Chair of
Sustainable **E**lectric **N**etworks
and **S**ources of **E**nergy (SENSE)

Decentralized Energy Systems in Germany: Development and Research

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2011 APEC Workshop on Addressing Challenges in AMI Deployment and Smart Grids in APEC

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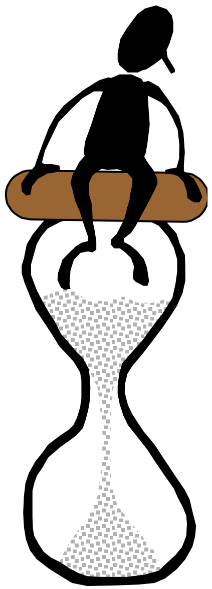
Outline



1. Introduction
2. Current Power System Structure in Germany
   Overview, development of renewable energies, grid operators
3. Future Power System Structure in Germany
   Political goals, Smart Grids in Germany
4. Examples of Dezentralized Energy Sources in Germany
   E-Mobility, Cogeneration
5. Summary Power System Germany
6. Research Example: Tidal Energy Conversion Systems
   Tidal current characteristics, technology, grid connection

1. Introduction
– Decentralized Energy Sources in Germany

- Germany has a long history and experience in the field of decentralized energy sources

  - Legal framework for systematic development of decentralized energy structures is formulated in the German Renewable Energy Act (EEG)
- This framework follows a feed-in tariff based approach, which guarantees certain compensation to plant owners
- The German concept is being continuously improved and adapted by new developments such as Smart Grids or E-Mobility
- It has served as exemplary guidance for numerous countries

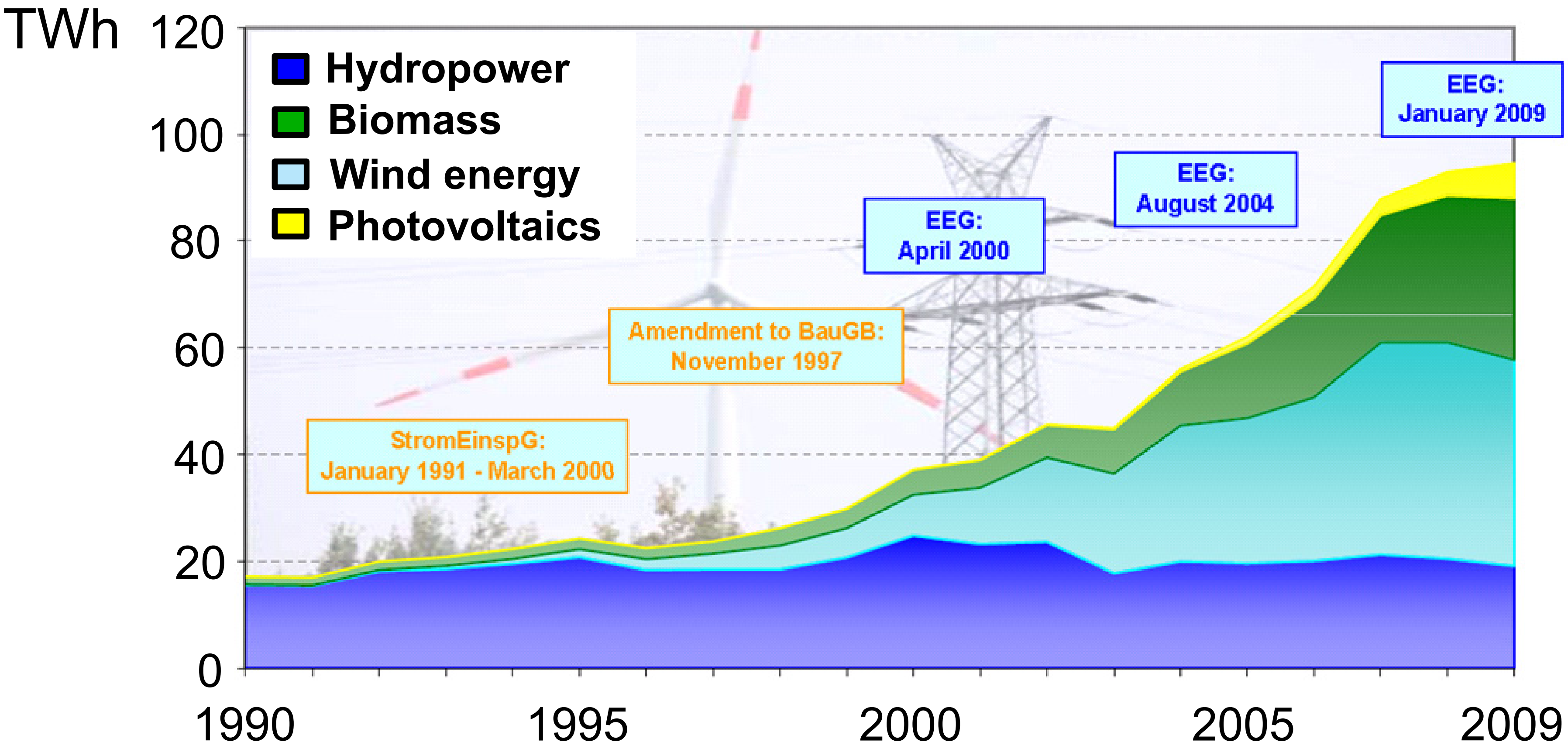
2. Current Power System Structure in Germany

– Overview

Consumption	522 TWh (2007)
Installed capacity share (2007)	Total installed capacity: 137.5 GW
Energy production share (2008)	Mostly: lignite (23.5 %) nuclear (23.3 %) hard coal (20.1 %) natural gas (13 %)
Share of renewables in production (2008)	Mostly: wind power (6.5 %) biomass (3.7 %) hydro power (3.4 %) photovoltaic (0.7 %)

2. Current Power System Structure in Germany

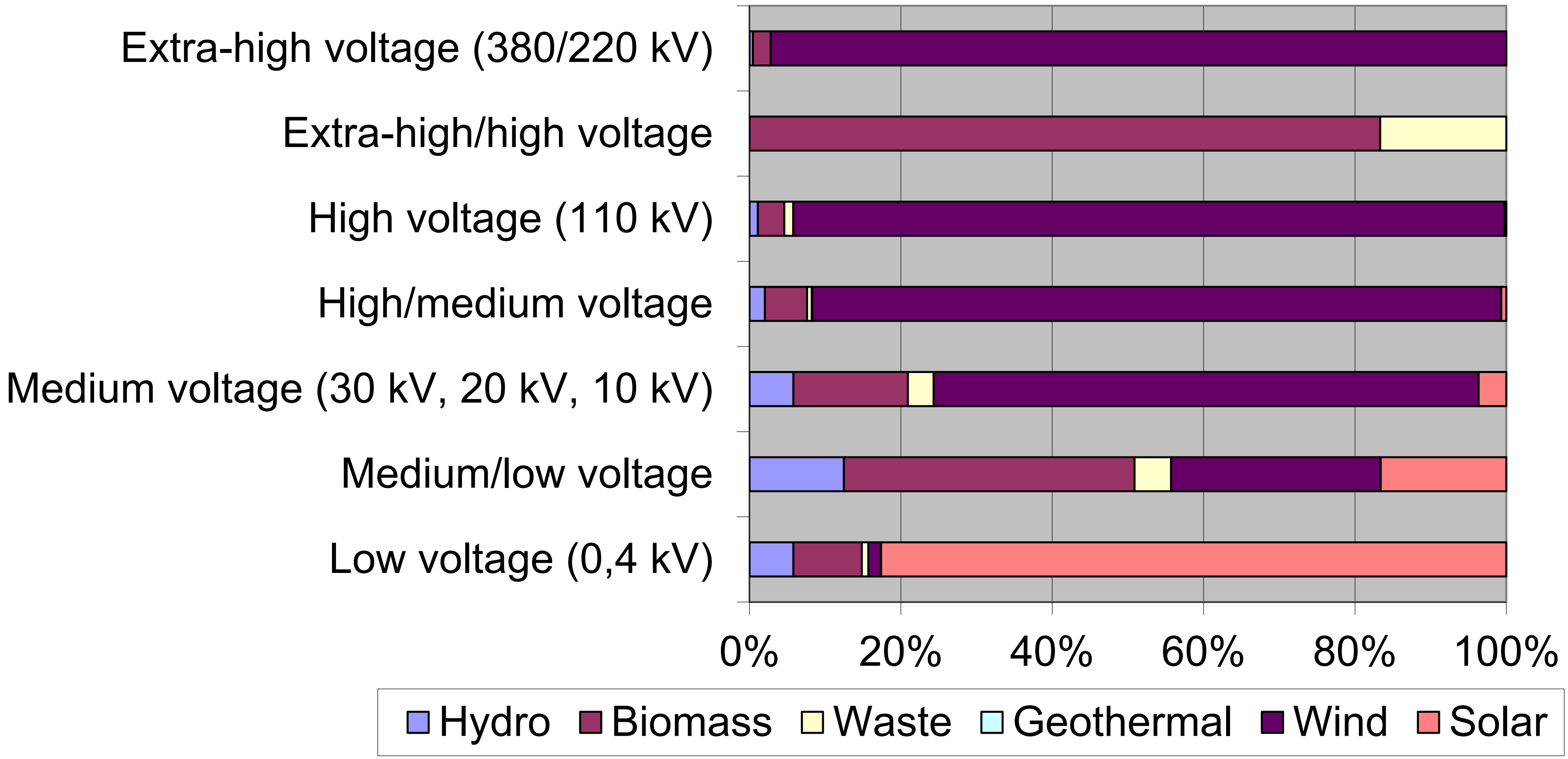
– Development of Electricity Generation from Renewable Energy Sources in Germany 1990 - 2009



Source: German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Renewable energy topics

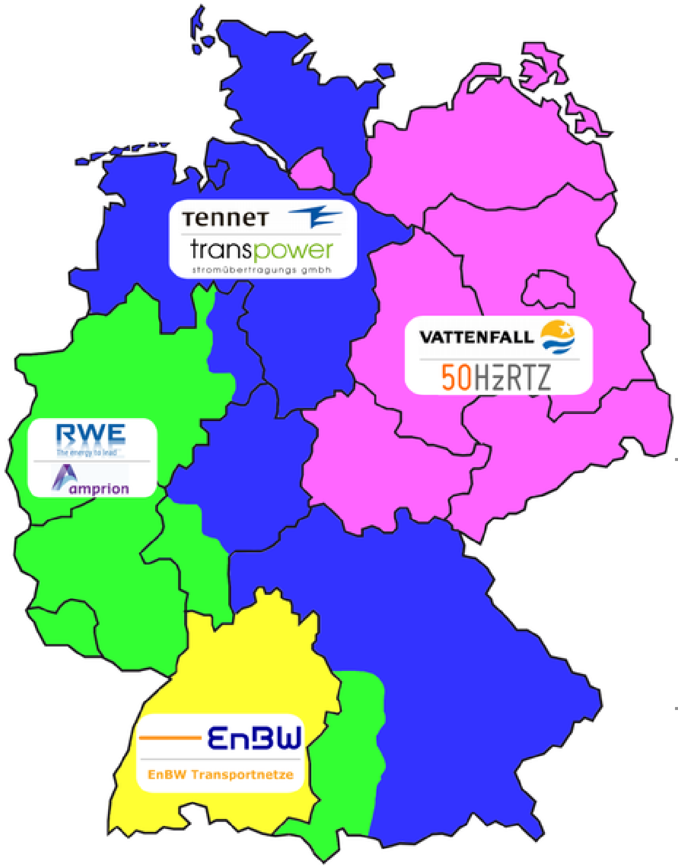
2. Current Power System Structure in Germany

– Installed Renewables at Different Voltage Levels 2007



2. Current Power System Structure in Germany

– Grid Operators



Transmission Grid Operators	TSOs have commercial interest • TenneT • Amprion • 50Hertz Transmission • EnBW Transportnetze
Regional and Local Grid Operators	Around 60 regional and more than 700 local distribution companies
Market Place	• European Energy Exchange (EEX) market • Trading outside the market possible

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   Tidal current resource, technology, system structure, analysis

3. Future Power System Structure in Germany

– Political Goals

- The aim of the Federal government is to systematically achieve a modern, climate-friendly, sustainable and secure energy supply
- It has stated the following legally binding goals for future energy supply:

2000

2020

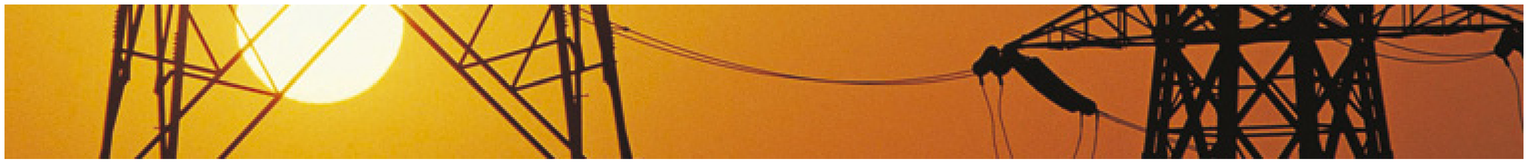
Share of renewable sources:

in total gross energy production: 30 %

in total gross heat production: 14 %

continuous increase

- The most powerful governmental tool to systematically promote these goals is the German Renewable Energy Act (EEG)

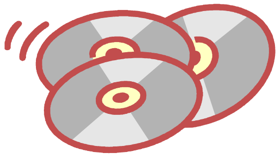


3. Future Power System Structure in Germany

– Incentives for Decentralized Storage

- Up to now, there is no specific instrument to promote decentralized storage in Germany
- The last amendment of the EEG included a special feed-in tariff for photovoltaic installations with a certain amount of self consumed energy
- This could be seen as a first attempt to promote decentralized storage

www.e-energy.de



- As a consequence, first solutions of combined photovoltaic/storage installations are on the market
- But future amendments of EEG are likely to offer explicit promotions for decentralized energy sources combined with storage

3. Future Power System Structure in Germany

– Smart Grids in Germany

- E-Energy – Smart Grids made in Germany is a major funding project initiated by the Federal Ministry of Economics and Technology (BMWi) in line with the German Federal Government's technology policy
- A technology competition identified six model regions to carry out research and development activities with support from two ministries
- Project duration is four years until October 2012

Source: www.e-energy.de

3. Future Power System Structure in Germany

– Smart Grids in Germany

eTelligence
Model region Cuxhaven

RegModHarz
Model region Harz

E-DeMa
Model region Rhein-Ruhr

Smart Watts
Model region Aachen

Modellstadt Mannheim
Model region Rhein-Neckar

MEREGIO
Model region Baden-Württemberg

E-Energy initiative focuses chiefly on development and testing of strategies for introducing smart grids

140 Mio. Euro

- Own resources of Smart Energy Regions
- National support 60 Mio.€

Source: www.e-energy.de

3. Future Power System Structure in Germany

– Smart Grids in Germany

Source: www.e-energy.de

Project	Objectives	Concept
eTelligence	- Market place installation - Definition of products, access conditions, trade mechanisms - Intelligent system integration	- Regional market place in rural area with less suppliers and high rate of renewables - Bulk consumer integration
E-DeMa	- Increase of energy efficiency - Active participation of user at energy market - Integrated data- & energy network	- Rural & city areas with two different distribution grids - Connection of private users via ICT-gateways to open electronic energy market
MeRegio	- Real & virtual connection of loads, generators & storage devices - Build-up of grid simulator - Market platform for new products - Optimization of CO_2 emission	- Rural & city areas - Smart Grid installation for private&business customers - Smart meter, operation control, thermal storage

3. Future Power System Structure in Germany

– Smart Grids in Germany

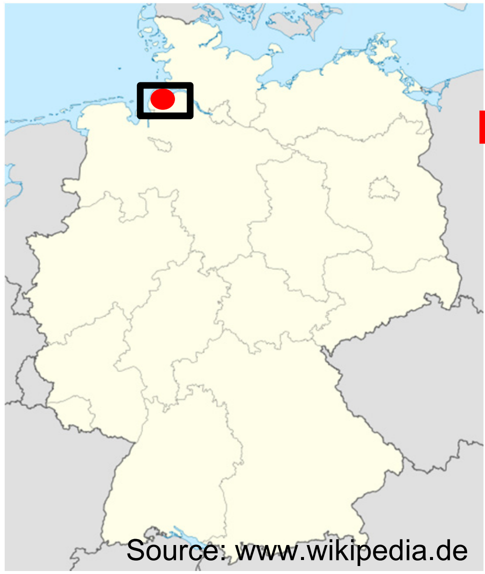
Source: www.e-energy.de

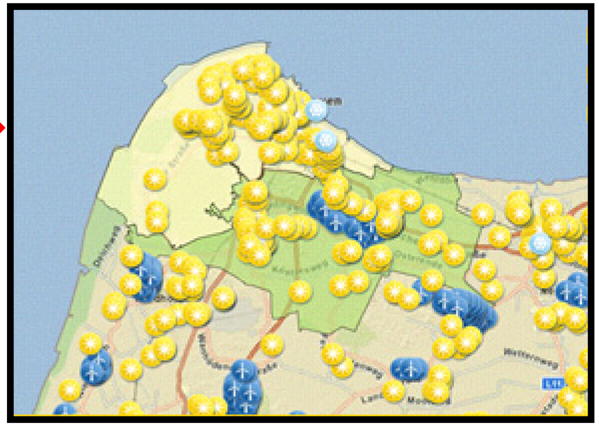
Project	Objectives	Concept
Modellstadt Mannheim	- ICT for grid and buildings - Service-oriented & realtime architecture for user connection - Use of power line for communication	- Cities Mannheim, Dresden - Market connection of 1000 users with controllable loads & demand-oriented tariffs and decentralized generators
RegModHarz	- Build-up of power grid control center for VPP Harz - Commercialisation of VPP - Grid monitoring & system service	- Rural area - VPP of renewables, controllable loads, storage for proof of reliable energy supply
Smart Watts	- Information system & control model - Demonstration with private homes	- Private homes - Modular smart meters further developed as control station - Demand side management

3. Future Power System Structure in Germany

– Smart Grids in Germany: eTelligence Project

City of Cuxhaven





Wind turbine
Photovoltaic

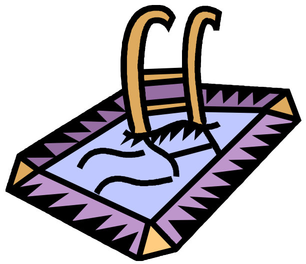
- Cuxhaven is situated at estuary of river Elbe flowing into North Sea
- Around 52,000 inhabitants, 3 million tourists overnight
- 50 % of electricity demand is covered by renewable energy sources
- Has an important fishing harbor

Source: www.e-energy.de

3. Future Power System Structure in Germany

– Smart Grids in Germany: eTelligence Project

- 650 private homes participate in Smart Grid test for one year
- Virtual Power Plant concept including fishing industry with its refrigerated warehouses, two large swimming pools with heat power co-generation systems, wind turbines and photovoltaic
- Range of temperature in cooling process is used
- At wind energy peak fish in refrigerated warehouse is cooled more, peak load is shaved by cutting back on refrigeration
- Considering the heat as an inert system and using the swimming pools as storage units



Source: www.e-energy.de

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Tidal current resource, technology, system structure, analysis

4. Examples of Decentralized Energy Sources in Germany

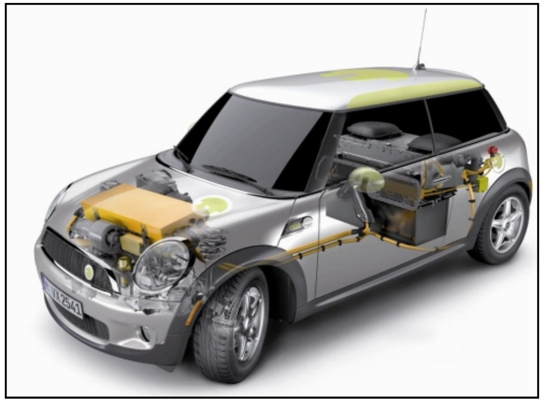
– E-Mobility and Smart Grids

- In Germany, energy and automotive industries are important pillars of the economy
- The intersection of energy and automotive sectors and the Smart Grid potential given by electric mobility is followed with great interest
- There are several ongoing field tests and research projects
- TU Berlin and SENSE are at the heart of many these processes
- SENSE hosts the following E-Mobility and Smart Grid research projects:
  - **M**obile **E**nergy **R**esources for **G**rids of **E**lectricity (MERGE) is a major European Union project
  - **E**lectro-**M**obile **E**nergy **R**esources in **G**rids of **E**lectricity (E-MERGE) Laboratory

4. Examples of Decentralized Energy Sources in Germany

– E-Mobility Field Tests

There are three major electric vehicle (EV) field tests going on in Germany:



Source: http://evworld.com

Mini E

Source: http://www.hybridcars.com

Smart ED

Source: http://www.eon.com

VW Golf TwinDrive

- Mini E Berlin: Pure electric vehicle
- e-mobility Berlin: Pure electric vehicle
- VW Golf TwinDrive: Plug-in hybrid electric vehicle (PHEV)

4. Examples of Decentralized Energy Sources in Germany

– E-Mobility Field Tests: Objectives

Investigation

- Balancing of charging and fluctuating renewable energy in practice
- EV behavior in real-world driving and V2G operation
- User behavior in real-world environment
- Energy consumption of EV in everyday use

4. Examples of Decentralized Energy Sources in Germany

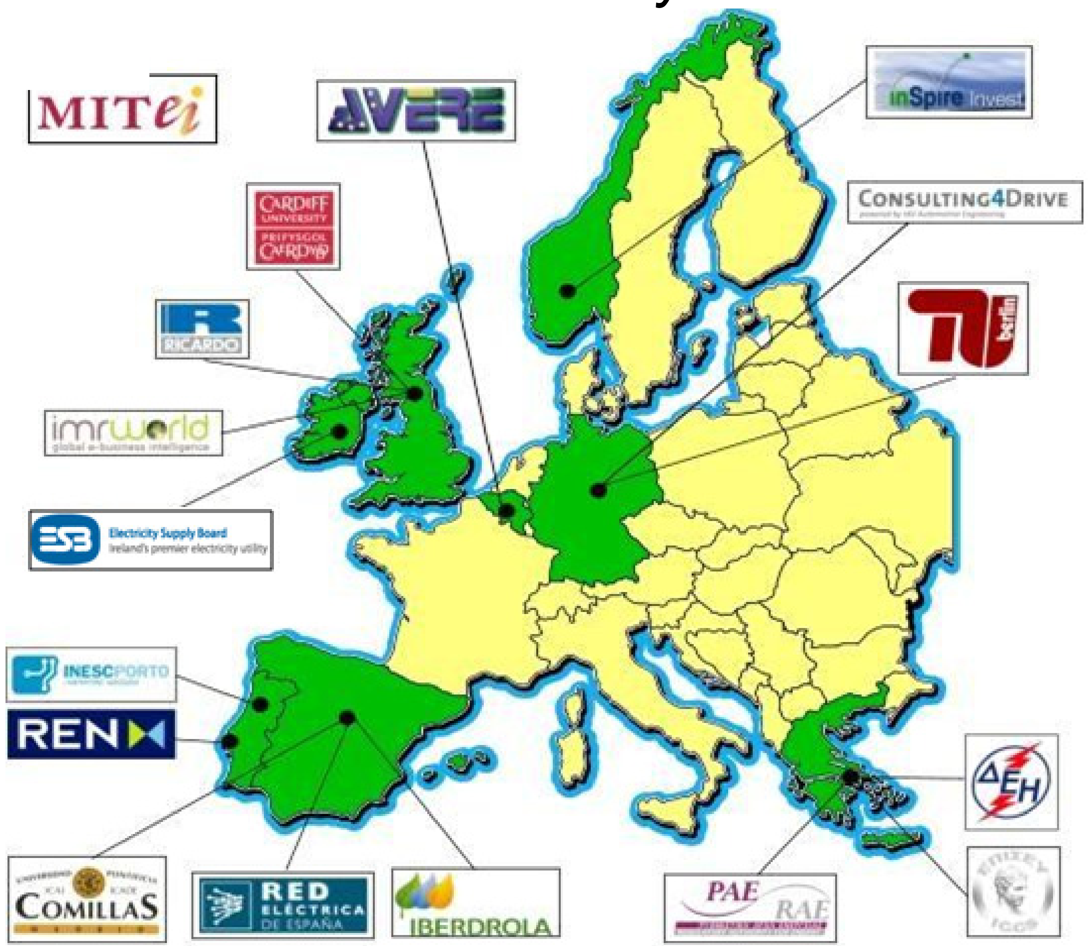
– E-Mobility Field Tests: Comparison

	Mini E Berlin	e-mobility Berlin	VW GOLF TwinDrive
Industry participants	BMW, Vattenfall Europe AG	Daimler, RWE	VW, E.ON, GAIA, Evonik, LiTech
Period	2009 - 2010	2009 - 2010	2008 - 2012
Location	Berlin	Berlin	Berlin, Wolfsburg
Number of EVs	50	100	20
Battery capacity	35.0 kWh	16.5 kWh	12.0 kWh
Battery type	Li-ion	Li-ion	Li-ion
Distance	250 km	135 km	50 km
Battery weight	300 kg	136 kg	160 kg

4. Examples of Decentralized Energy Sources in Germany

– E-Mobility Research Projects: MERGE

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

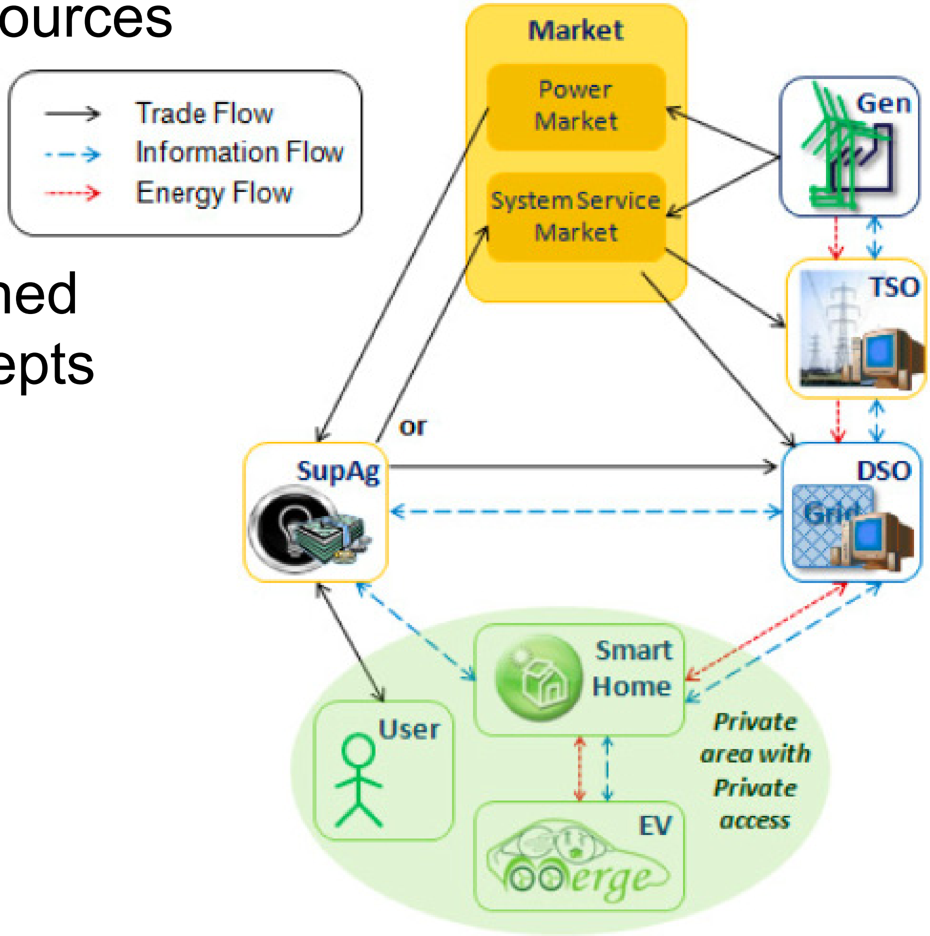


4. Examples of Decentralized Energy Sources in Germany

– E-Mobility Research Projects: MERGE

- 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

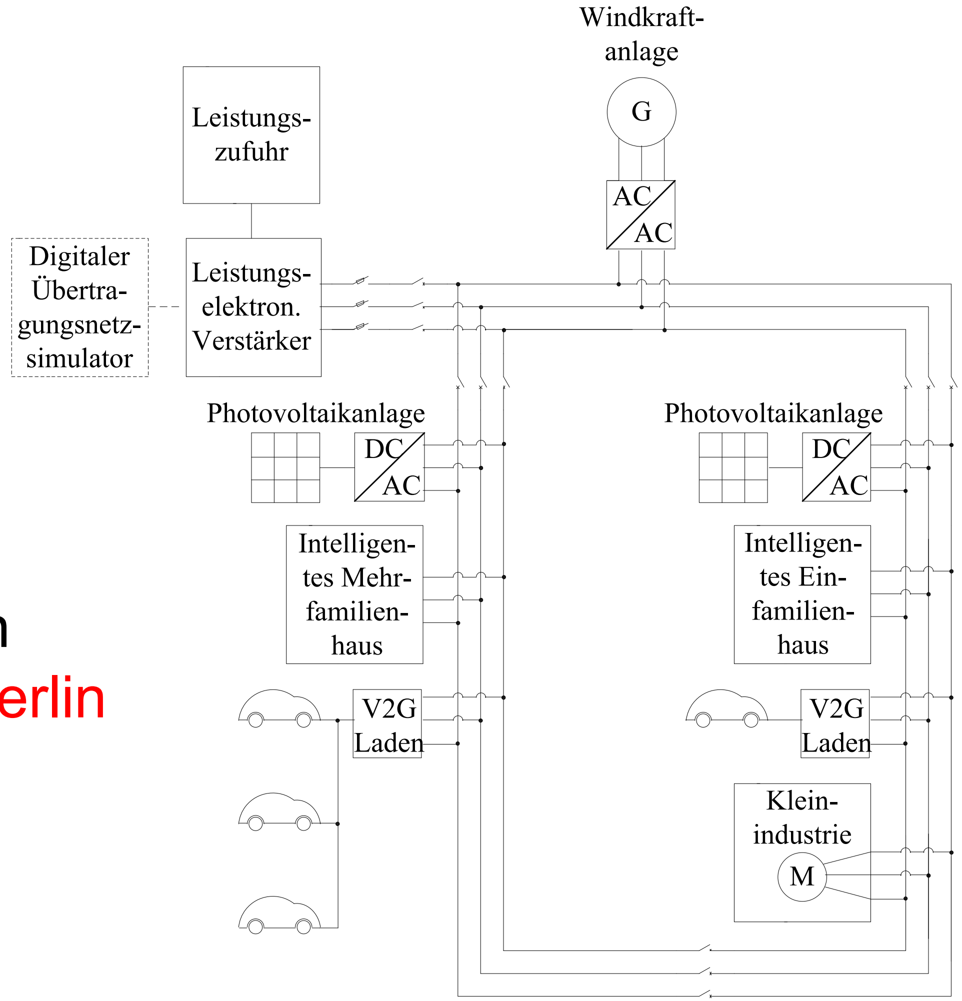
  www.ev-merge.eu



4. Examples of Decentralized Energy Sources in Germany

– E-Mobility Research Projects: E-MERGE

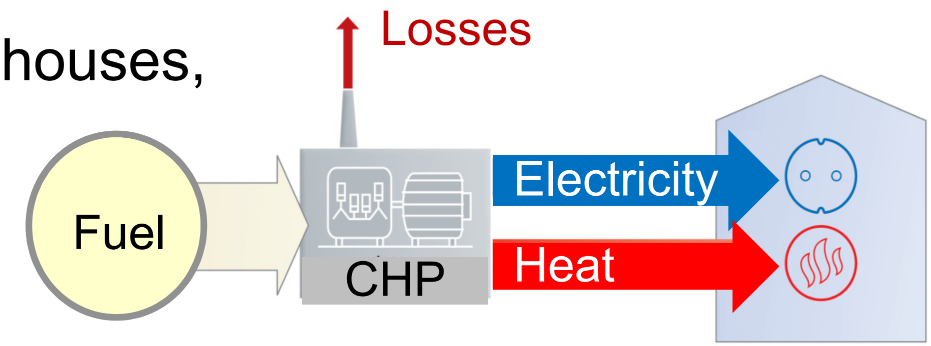
- *E-MERGE: Electro-Mobile Energy Resources for Grids of Electricity*
- Partner: German Federal Ministry of Economics and Technology (BMWi)
- Complementary to e-mobility field tests
- Realization of physical microgrid with integrated e-mobility in 2011 at TU Berlin
- Research on security and stability



4. Examples of Decentralized Energy Sources in Germany

– Cogeneration

- Thermal and electrical power rates of cogeneration plants can range from a few kW to several hundreds of MW
- Since 2000, more and more so called mini- and micro-cogeneration plants are on the market
- Typical users are one-/multi-family houses, small enterprises or hotels
- Cogeneration plants can achieve high efficiencies of up to 80 %



- In Germany, cogeneration is promoted via following legal frameworks:
  - CHP Act (KWKG)
  - German Renewable Energy Act (EEG) if fuel used in cogeneration is biomass

5. Summary German Power System

- Germany has a long tradition and experience with decentralized renewable energy
- The first governmental programs to promote decentralized energy sources date from the 1990s
- Currently, the German Renewable Energy Act (EEG) is in place
- There is a strong systematic movement to standardize and implement Smart Grid related methodologies

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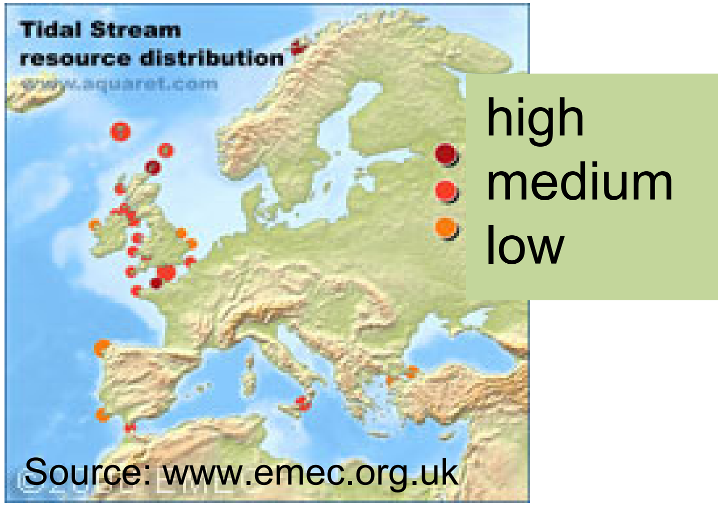
Tidal current resource, technology, system structure, analysis

6. Research Example: Tidal Energy Conversion Systems

– Tidal Current Resource

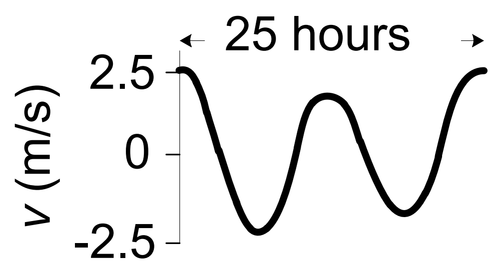
- According to *European Ocean Energy Association (EU-OEA)*, European ocean energy potential is 15 % of Europe's electricity demand
- Tidal current resource distribution in Europe:

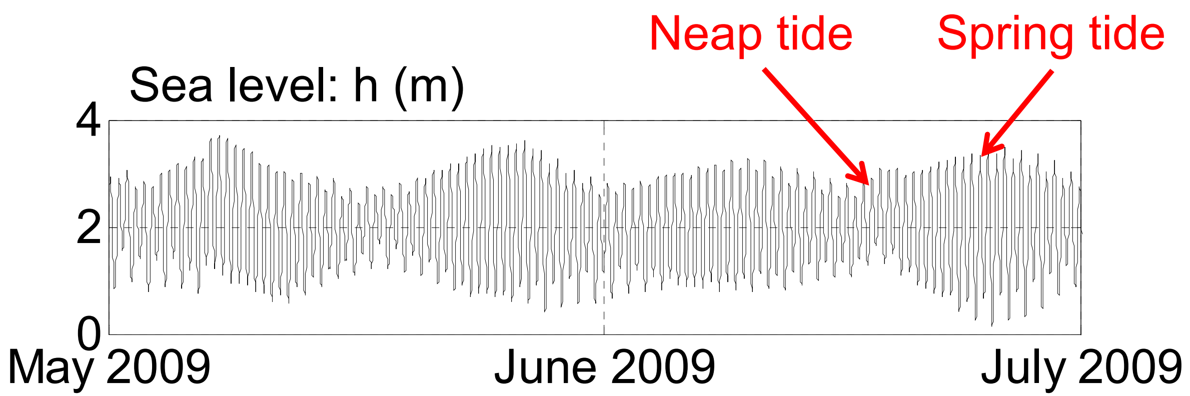


6. Research Example: Energy Conversion Systems

– Tidal Current Resource

- Tidal energy conversion systems exploit kinetic energy of sea currents
- Tides follow a sinusoidal shape
- Ebb and flood occur twice during a lunar day of about 25 hours
- Also, a 14-days cycle exists with spring tides (maximum) and neap tides (minimum)
- Measured at Station Wick, UK:

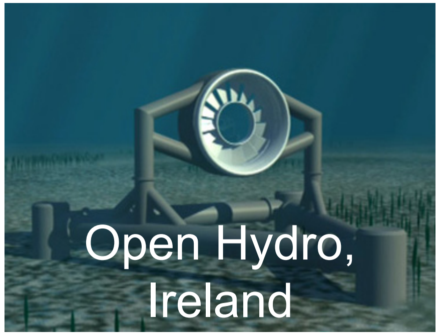




6. Research Example: Tidal Energy Conversion Systems

– Technology

- Horizontal axis turbines are predominant
- Blade length up to 15 m for tidal turbines in the MW-range
- Blades much smaller than for wind turbines due to high water density
- Duct may concentrate the flow towards the rotor
- Examples from Europe:



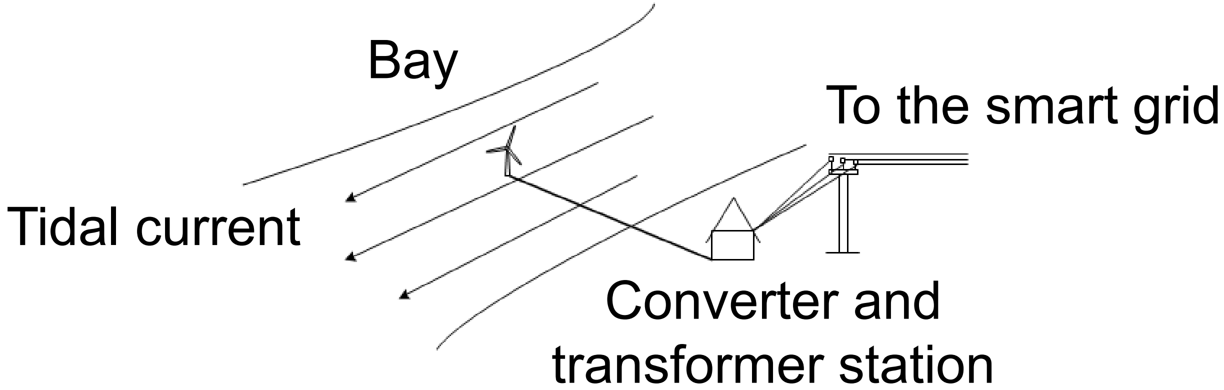
Source: www.openhydro.com

Source: www.marineturbines.com

Source: www.lunarenergy.co.uk

6. Research Example: Tidal Energy Conversion Systems

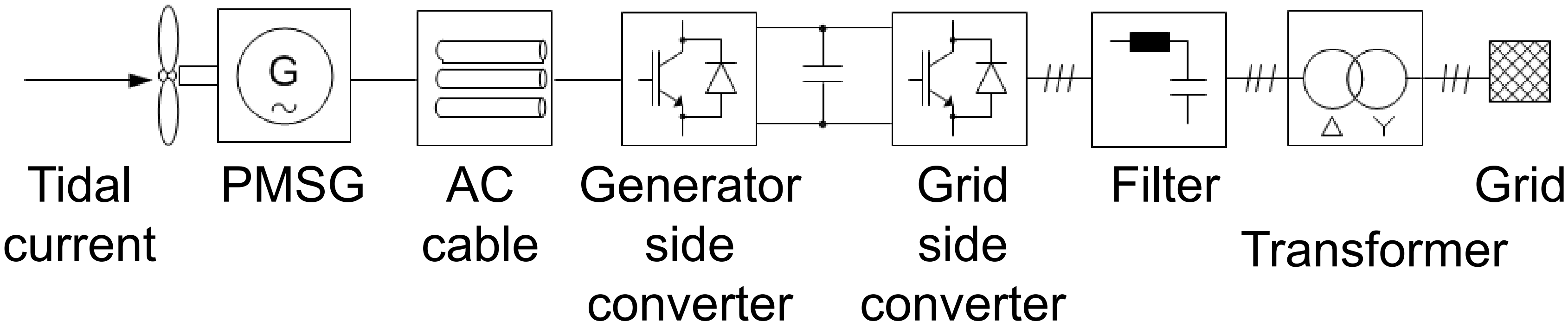
– System Structure



- 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

6. Research Example: Tidal Energy Conversion Systems

– System Structure

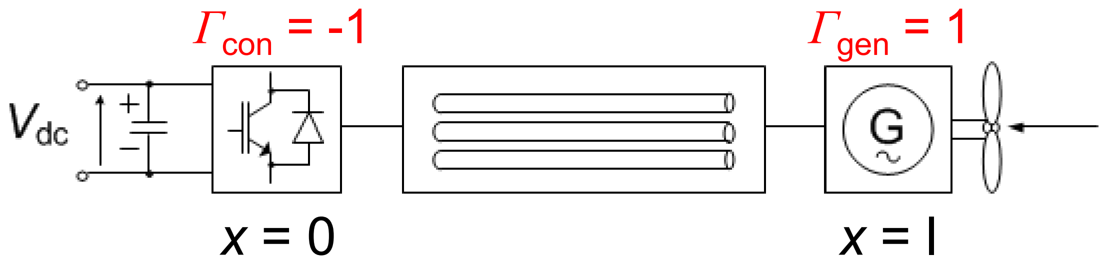


- Direct connection of permanent magnet synchronous generator (PMSG) to generator side converter → no gearbox
- High-frequency switching occurs at generator side converter
- Challenge as traveling waves on cable may cause overvoltage at PMSG
- Pulse rising time t_r at converter and traveling time over cable t_t are the influencing parameters

6. Research Example: Tidal Energy Conversion Systems

– Analysis Setup

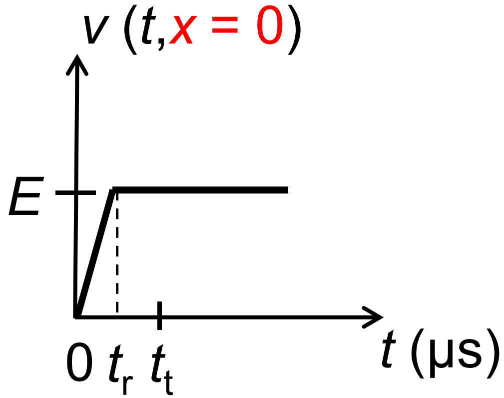
- In order to analyze traveling waves, the following setup is considered



- Generator behaves close to open circuit, converter similar to short circuit

  ⇨ Reflection coefficients: $\Gamma_{con} = -1$ and $\Gamma_{gen} = 1$

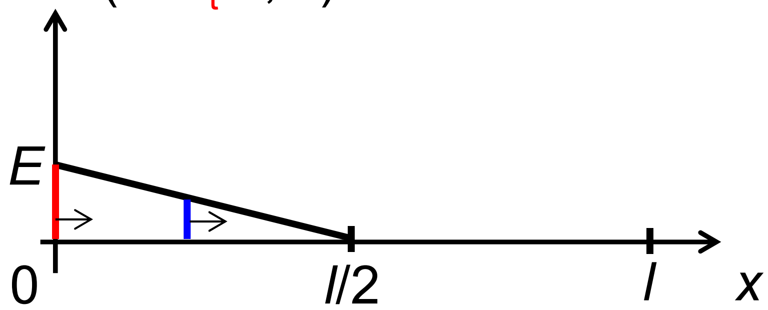
- Waves need traveling time t_t to move from one to the other end of cable
- Test function is a ramp with $t_r = t_t/2$ applied at location x = 0



6. Research Example: Tidal Energy Conversion Systems

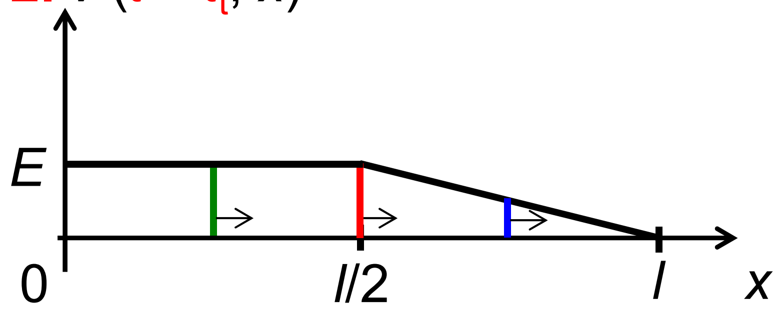
– Cable Voltage Profile

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



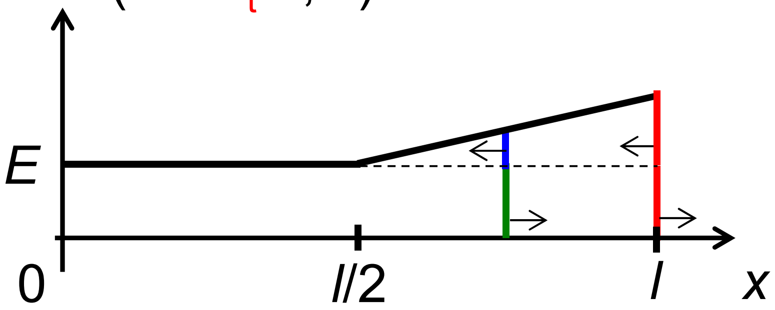
1. Pulse ramp stops rising at converter

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



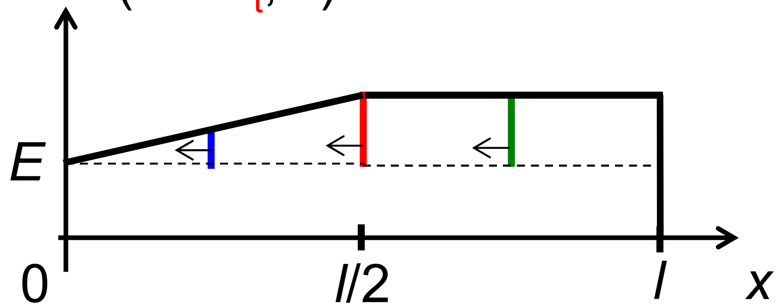
2. Start of ramp reaches generator

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



3. End of ramp reaches generator, voltage is doubled

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

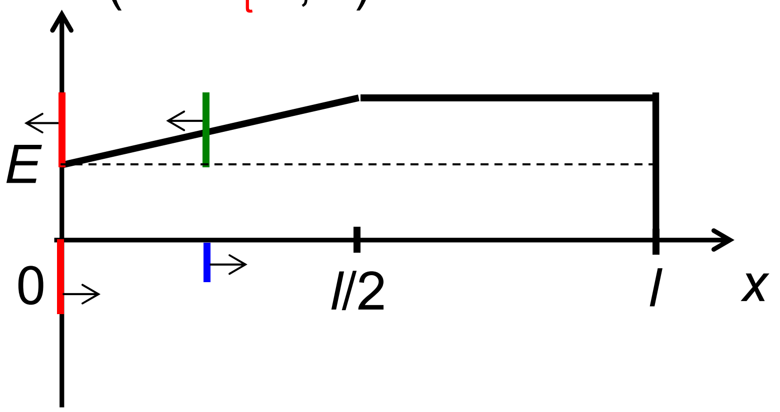


4. Start of ramp reaches converter after having traveled back to $x = 0$

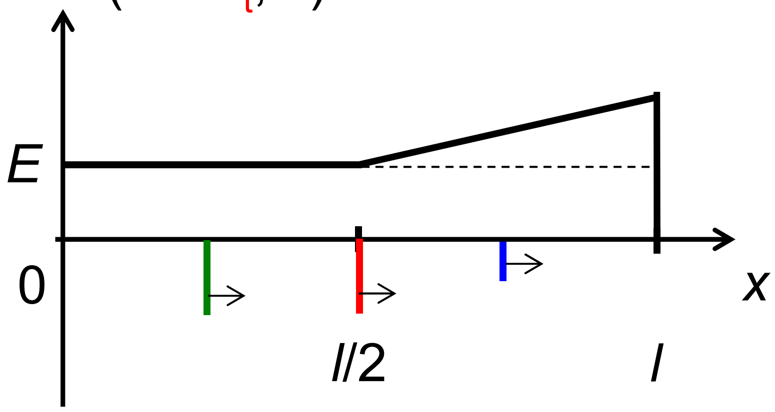
6. Research Example: Tidal Energy Conversion Systems

– Cable Voltage Profile

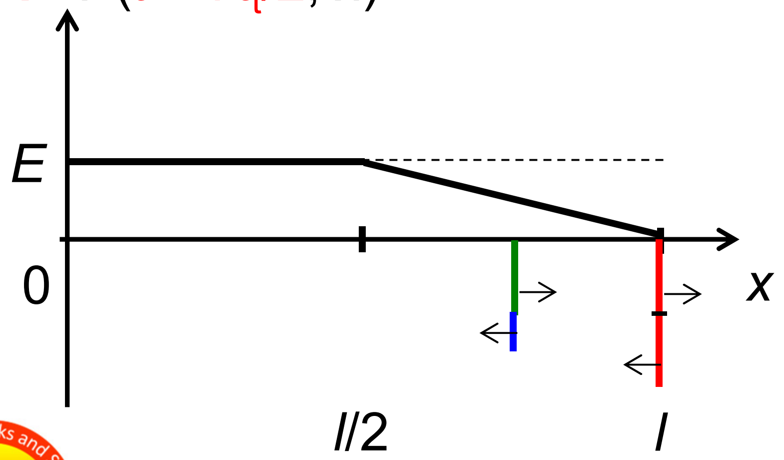
5. $v\ (t = 5t_t/2,\ x)$



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

6. Research Example: Tidal Energy Conversion Systems

– Overvoltage Equation

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

- 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!

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Educational Background	• Study: electrical engineering at Berlin University of Technology, Germany (TU Berlin) and Royal Institute of Technology Stockholm, Sweden • 2008, Dipl.-Ing. (Master) degree from TU Berlin • expected in 2011, PhD degree from TU Berlin	
Working experience	• 2007, ABB Corporate Research in Västerås, Sweden • Since 2009, Research Assistant at TU Berlin, involved in projects concerning grid integration of renewable energies in Germany • Since 2010, IEEE PES Co-worker for internet platform "PES-Careers Global" • 2010 and 2011, member in the VDE (German Association of Electrical, Electronic & Information Technologies) Task Force Infrastructure and Co-author of the VDE Report „Power Transmission for Climate Protection" (in German)	
Autobiography	• Awards: For her outstanding study performance Maren Kuschke received the VDI Award from the Association of German Engineers in 2009. Furthermore, she received the IEEE PES German Chapter Best Master Thesis Award in 2010. • Research Interests: Her research is concerned with grid integration of renewable energies, especially tidal energy conversion systems, and power grid control. Her work is supported by the nonprofit Reiner-Lemoine-foundation established by the founder of the German photovoltaics company Solon.	