Lecture 11: Smart Grids Worldwide (an overview)

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Content of the lecture

1. Ambitious power system development strategy in China
2. Development targets for interconnections in the USA
3. Overview of Smart Grid projects in Europe
    3.1 Low voltage experimental microgrid laboratory (University of Cyprus)

1. Ambitious power system development strategy in China

- China became the world's largest producer and consumer of electricity during the first decade of the 21st century. The Chinese electricity generation increased rapidly and achieved an annual generation of 7714 TWh in 2021 and doubling every 10 years or less https://www.enerdata.net/estore/energy-market/china/). The need for establishing Smart Grids in China is driven by two major objectives:

1. Establishment of a unified national transmission system
2. Significant growth in the use of renewable energy sources.

1. Ambitious power system development strategy in China

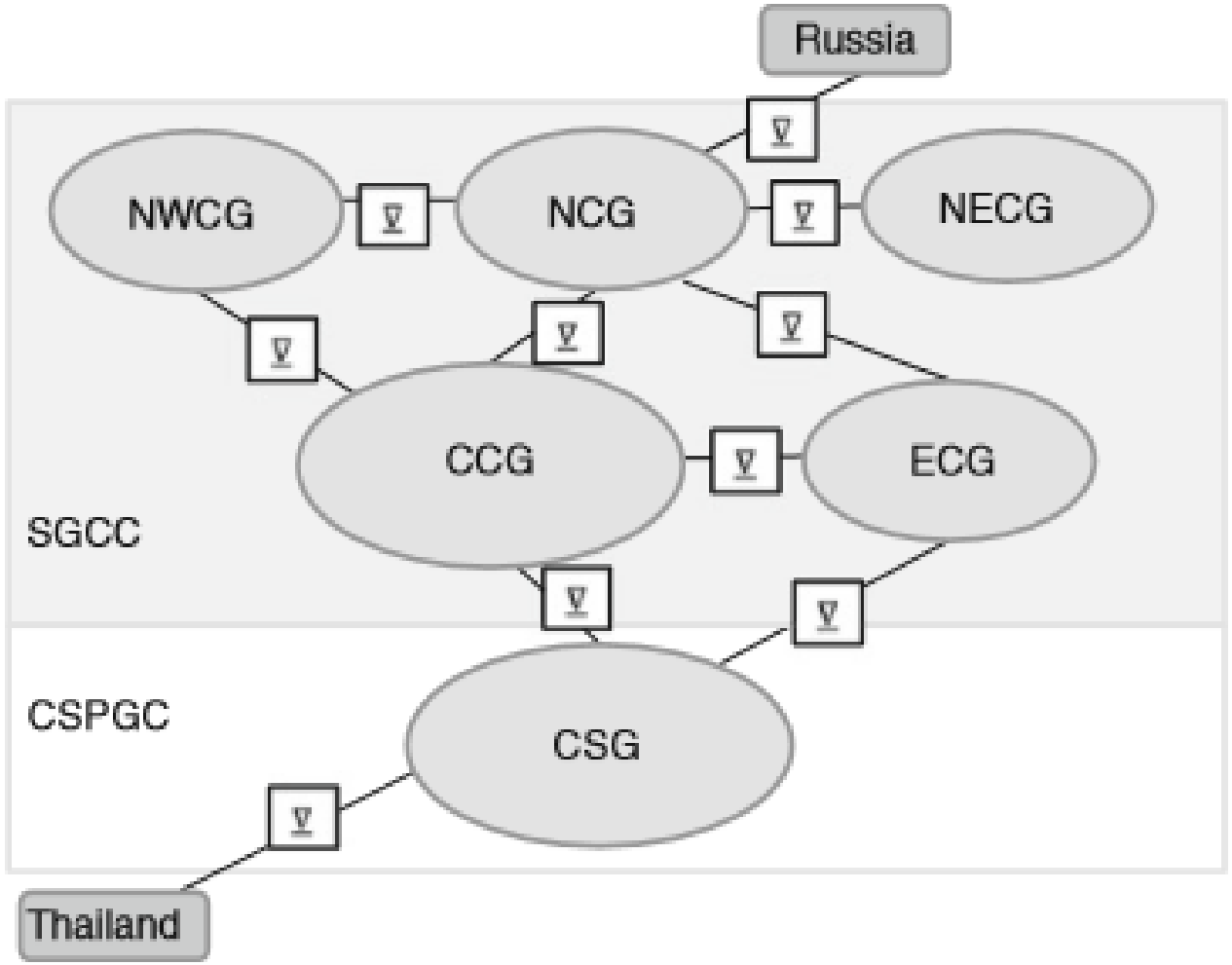
The Chinese power system is operated by six regional transmission networks. Five of these transmission networks are managed by the State Grid Corporation of China (SGCC):

- NCG—North China Grid,
- NECG—North-East China Grid,
- **ECG—East China Grid**
- CCG—Central China Grid,
- **NWCG—North-West China Grid,**
- Southwest China Grid (SWG)
- China Sourthern Power Grid (CSG)

1. Ambitious power system development strategy in China

- The China Southern Power Grid Company Limited (CSPGC) is the second state owned Chinese transmission enterprise and leads the China South Grid CSG. The absence of a unified national transmission system with strong interconnections is a barrier to the nation-wide efficient use of the power plants and heightens the risk of local congestions.
- For example, the peak and weak load situations are quite different in different areas in China. The Northern areas experience a stronger winter peak load. On the other hand, a high summer demand is observed in the Southern regions where the levels of the reservoirs of the hydro-power plants drop. The power gap has to be covered by oil and diesel aggregates.

1. Ambitious power system development strategy in China



Transmission grids in China and interconnections for establishing a unified grid

1. Ambitious power system development strategy in China

- China's power system is mainly based on coal fired thermal power plants (approximately 62 %) as of 2019. However, China is also the world champion regarding the electricity generation based on renewable energy sources (RES). First of all, this result is based on the enormous hydro power resources providing an annual generation of more than 2,218,300 GWh/a!
- China has the world market leadership in photovoltaic (261,100 GWh) and wind power generation (466,500 GWh).
- By 2020, 29% of Chinese electricity generation was from RES with further rapid growth planned. This acceleration of using RES is showing no signs of slowing down.

1. Ambitious power system development strategy in China

- The SGCC is the leading driver in developing the Smart Grid and has announced plans to invest $250 billion in electric power infrastructure upgrades by 2015, of which $45 billion is assigned to Smart Grid technologies.
- Another $240 billion between 2016 and 2020 will be added to conclude the Smart Grid enhancement.
- A deployment strategy has been decided upon, which includes the following three stages:

  - **Phase 1** is focused on the development planning, the setting of technology standards and the initiation of pilot projects.
  - **Phase 2** is a comprehensive construction phase from 2011 to 2015
  - **Phase 3**, the ‘‘leadership phase’’, is directed at completing a strong nation-wide interconnected Smart Grid

1. Ambitious power system development strategy in China

- **Phase 2** is concentrated on the following objectives:

– The establishment of a UHV overlay grid, which will apply (for the first time in the world) ultra-high voltage transmission lines 1000 kV AC and +800 kV DC. By 2015, UHV and other intra-regional transmission capacity will reach 240 GW.

– The improvements of the urban-rural distribution network are directed at improving the power quality. The electricity supply has to reach a reliability rate of 99.915 % or higher in the cities and 99.73 % or higher in rural areas.

– The Smart Grid operation philosophy and the appropriate control technologies.

– Key technological solutions will be broadly applied. For example, Smart Meters will be in widespread use and charging stations for electric vehicles will be deployed in numbers that will satisfy demand.

– The construction phase has been accompanied by Smart Grid standardizations efforts. SGCC is actively involved in developing international Smart Grid Standards specifying that 22 core criteria will be applied to determine and introduce the key standards in China in 2014.

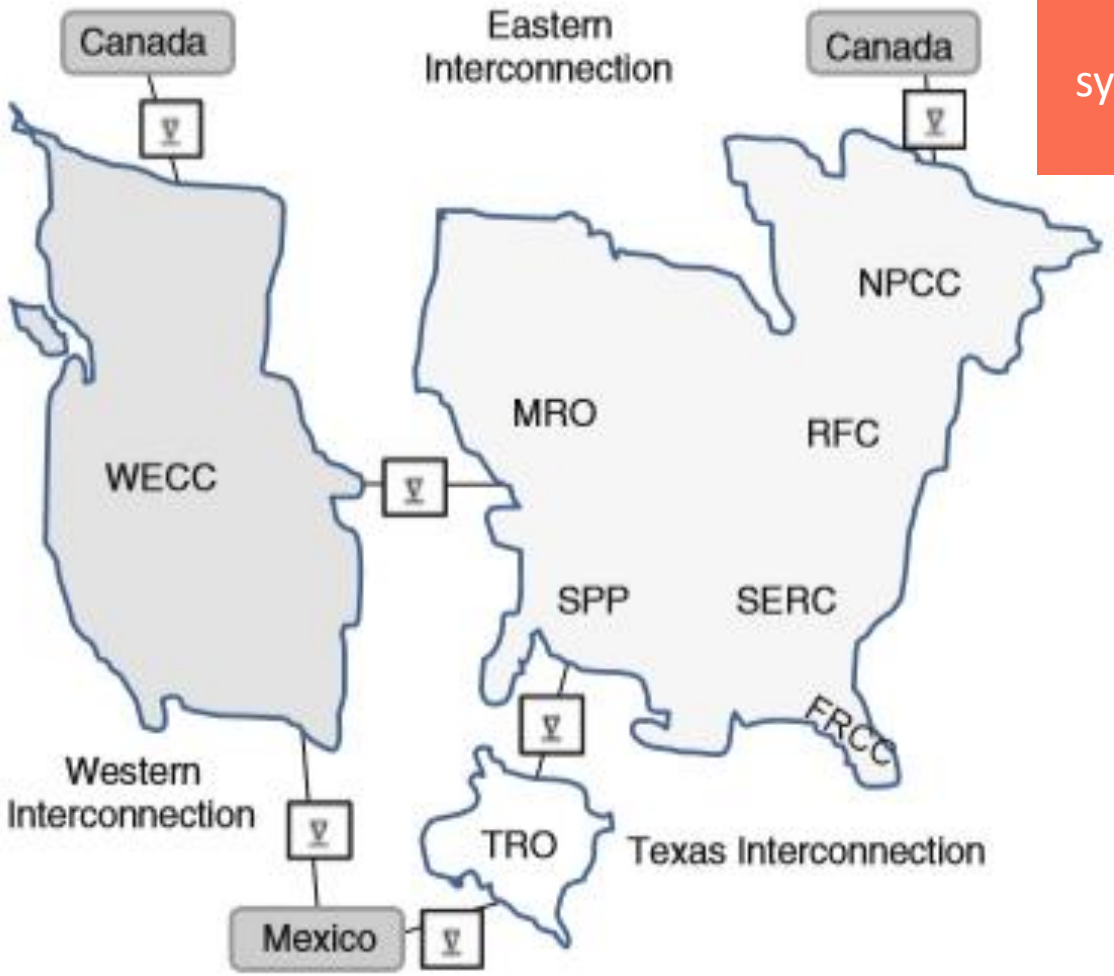
1. Ambitious power system development strategy in China

- **Phase 3** is directed at completing a strong nation-wide interconnected Smart Grid. By 2020, UHV and other intra-regional transmission capacity will reach 400 GW, enough for the transmission of the requested power from the installed coal, hydro, nuclear and wind power plants to the areas with high demand and with a gap of local generation.
- The distribution networks will be strengthened and the rural networks will be renovated. The electricity market will enable the active participation of consumers in demand side integration.
- As a result of the extensive Smart Grid strategy and the related deployment efforts, China intends to become the world leader in management, technology and system operation solutions.

2. Development Targets for Interconnections in the USA

- The second largest electric power system in the world is operated in the USA. The annual power generation of the USA has not significantly changed since 2002 (growth < 8%).
- By 2012, the power generation capacity of the USA was 1,168 GW (76.7% fossil primary energy sources (PES), 9.4% nuclear power, 13,9% RES), and it produced about 4,100 TWh electric energy.
- The USA is the second largest user of wind energy with an installed capacity of 60 GW in 2012.
- The North American power system of the USA consists of 4 synchronous transmission systems which are called ‘‘interconnections’’. The voltage levels are 230, 345, 500 and 765 kV. The areas of the three main interconnections (except Alaska and islands) are presented in the next Figure.

2. Development Targets for Interconnections in the USA



The three main transmission systems (interconnections) in the US

2. Development Targets for Interconnections in the USA

- The Eastern Interconnection covers the most of the territory of the Eastern USA, extending from the foot of the Rocky Mountains in the Mid-West to the Atlantic coast. The Eastern Interconnection is linked with the other interconnections and with Canada (Quebec) via high voltage DC transmission lines. The transmission system of Ontario (Canada) is connected by AC links.
- Within the Eastern Interconnection seven Reliability Councils coordinate the interactions of the TSOs:
  - NEPCC—North-East Power Coordination Council,
  - MRO—Midwest Reliability Organization,
  - RFC—Reliability First Corporation,
  - SPP—Southwest Power Pool,
  - SERC—South-East Reliability Corporation,
  - FRCC—Florida Reliability Coordinating Council.

2. Development Targets for Interconnections in the USA

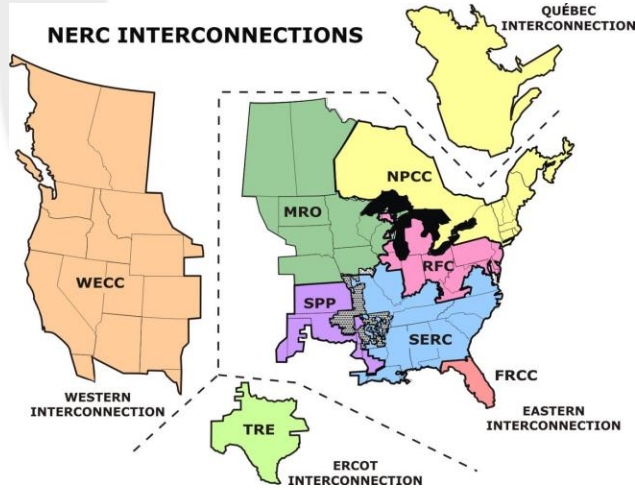
- The reliability councils are members of the North American Electric Reliability Corporation NERC [5]. NERC is the electric reliability organization for North America and its mission is to ensure the reliability of the transmission systems in North America by:

1. developing and enforcing reliability standards,
2. observing the reliability parameters and publishing appropriate statistics,
3. monitoring power flows between the transmission networks through system awareness.

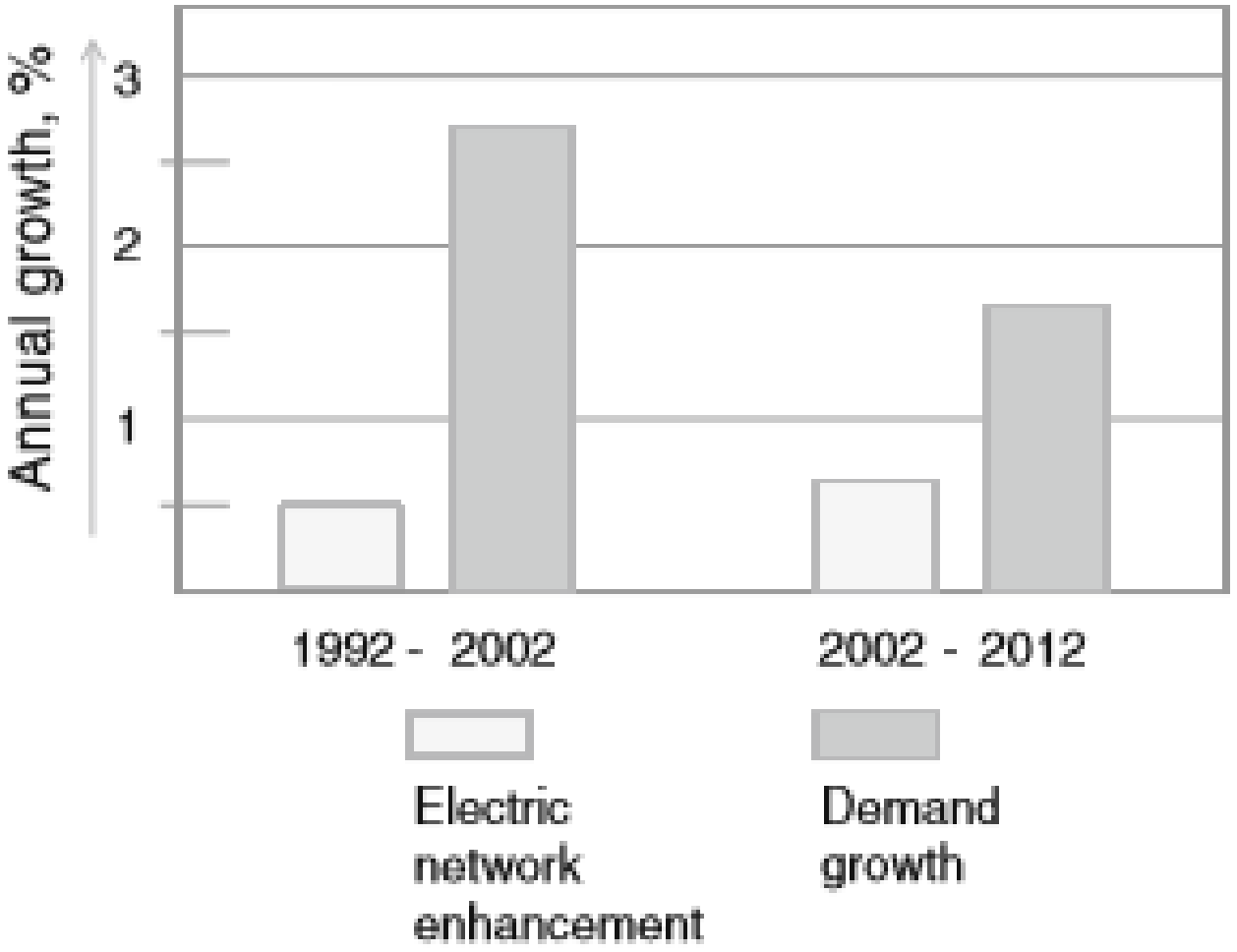
- NERC's area of responsibility spans the continental USA, Canada and the Northern part of Baja California, Mexico. It is responsible for the reliability parameters and publishes appropriate statistics, and it monitors the power flows.

2. Development Targets for Interconnections in the USA

- The Department of Energy (DOE) is a governmental ministry and has a leading role regarding the power system development strategies.
- The Office of Electricity Delivery and Energy Reliability (OE) is an entity of the DOE and is responsible for enhancing the reliability and resiliency of the nation's energy infrastructure. However, the reliability of the supply within the US power system is low compared to what has been reached in the central European countries.
- The reason for the low reliability of supply is seen in the disparity between the fast growth of the demand compared to the level of investments for the electric network enhancement, caused by missing incentives for power quality provision.



2. Development Targets for Interconnections in the USA



Divergence between demand growth and the extension of the electric networks

2. Development Targets for Interconnections in the USA

- The electricity consumption per capita of 12,700 kWh is in the USA twice higher compared to the industrial countries in Europe (e.g. Germany with 6,700 kWh) [9]. There are two main reasons for the high energy demand in the USA.
- Firstly, the annual electricity consumption of an average household adds up to 11,000 kWh, which is caused by a significant number of single family houses and the typical American end-user behavior. The main single appliances are electric space heating and water heating as well as air conditioning systems, which cover slightly less than 50% of the total residential energy consumption.
- Secondly, the rate of energy efficiency, mainly in the industrial sector, is lower than in other industrialized countries.
- Due to the high demand for electricity and the deficits in the appropriate electric network enhancements the reliability of the supply characteristics is relatively weak.

2. Development Targets for Interconnections in the USA

Date	Location	Affected consumers	Comment
January 14th	Minnesota	12,000	
January 28th	Baltimore, Maryland	70,000	
February 6th	Ohio	2,500	Reasons not known
March 1st	Florida	15,000	
March 12th	Albuquerque, New Mexico	20,000	
April 22nd	Lax, California	30,000	Fault caused by birds
April 29th	Washington state	200,000	
May 12th	Utah	31,000	Tree contact
May 17th	Michigan-Indiana	Border area	Multiple faults
May 27th	Detroit, Michigan	Schools closed	Power outage
May 31st	Illinois	Fire at hospital	Power outage
June 3rd	Texas	400,000	

Outage statistics in the USA for the 1st half of 2004

Frequent supply interruptions are a daily problem for rural consumers who are usually supplied by MV and LV overhead lines with pole pots (MV/LV transformers installed on wooden poles).

2. Development Targets for Interconnections in the USA

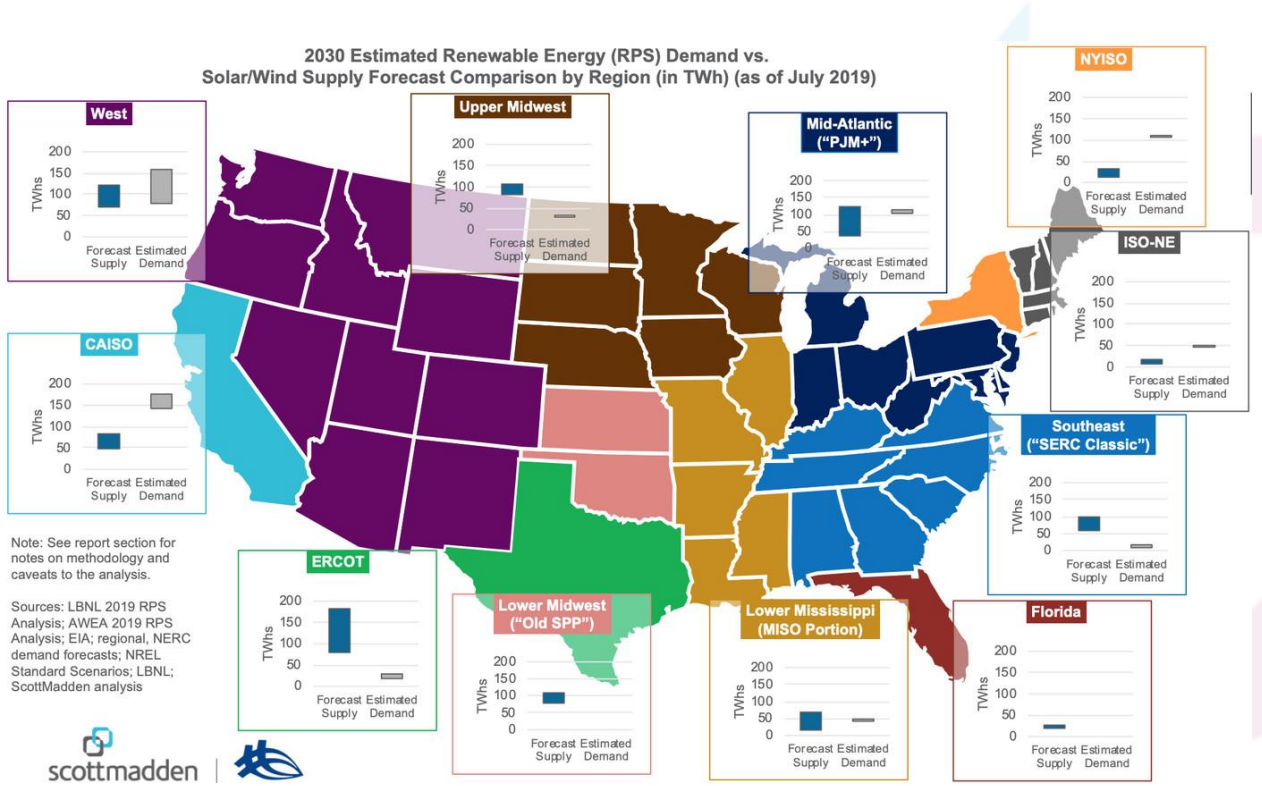
- Consequently, the efforts to enhance the electric power system in the USA were strengthened by research and several legislative initiatives.
- EPRI started the technology platform project ‘‘Intelligrid’’ in 2004, which became the ‘‘Smart Grid Initiative’’ after the introduction of the term ‘‘Smart Grid’’ in the context of the European Technology Platform (ETP) for the electricity networks of the future.

Initiator	Year	Activity	Comment
OE/DOE	2003	Study: Grid 2030—A national vision for electricity’s second 100 years. Transforming the grid to revolutionize electric power	Vision and deployment controlling
OE/DOE	2004	National electric delivery technologies roadmap	Action plan
OE/DOE	2005	Grid-works multi-year plan	Research priorities
Congress	2007	Energy Independence and Security Act “EISA”	Security of supply
Congress	2009	American Recovery and Reinvestment Act	Network enhancement

Activities towards the Smart Grid in the USA

2. Development Targets for Interconnections in the USA

- The study ‘‘Grid 2030’’ defines the national vision as follows: ‘‘Grid 2030” energizes a competitive North American market place for electricity. It connects everyone to abundant, affordable, clean, efficient, and reliable electric power anytime, anywhere. It provides the best and most secure electric services available in the world.’’
- The US vision of a Smart Grid uses digital technology to improve reliability of supply, resiliency, flexibility, energy efficiency, and economy of the electricity supply processes at all levels of the power system.



2. Development Targets for Interconnections in the USA

- The key activities that comprise the Smart Grid strategy are directed:

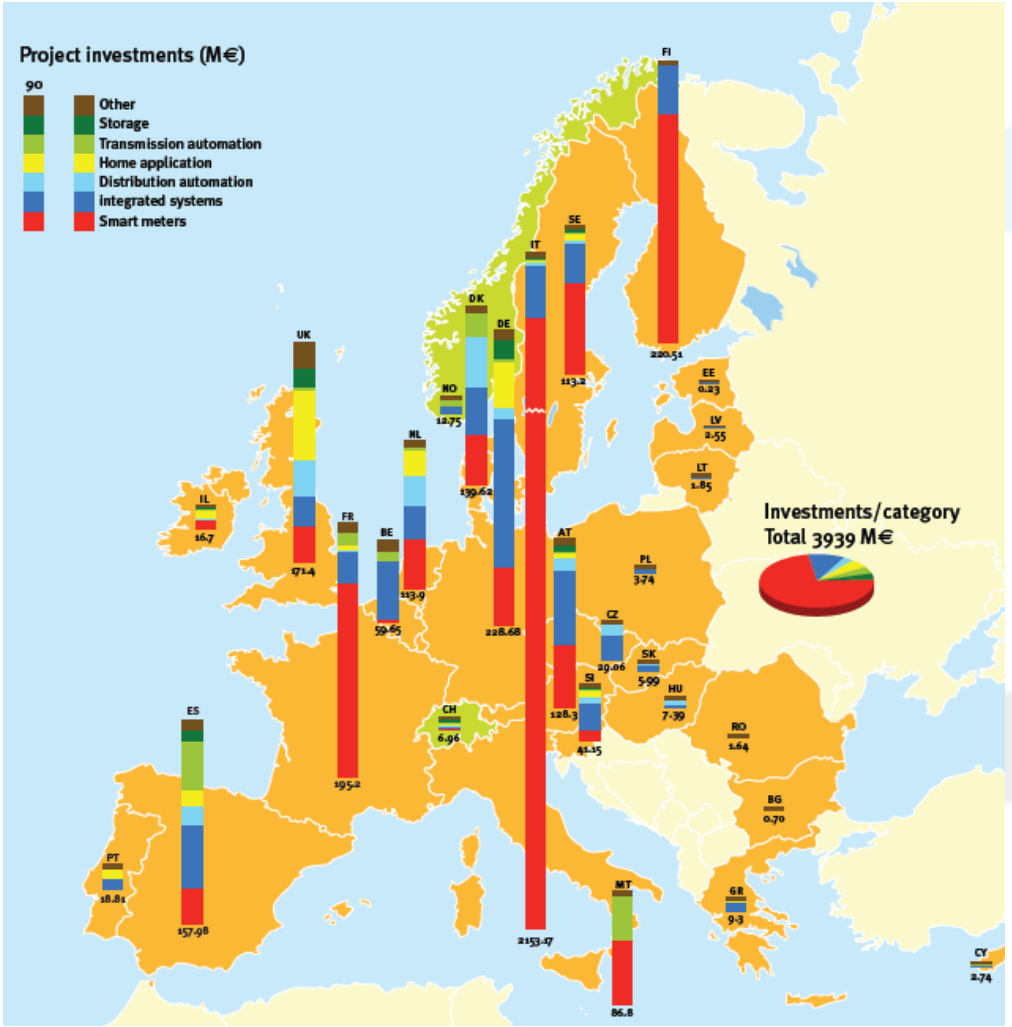
- to generate research and development initiatives for the design of prospective technologies in the areas of transmission, distribution, energy storage, power electronics, cyber-security,
- to support demonstration projects and the subsequent deployment strategies,
- to develop and introduce standards in the area of interoperability,
- to create greater certainty with respect to the future extension of the electricity network

2. Development Targets for Interconnections in the USA

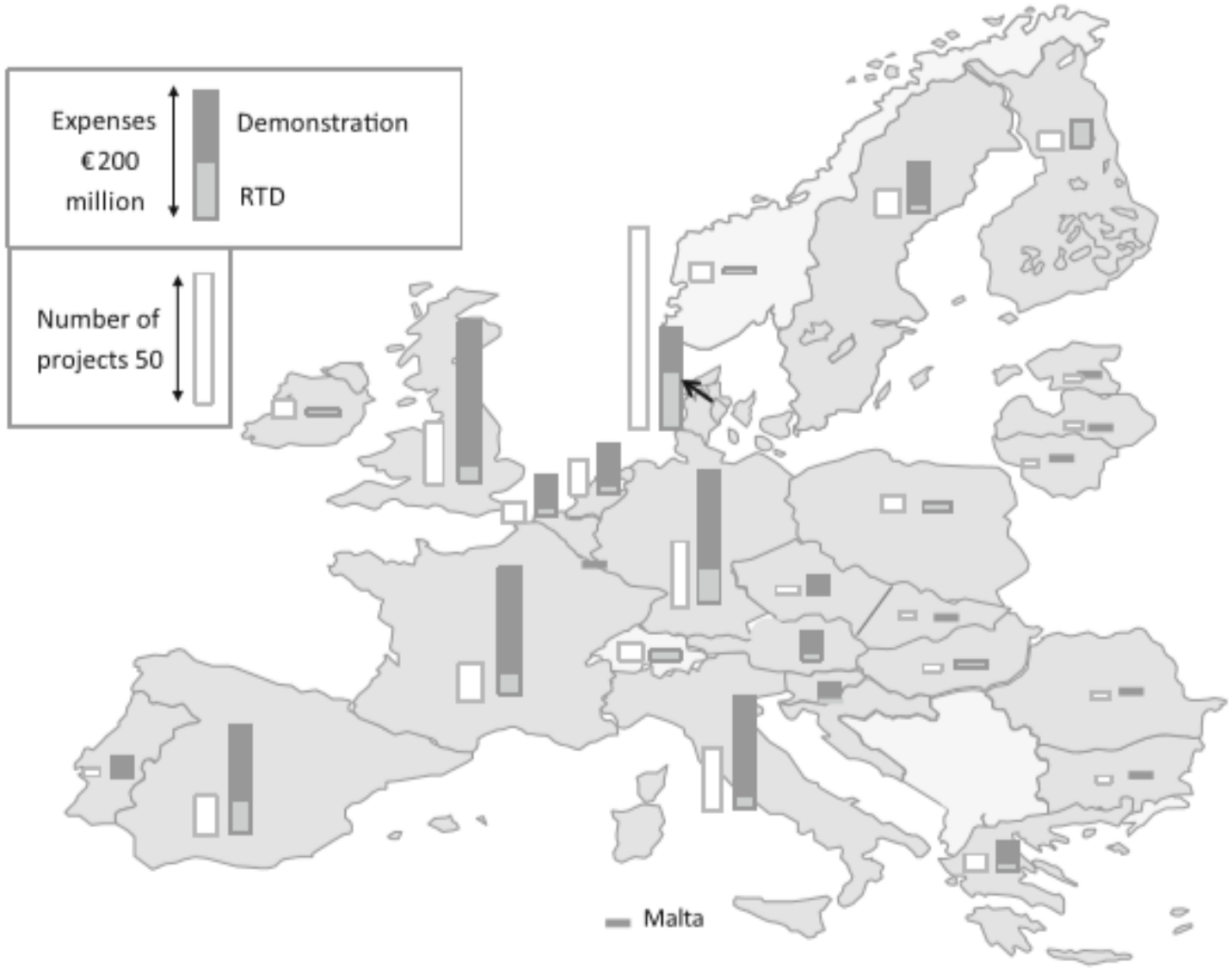
- to address the impending workforce shortage by developing a greater number of well-trained, highly skilled electric power sector personnel knowledgeable in Smart Grid operations,
- to motivate the stakeholder's engagement by informing them about benefits, sharing of lessons learned for continuous improvement, and exchanging technical and cost performance data,
- to establish data collection to show the national progress with respect to overcoming challenges and achieving Smart Grid characteristics.

3. Overview of Smart Grid projects in Europe

- In 2013 the European Commission published an inventory study regarding the national Smart Grid projects in Europe. This study is based on a questionnaire and presents the 2012 update of the inventory carried out in 2011 focusing specifically on the Smart Grid RTD and demonstration projects.
- The inventory document contains 281 Smart Grid RTD and demonstration projects from 30 European countries (EU 28 plus Norway and Switzerland), representing a total investment of €1.8 billion.



3. Overview of Smart Grid projects in Europe



Geographical distribution of national Smart Grid projects in Europe

3. Overview of Smart Grid projects in Europe

- 151 RTD projects and 130 demonstration projects were analyzed. The majority of projects (93 %) were performed within the EU15 countries, while the new member countries EU13 are significantly behind.
- Some countries are in advance regarding the funding: The UK represents 15 % of the total sum. Germany and France follow with 12 % each. Denmark, Italy and Spain are each spending about 10 %.
- Denmark is the leading country regarding the:

  1. number of projects and
  2. the investment per

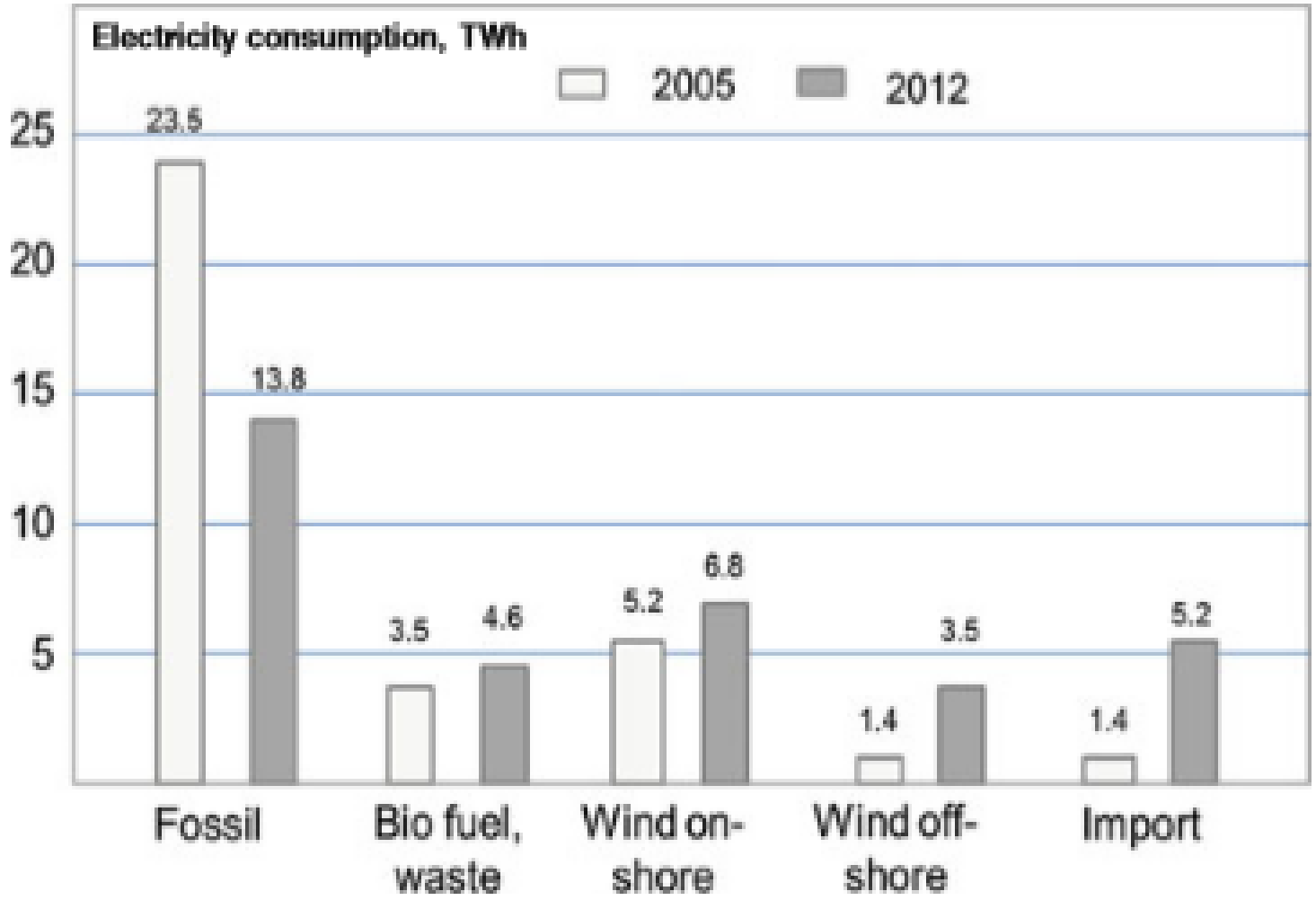
  – capita (30 €/person) and

  – consumed energy (0.5 €/MWh).

- Denmark is active in several small-scale projects supported by the national Forskel funding program. The large number of projects is the result of the ambitious Danish energy policy.

3. Overview of Smart Grid projects in Europe

Development of the energy mix in Denmark



3. Overview of Smart Grid projects in Europe

- Denmark has an installed power generation capacity of 14.3 GW with 9.7 GW from thermal power plants (of which 8.8 GW are CHP), 4.2 GW from wind power plants and 400 MW from PV panels.
- By 2012, Denmark reached a 30 % contribution of wind energy in its annual consumption. This is the worldwide largest contribution of wind energy in the annual balance.
- In 2012, the Danish government adopted a plan to increase the share of electricity production from wind to 50 % in 2020 and to cover 100 % of the consumption by RES in 2050.

3. Overview of Smart Grid projects in Europe

- In several European countries, Smart Grid projects are receiving increasing levels of national support funded by the responsible governmental organizations. The German E-Energy initiative is a best practice example for such support.

Cumulative budget and number of projects

Application group	Level	Number projects	Budget, million €
Smart network management	D	~60	~400
Integration of distributed energy resources	D	~50	~340
Smart consumer/smart home	D	~50	~340
Aggregation, demand side integration, VPP	D	~45	~260
Electric vehicle management	D	~30	~200
Integration of large scale RES	T	~10	~100

D distribution, *T* transmission

3.1 Low voltage experimental microgrid laboratory (UCY)

- The Low Voltage Experimental Microgrid Laboratory (LVEM lab) at the FOSS Centre of the University of Cyprus (UCY) is a flexible and scalable microgrid testing, demonstration and R&D platform for smart grid and other advanced energy technologies.
- The infrastructure comprises of DER (Distributed Energy Resources) components (grid-connected PV systems and inverters of total capacity 30 kVA), battery energy storage systems (BESS) (capacity of 10 kWh) and controllable AC and DC loads that allow full-power testing capability up to 10 kVA (AC).
- In addition, the infrastructure includes smart meters, DAQs (Data Acquisition) and a home energy management system (HEMS) and a residential electric vehicle (EV) emulator (equipped with smart plugs emulating home appliances) for the monitoring and automated control of electricity usage within the microgrid feeder.

3.1 Low voltage experimental microgrid laboratory (UCY)

- The infrastructure is further equipped with a state-of-the-art weather station and meteorological data-sets are continuously acquired and analysed facilitating research in the area of energy meteorology.
- The overall observability and management of the infrastructure is performed by a high-level management system (incorporating OpenMUC and Node-Red functionalities) that communicates with the energy resources via Ethernet, RS-485 serial, IEEE 802.15.4 and supports various application protocols such as Modbus and IEC 61850.
- Ultimately, the laboratory infrastructure offers a modular and scalable interoperable platform for smart grid system and DER-oriented simulation and validation/testing activities.

3.1 Low voltage experimental microgrid laboratory (UCY)

Electrical setup and components:

- DER components (grid-connected PV systems and inverters of total capacity 30 kVA)
- Programmable loads for active and reactive power (10 kVA – capacitive and inductive behaviour; individual control possibilities) and BESS (capacity of 10 kWh)
- Environmental simulation (test chamber for performance and accelerated lifetime testing)
- DAQ and measurement (multiple high precision power analysers with high acquisition rate; simultaneous sampling of asynchronous multi-domain data input)
- Weather station (acquisition of meteorological data-sets)
- HEMS (fully equipped with EV charging points and smart plugs to emulate the operation).

3.1 Low voltage experimental microgrid laboratory (UCY)

Simulation tools and components:

- General simulation tools: Matlab/Simulink, SimPowerSystems, PSpice/Cadence, and Mathworks xPC-Target
- Network simulation tools: DigSILENT PowerFactory
- Interoperable interfaces: OpenMuc and Node-Red

ICT/Automation tools and components:

- Communication methods: IEC 61850, OPC/OPC-UA, Industrial Ethernet (EPL, Modbus / TCP, etc.)
- Network information system
- Cyber-security assessment methods and tools for Smart Grid systems and components.

3.1 Low voltage experimental microgrid laboratory (UCY)

DER grid smart infrastructure

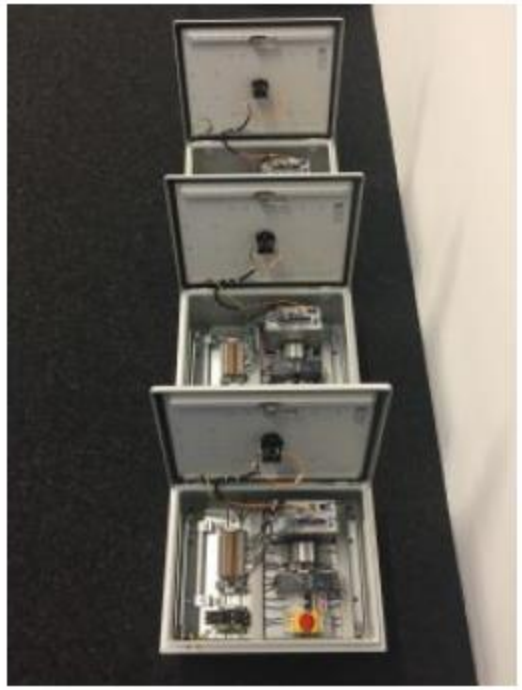
PV tracking systems

3.1 Low voltage experimental microgrid laboratory (UCY)

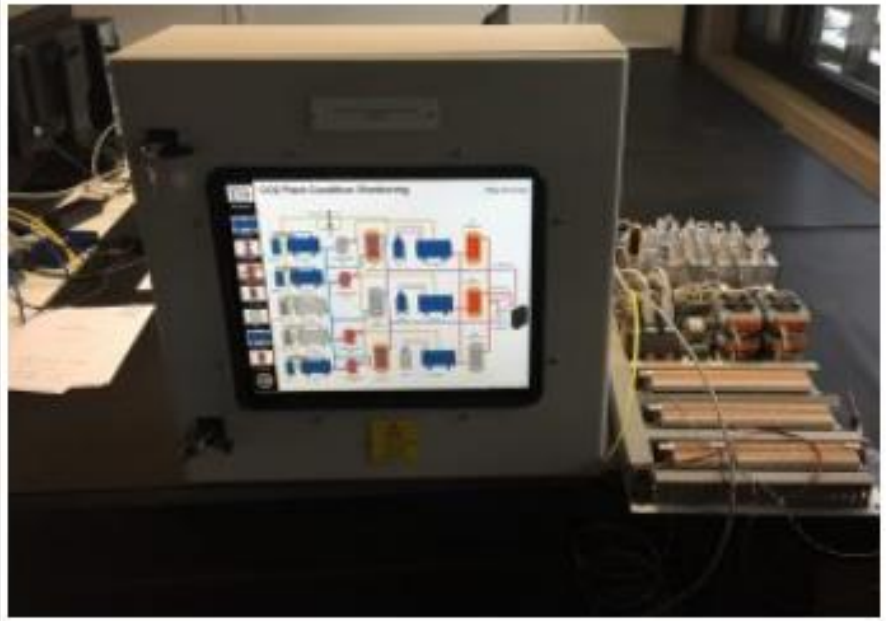
Smart Grid system and DER-oriented expertise and validation/testing activities:

- Integration of DER, standards and grid codes
- Power quality (lab test/field monitoring): impact of DER components on PQ (e.g., voltage levels and harmonics)
- Assessment of demand response in future smart grids and smart metering
- PV production forecasting (day- and hour-ahead) and load forecasting (short-term)
- Qualification testing/conformity assessment of PV according to diverse national standards and recommendations
- Interoperability and communication testing

3.1 Low voltage experimental microgrid laboratory (UCY)



Nanogrid control



PV power plant controler

More information:
https://www.foss.ucy.ac.cy/

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