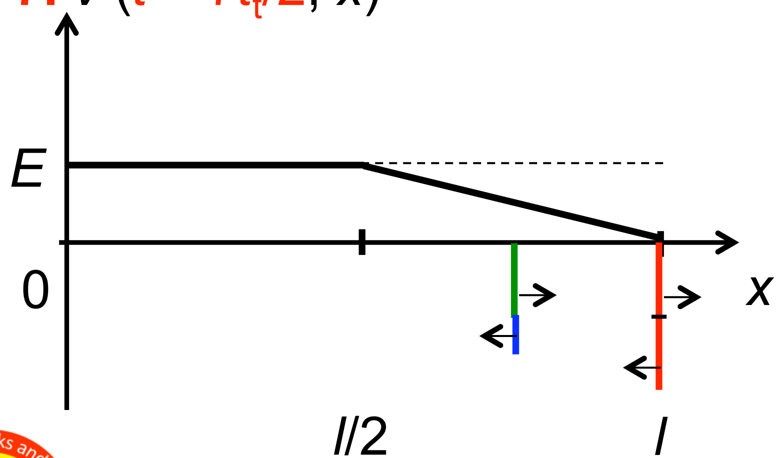
5. $v\ (t = 5t_t/2,\ x)$



6. $v\ (t = 3t_t,\ x)$



7. $v\ (t = 7t_t/2,\ x)$



5. Back traveling wave is reflected with negative sign, then moving forward again

6. Forward traveling wave reaches generator again, reducing voltage

7. Pulse ramp fully back reflected for second time

4. Tidal Energy Conversion Systems for Microgrids: Grid Connection ─ Equation for Overvoltage

- Based on analysis, the following equations for the voltage at the generator terminals $x = l$ at time $t = t_r + t_t$ were developed:

t_r range	$v(t_r+t_t,l)$
$t_r \in [0,2t_t[$	$2E$
$t_r \in [2t_t,4t_t[$	$4E\dfrac{t_t}{t_r}$

- Then, an equation for resulting per unit overvoltage at the generator terminals is obtained as:

$$\Delta V_{max} = 4\frac{t_t}{t_r} - 1$$

for example, if $t_r = 3t_t$, overvoltage is 33%

- t_r can for example be adjusted by filter, therefore the research result has an important practical value

THANK YOU!