

# Energy Economics and Environment

## Lecture 2

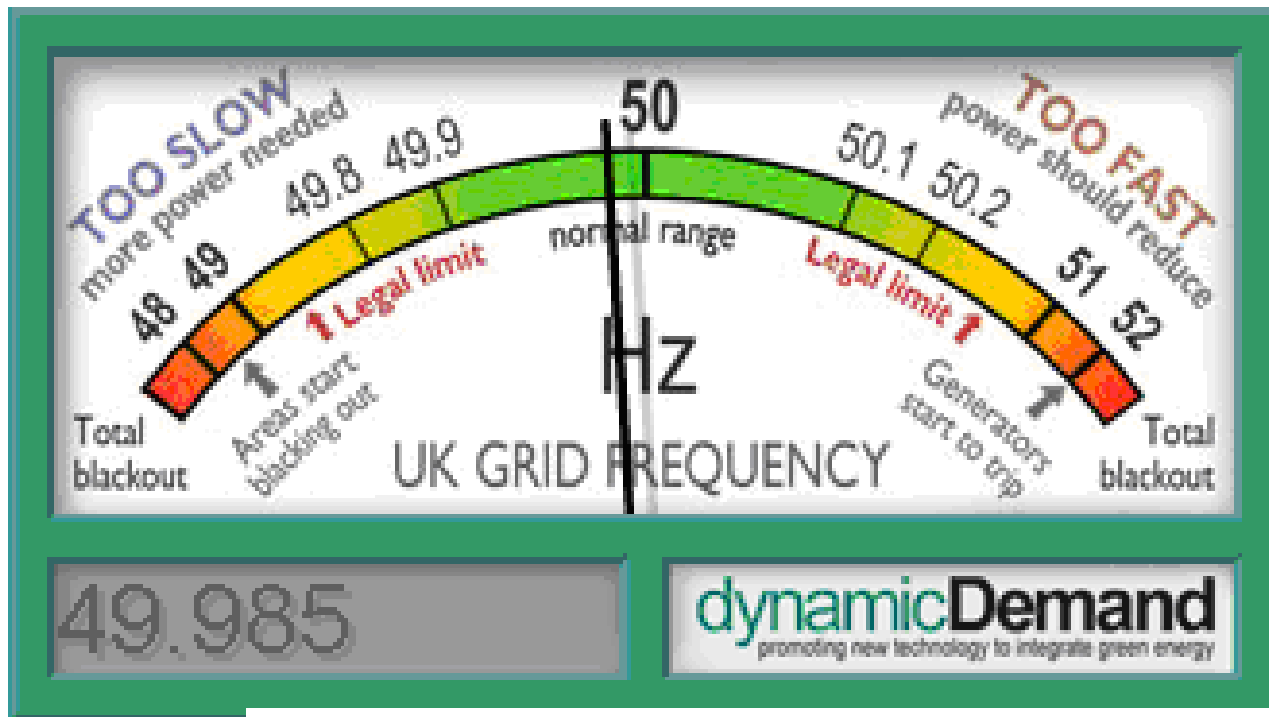


EVROPSKÁ UNIE  
Evropské strukturální a investiční fondy  
Operační program Výzkum, vývoj a vzdělávání



MINISTERSTVO ŠKOLSTVÍ,  
MLÁDEŽE A TĚLOVÝCHOVY

- <http://www.dynamicdemand.co.uk/grid.htm>

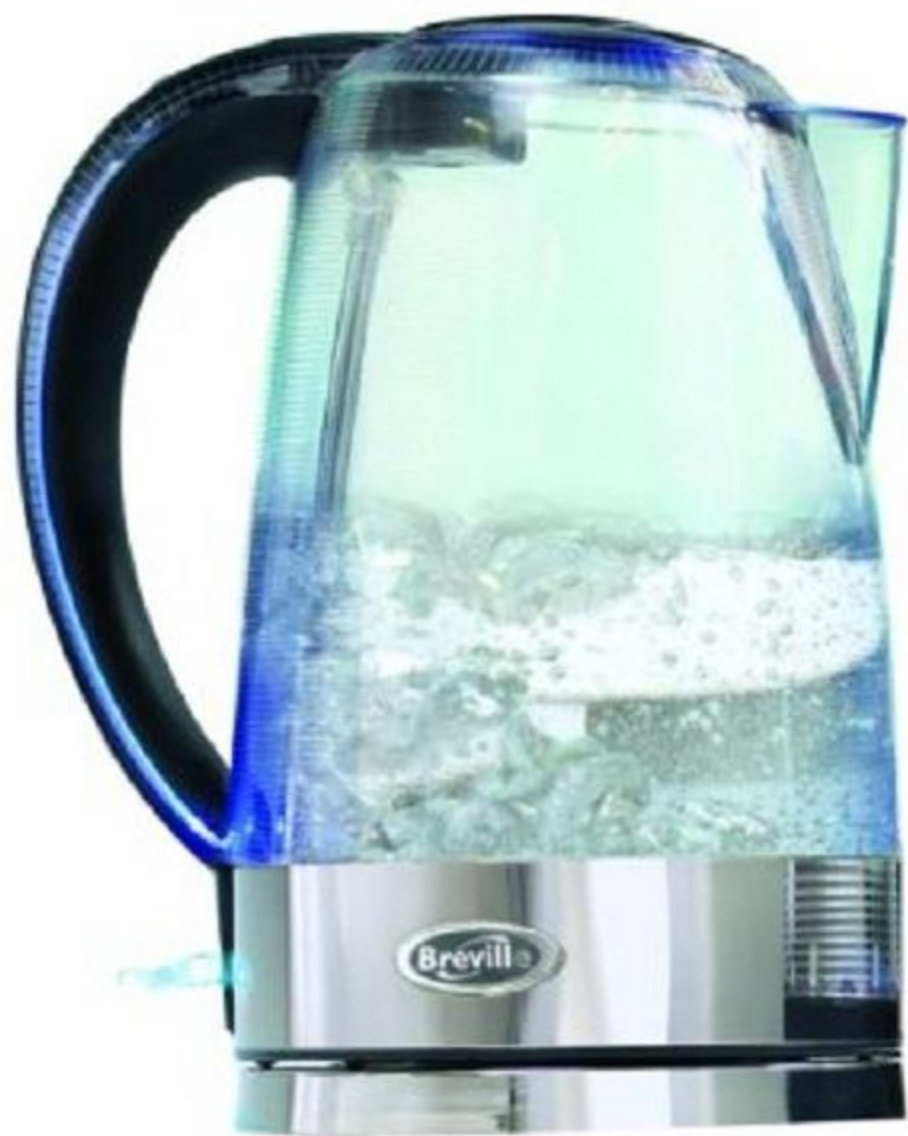


- What is (one TSO?)



EVROPSKÁ UNIE  
Evropské strukturální a investiční fondy  
Operační program Výzkum, vývoj a vzdělávání





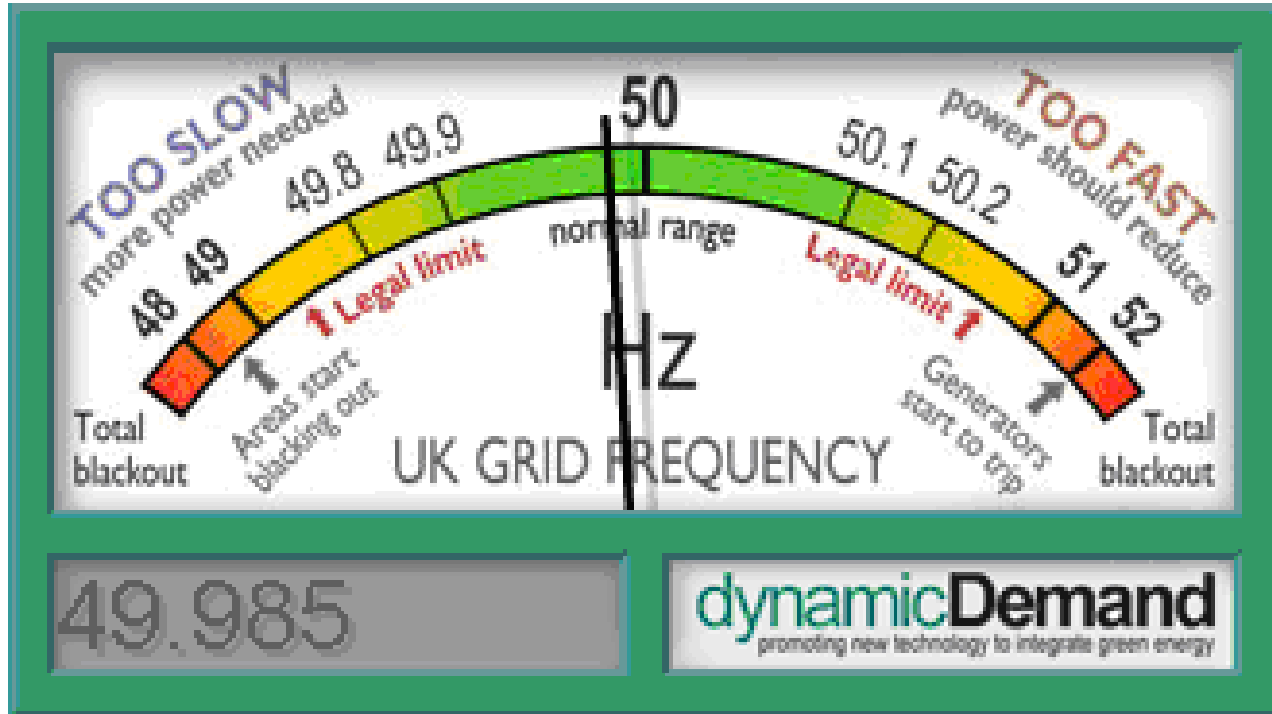


- *“TV channels are monitored as popular programs and football game etc. can mean that the demand will change by 2000 MW during adverts and breaks.”*

*<http://www.sapp.co.zw/docs/frequency%20relaxation.pdf>*

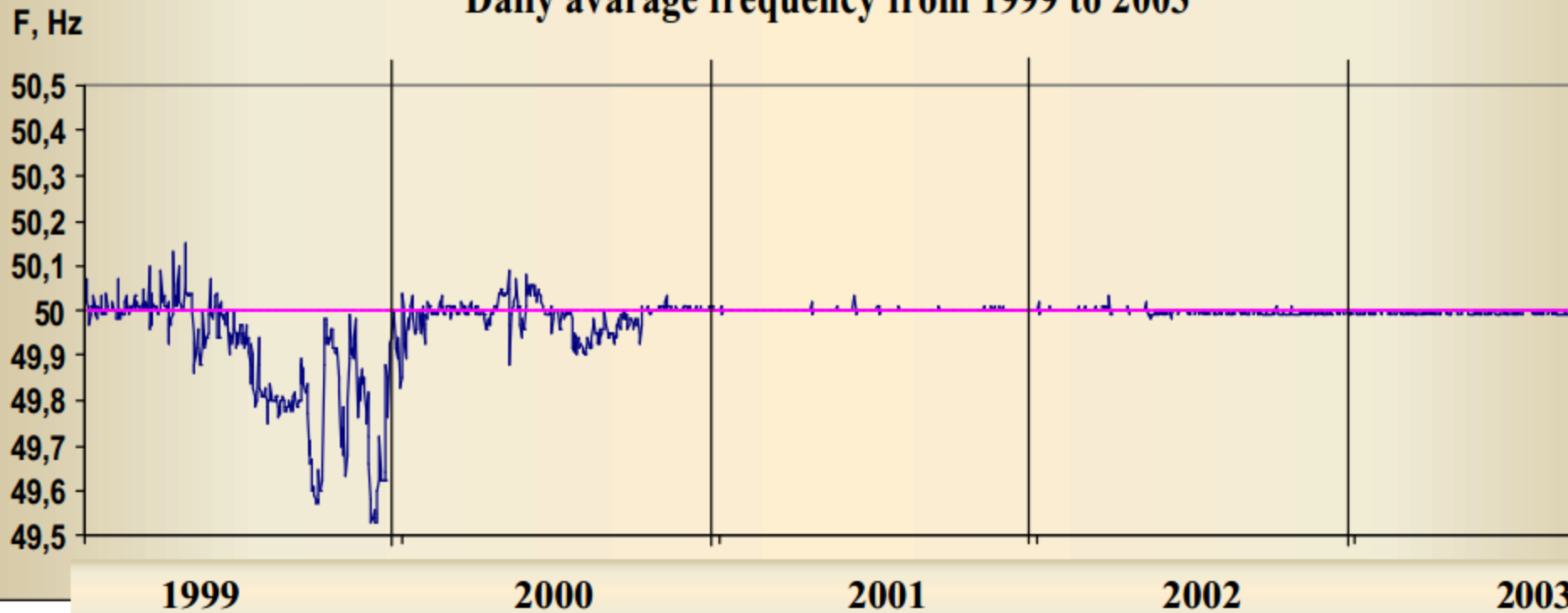
# Frequency and Synchronicity

- <http://www.dynamicdemand.co.uk/grid.htm>

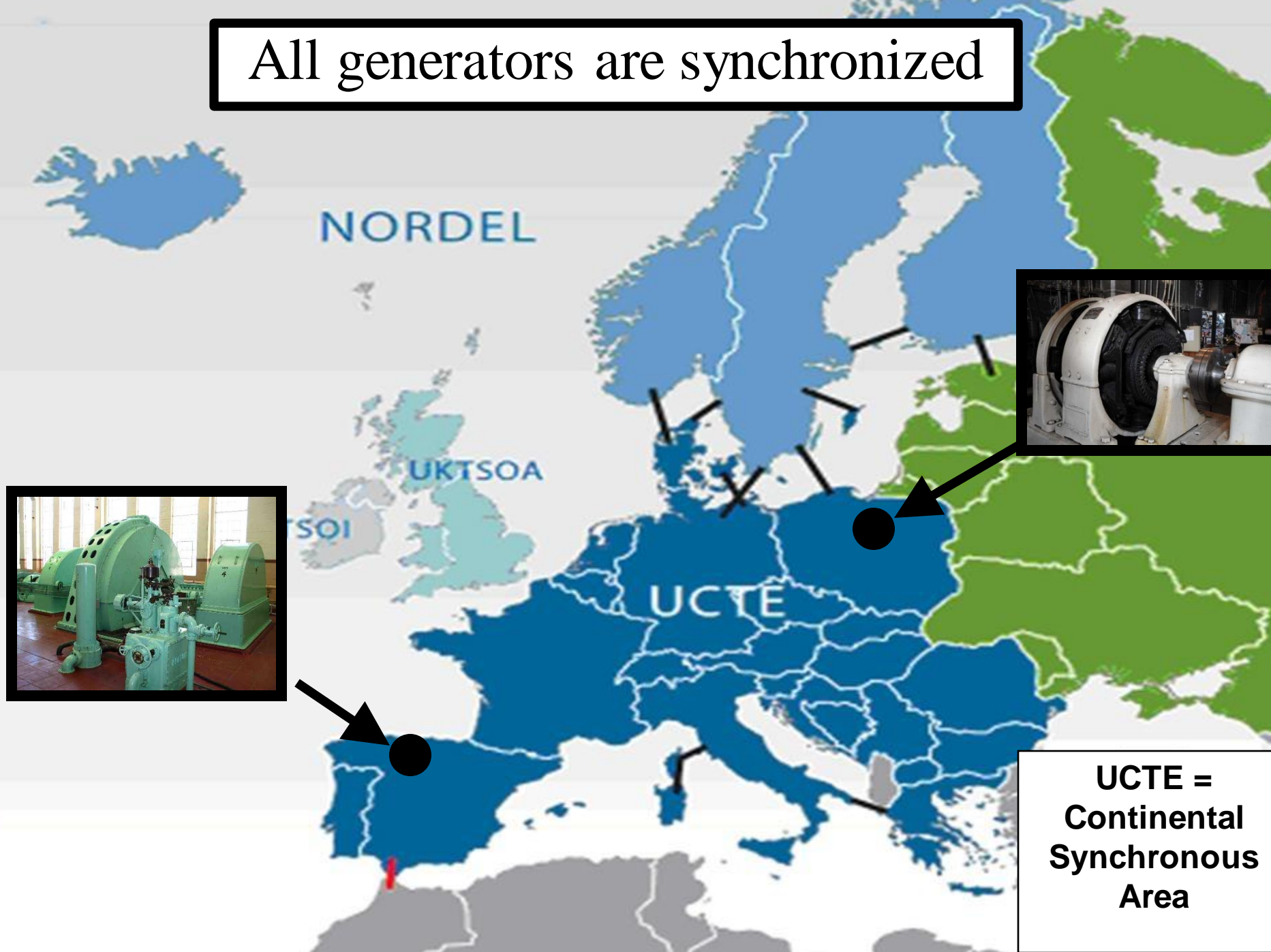


# Russian frequency

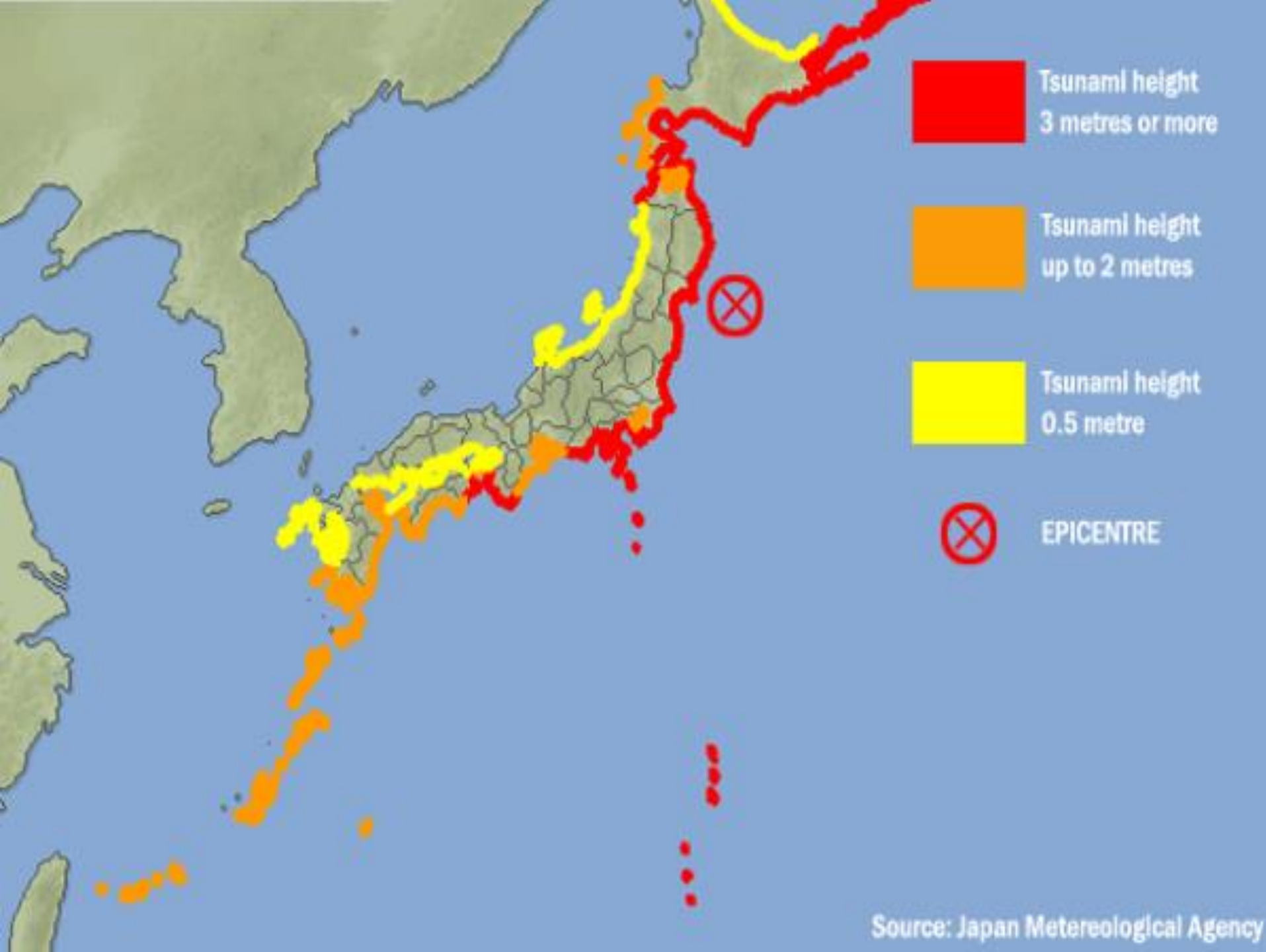
Daily average frequency from 1999 to 2003



All generators are synchronized



**UCTE =  
Continental  
Synchronous  
Area**







CHINA

RUSSIA

JAPAN

N. KOREA

Sea of Japan

50 hertz

Sendai



Epicenter

60 hertz

S. KOREA

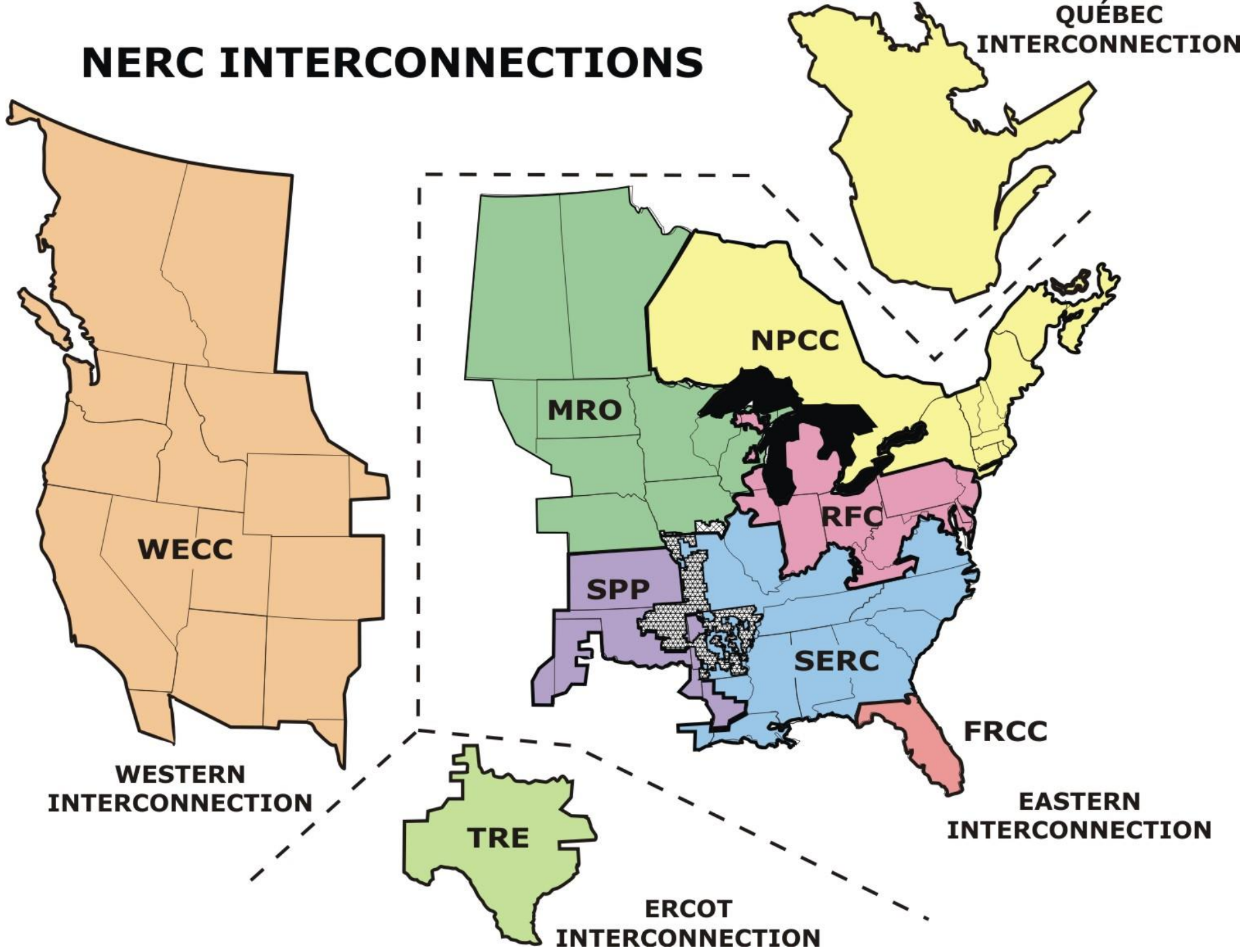
Tokyo

TEPCO service area

PACIFIC OCEAN



# NERC INTERCONNECTIONS



# HVDC & B2B



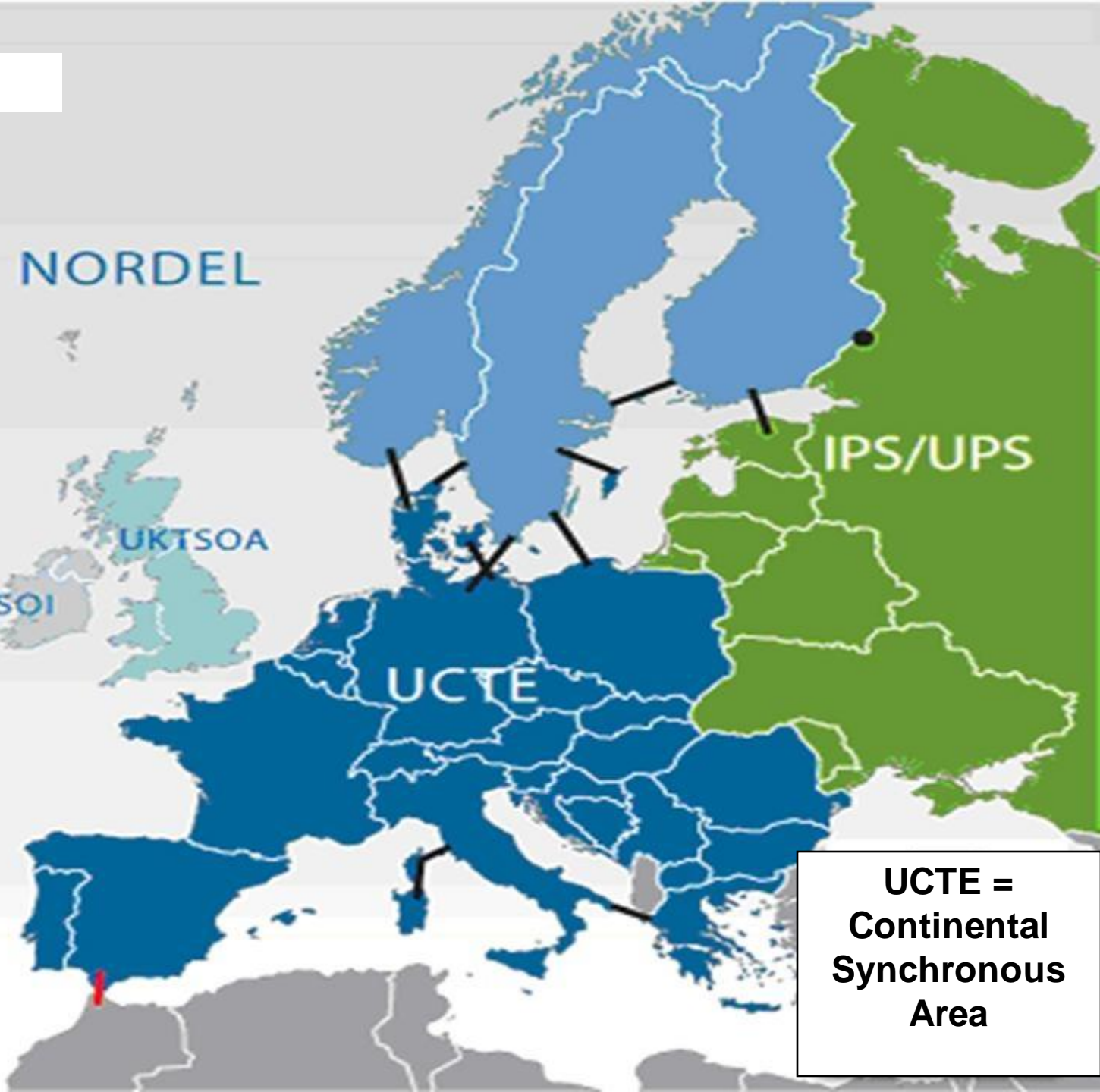
NORDEL

UKTSOA  
ATSOI

UCTE

IPS/UPS

**UCTE =  
Continental  
Synchronous  
Area**







**France**

**Spain**

**Italy**

**Algeria**

**Libya**

**Egypt**

**Ukraine**

**Romania**

**Turkey**

**Czech Republic**

**Slovakia**

**Austria**

**Hungary**

**Switzerland**

**Slovenia**

**Bosnia and Herzegovina**

**Serbia**

**Bulgaria**

**Kosovo**

**Macedonia (FYROM)**

**Albania**

**Greece**

**Montenegro**

**Cyprus**

**Syria**

**Lebanon**

**Damascus**

**Amman**

**Jordan**

**Israel**

**Alexandria**

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**Konya**

**Antalya**







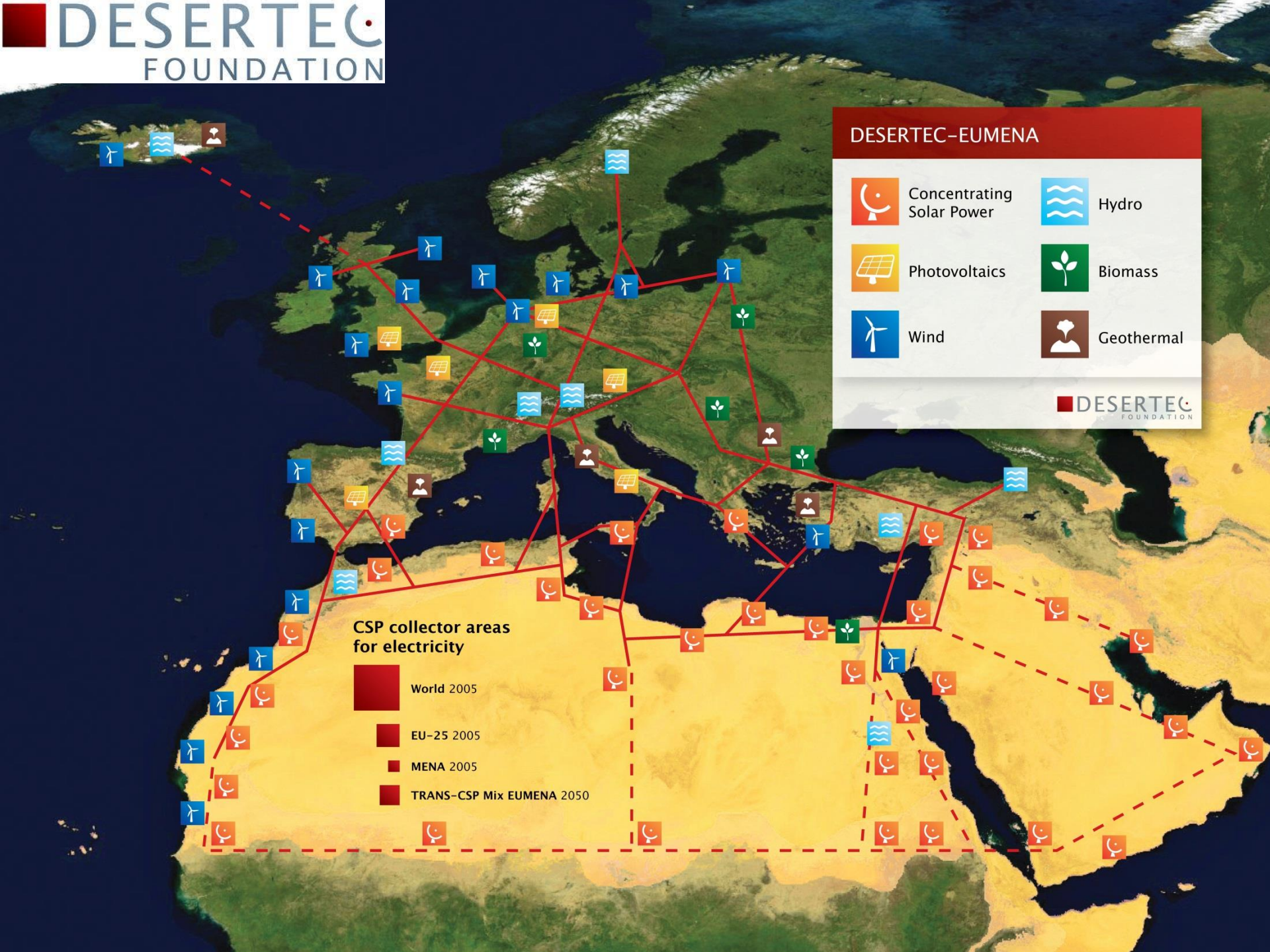
## DESERTEC-EUMENA

	Concentrating Solar Power		Hydro
	Photovoltaics		Biomass
	Wind		Geothermal



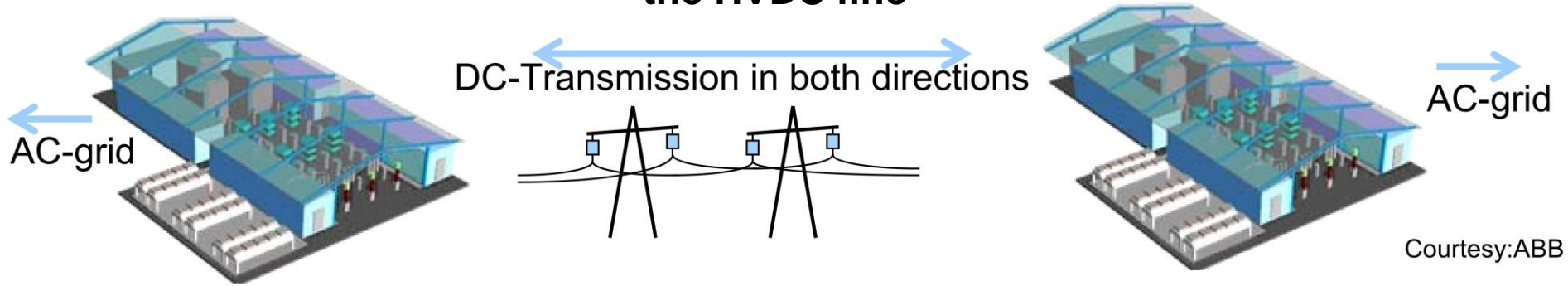
### CSP collector areas for electricity

	World 2005
	EU-25 2005
	MENA 2005
	TRANS-CSP Mix EUMENA 2050

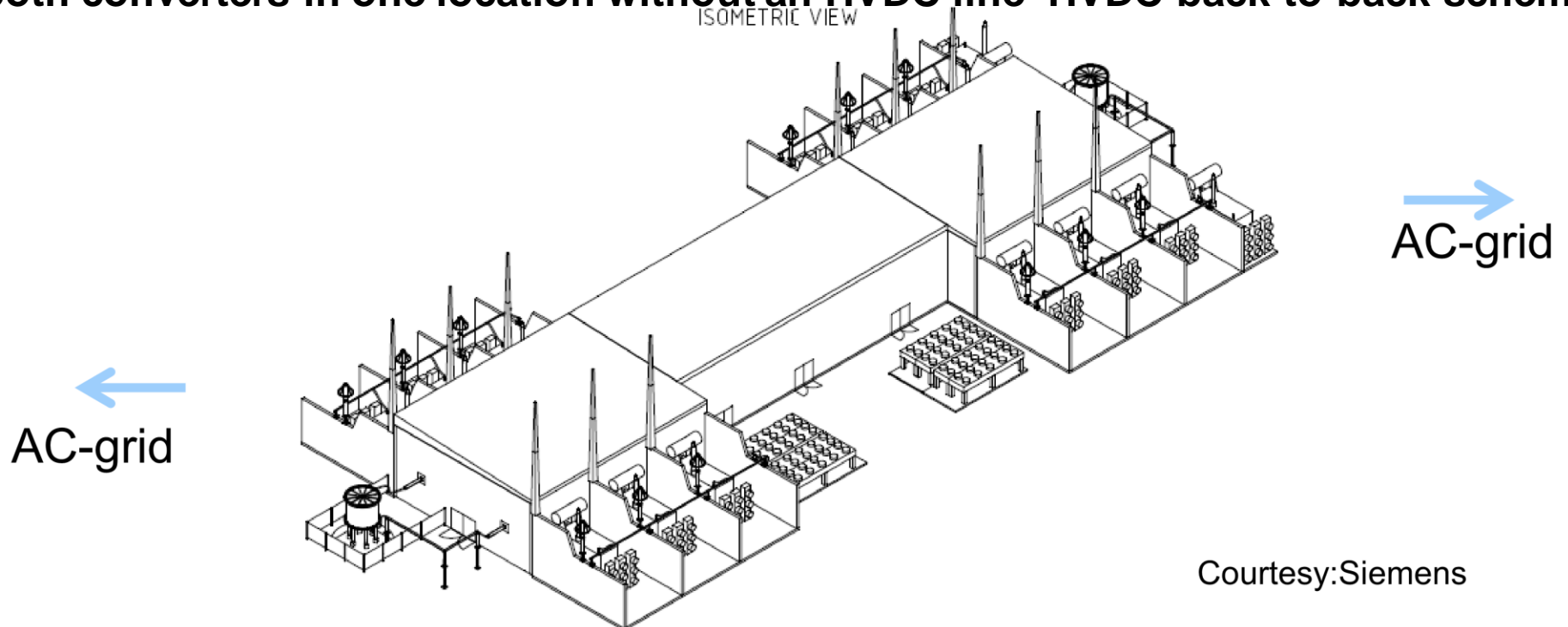


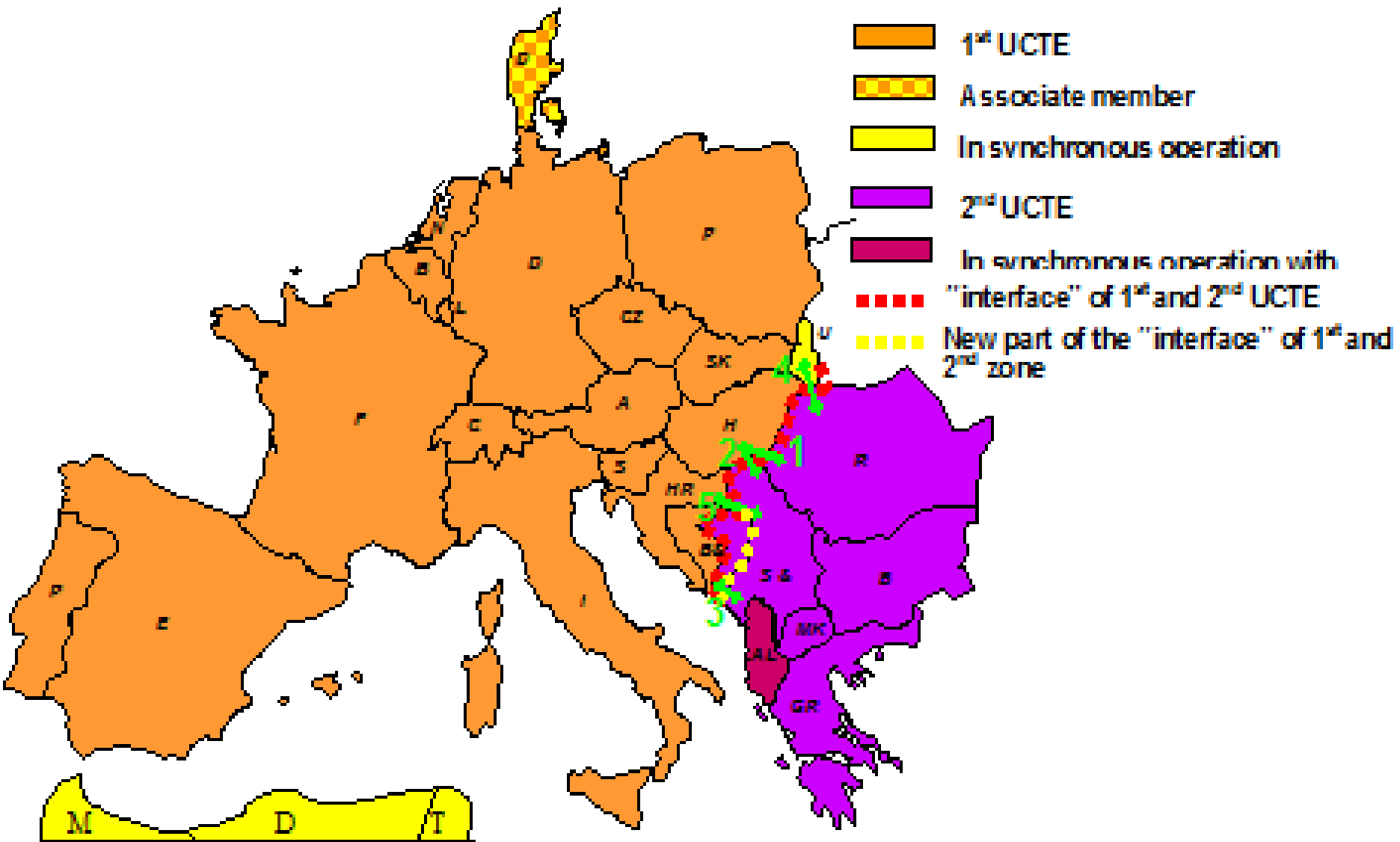


# Long-distance HVDC lines with an HVAC/HVDC converter station at each end of the HVDC line



# both converters in one location without an HVDC line -HVDC back-to-back scheme





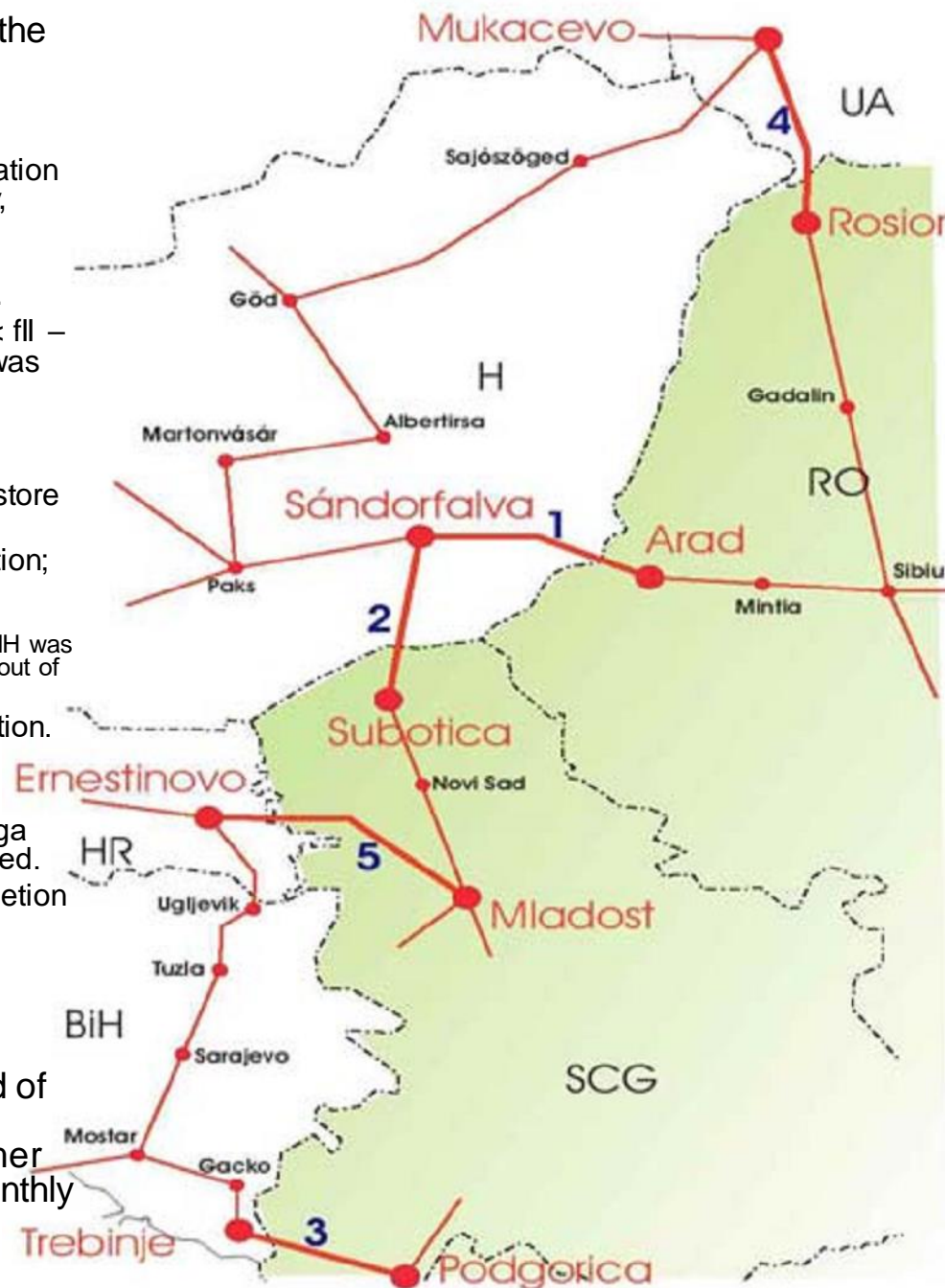
400 kV overhead line Ernestinovo – Mladost on September 26, 1991

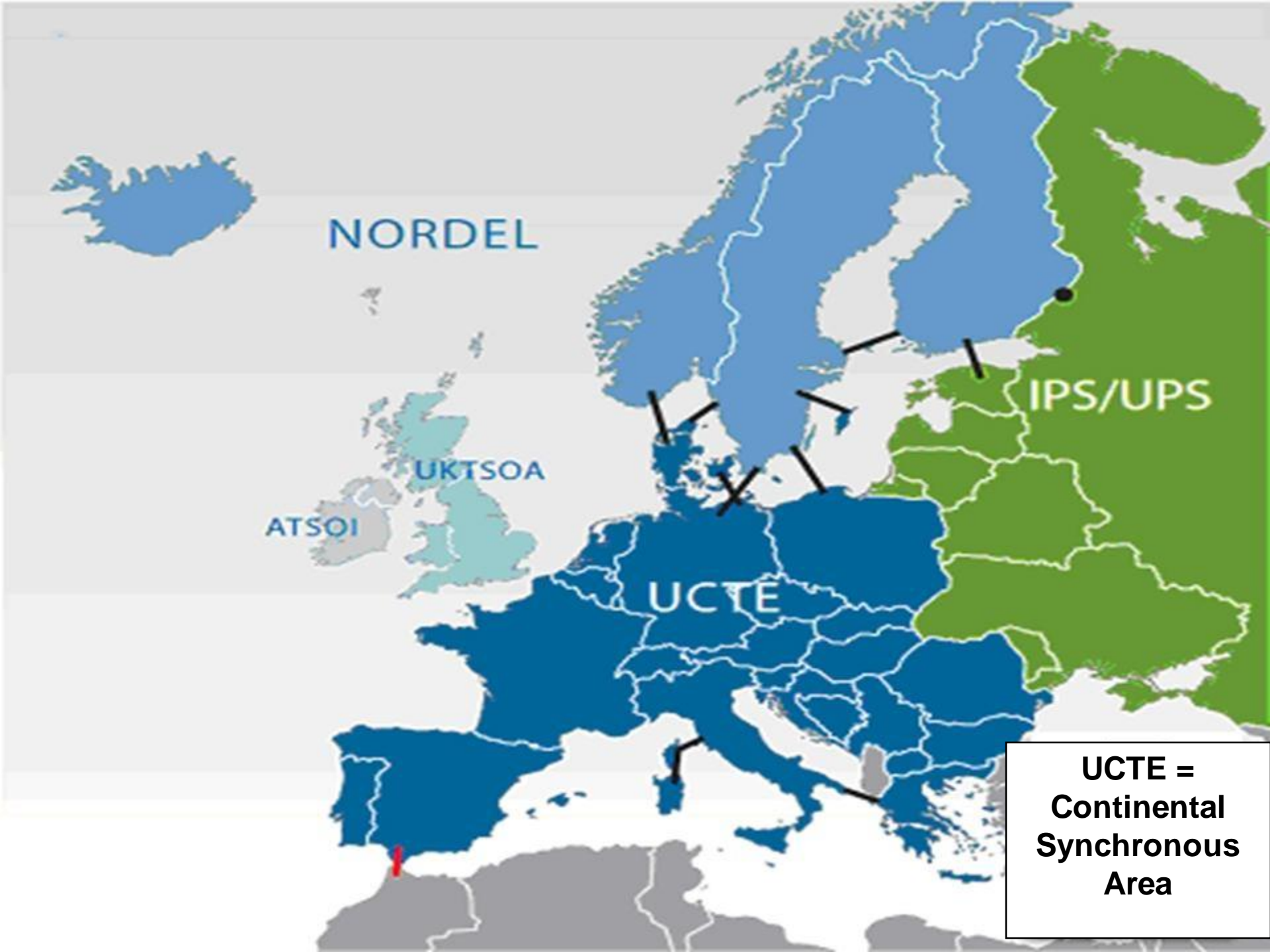
On the very day of the reconnection, October 10 2004, the key steps were the following:

- Preparation: all interconnecting overhead lines ready for operational use and idle.
- The command to Bucuresi to take over the frequency regulation in 2nd synchronous zone (Romania regulates the frequency, Greece, Bulgaria and EKC only the exchange).
- The command to Budapest to discontinue the pluralistic CENTREL regulation and to assume the regulation by itself.
- 9:34 after fulfilling conditions  $\Delta U < 20\text{kV}$ ;  $\alpha < 10^\circ$ ;  $0,03\text{ Hz} < f_{ll} - f_l < 0,05\text{ Hz}$  in Arad substation, Sandorfalva overhead line was connected (RESYNCHRONIZATION was carried out).
- 9:41 Subotica overhead line connected to Sandorfalva substation.
- Command to all synchronous zone block 2 controllers to restore the LFC regulation mode.
- 9:58 Podgorica overhead line connected to Trebinje substation;
  - Prior to the resynchronization, this overhead line had the biggest voltage difference (over 60 kV) which activated all compensation equipment in Croatia, the operating compensation generator in BIH was CHE Capljina, and in Montenegro the aluminium factory was put out of operation for a few minutes in order to raise voltage.
- 10:07 Rosiori overhead line connected to Mukačevo substation.
- 10:20 Mladost overhead line connected to Ernestinovo substation.
- 10:58 220 kV Trebinje – Peručica, 220 kV Višegrad – Požega and 110 kV Trebinje – Herceg Novi overhead lines connected.
- 11:00 – Main coordinators announced the successful completion of the reconnection.

• Test run commencing on October 31 2004 was rated successful.

• For the period between November 1 2004 and the end of 2004, UCTE issued the recommendation regarding the gradual increase of trade volume directed from the former 2<sup>nd</sup> UCTE zone towards the former 1<sup>st</sup> UCTE zone (monthly increase by 30% to complete NTC values).





NORDEL

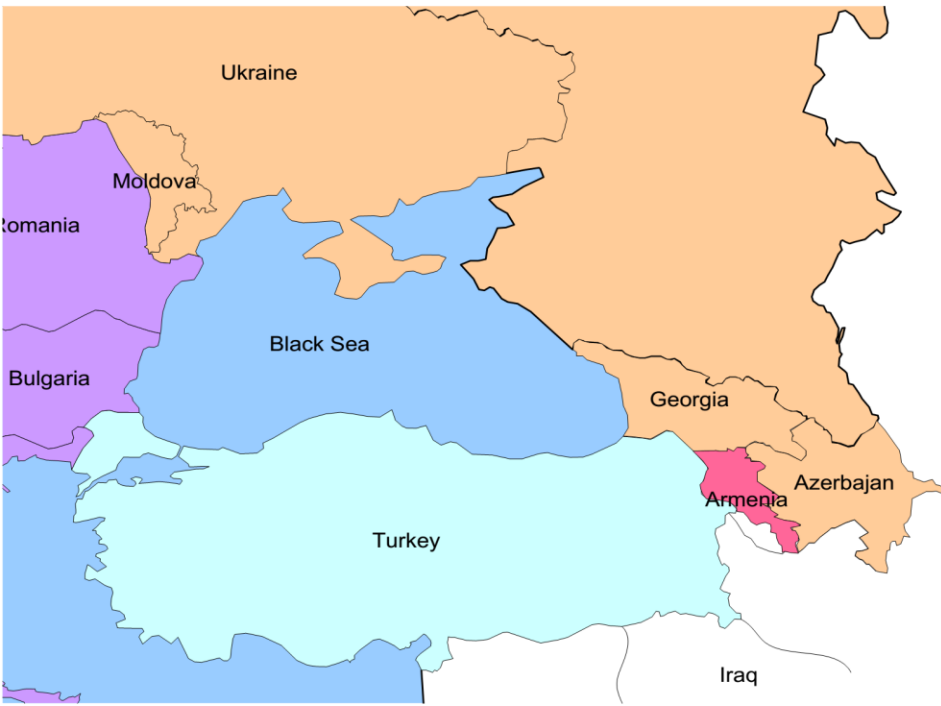
UKTSOA

ATSOI

UCTE

IPS/UPS

**UCTE =  
Continental  
Synchronous  
Area**



*2010*



*2012*





**France**

**Spain**

**Italy**

**Algeria**

**Egypt**

**Ukraine**

**Romania**

**Turkey**

**Czech Republic**

**Slovakia**

**Austria**

**Hungary**

**Switzerland**

**Slovenia**

**Bosnia and Herzegovina**

**Serbia**

**Bulgaria**

**Greece**

**Albania**

**Kosovo**

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**Damascus**

**Amman**

**Jordan**

**Israel**

**Libya**

**Tunisia**

**Tripoli**

**Benghazi**

**Alexandria**

**Cairo**

*Celtic Sea*







*Bay of Biscay*


*Black Sea*

*Mediterranean Sea*







### DESERTEC-EUMENA

	Concentrating Solar Power		Hydro
	Photovoltaics		Biomass
	Wind		Geothermal

 DESERTEC FOUNDATION

### CSP collector areas for electricity

	World 2005
	EU-25 2005
	MENA 2005
	TRANS-CSP Mix EUMENA 2050



- Finish lecture
- Question: what is the drawback of the desertec project?

- Azerbaijan, Belarus, Georgia, Kazakhstan
- Armenia, Turkmenistan
- Uzbekistan, Tajikistan? Mongolia?
- Kazakhstan, Kyrgyzstan?
- Latvia, Lithuania, Estonia
- Moldova, Ukraine





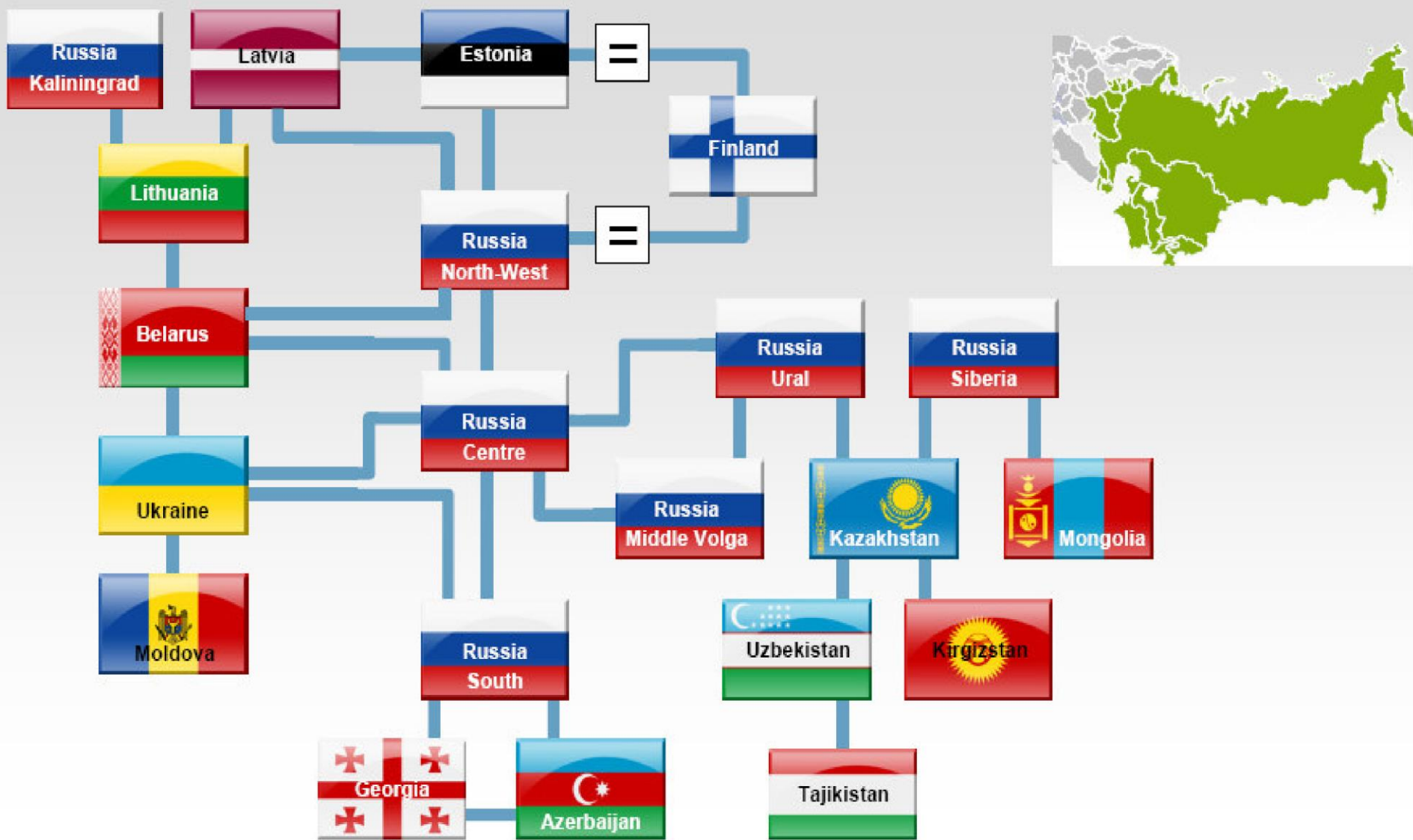




- Armenia is presently not synchronous with any of its BSTP neighbors.

<http://www.usea.org/sites/default/files/BSTP%20OPF%20Report%20Final.pdf>

- Uzbekistan has disconnected from IPS/UPS according to some sources from 2009, but is connected according to official UES sources <http://so-ups.ru/index.php?id=ees> (?)



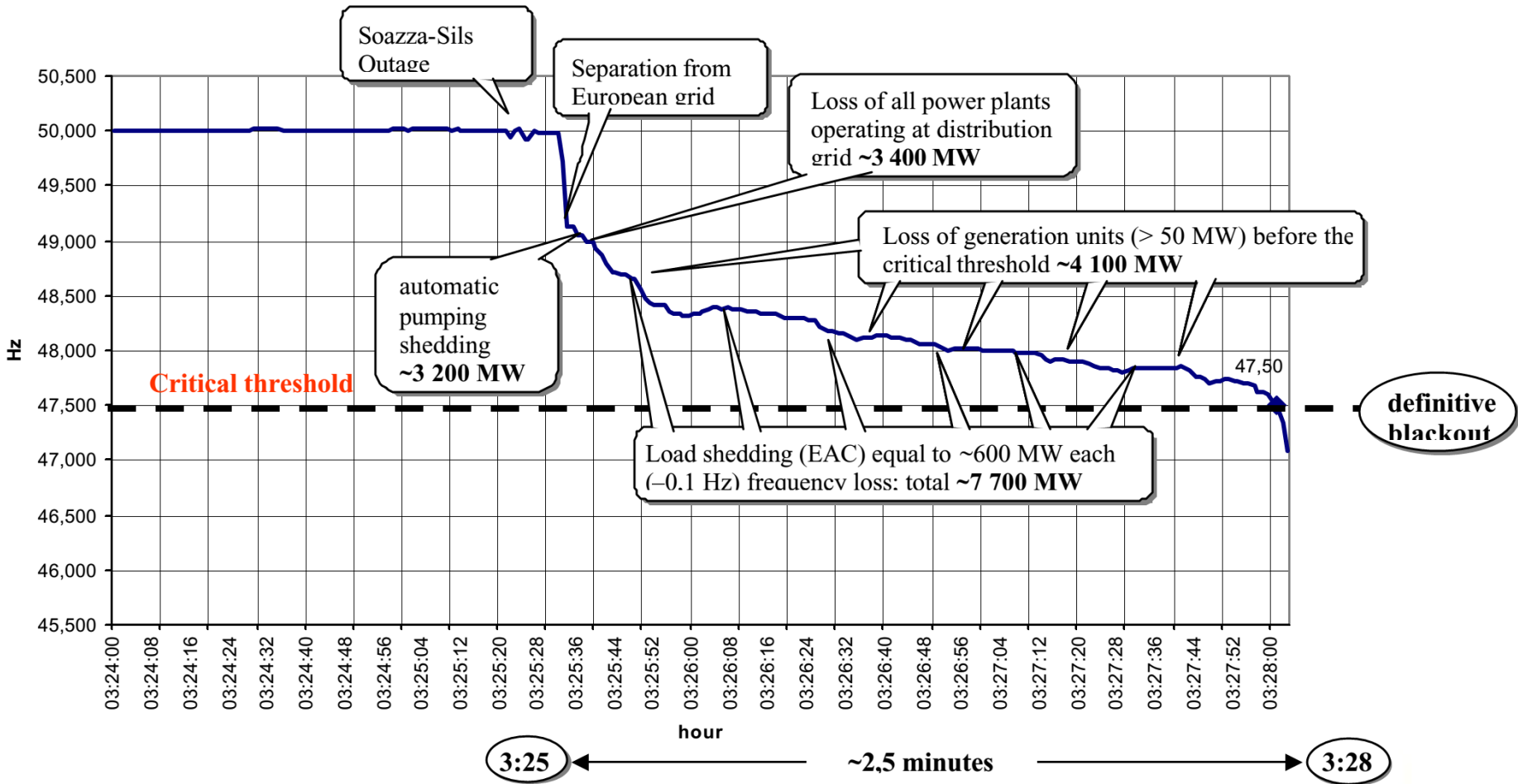
users – 280 million      337 GW      1285 billion TWh in a year

- <http://so-ups.ru/index.php?id=ees>

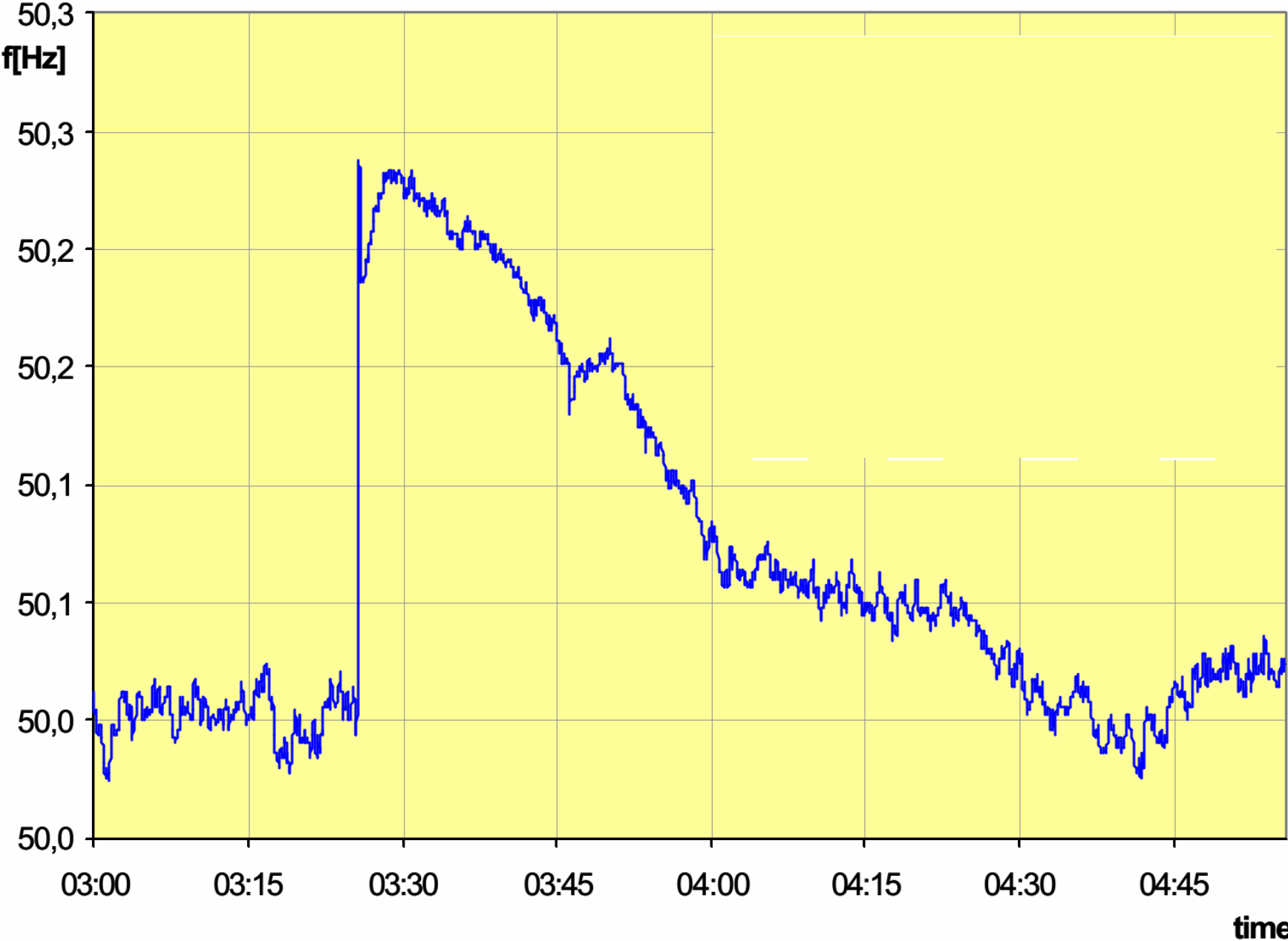




# Frequency behaviour in Italy in the transitory period



# Rest of the ENTSO-E system?



Frequency and Synchronicity

# Circuit breakers



# High voltage circuit breakers





# Why AC?

**AC or DC: What sort of lines where built first?**

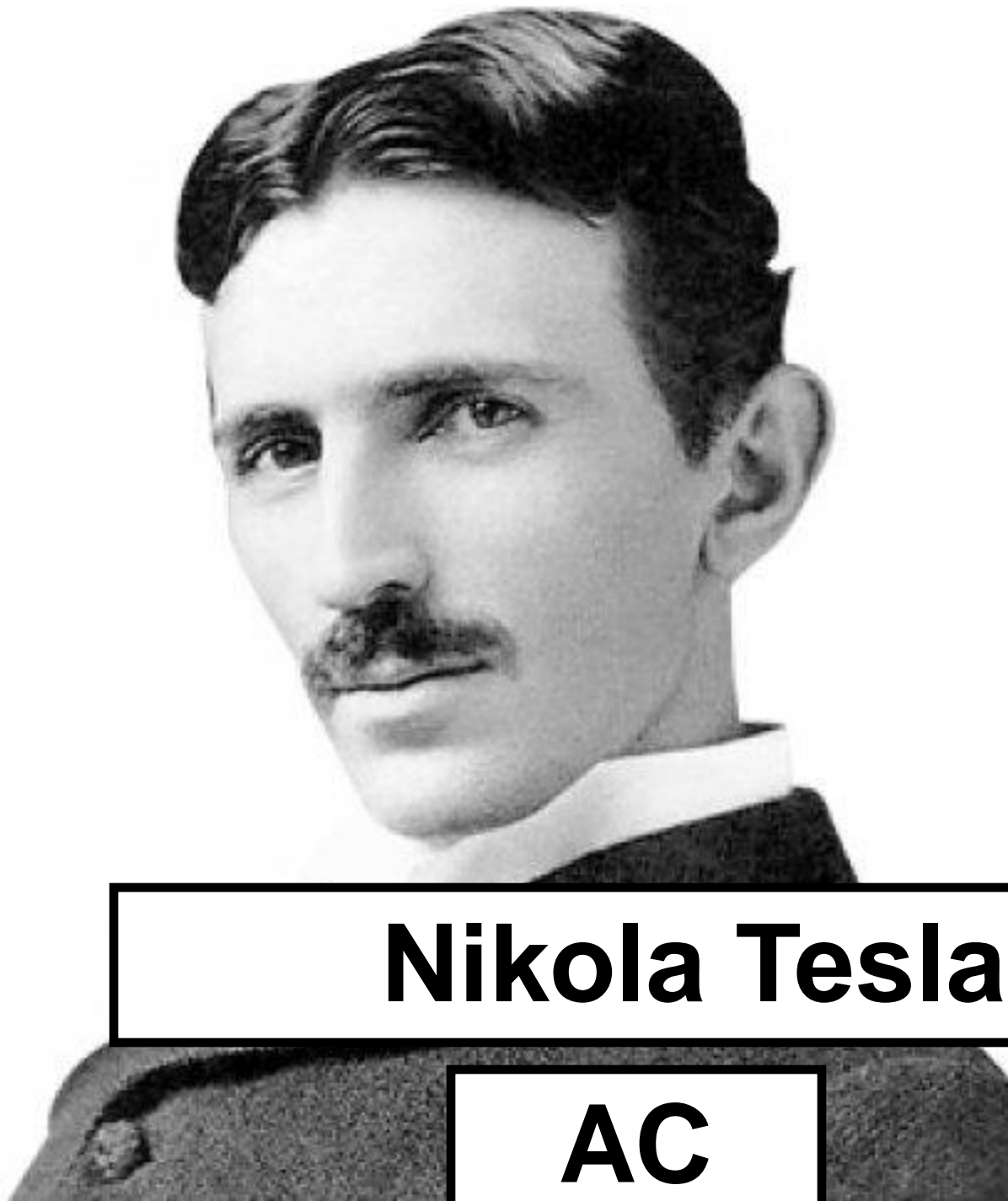


General Electric  
Company



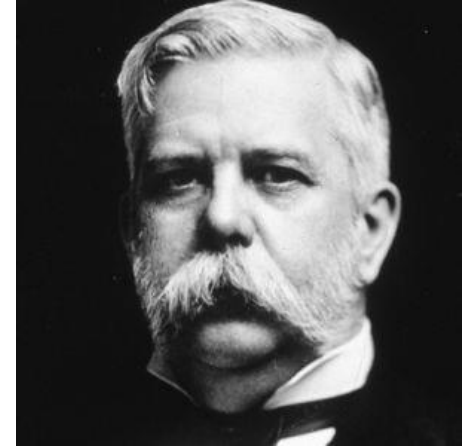
**Thomas Edison**

**DC**



**Nikola Tesla**

**AC**



**George  
Westinghouse**

# TESLA



**Elon Musk**

**Why are Tesla's (electrical cars) called "Tesla"?**

Use battery : DC

More fitting name would be "Edisons"?



# THE BAILEY ELECTRIC VICTORIA PHAETON



## A REPRESENTATIVE TYPE OF AMERICA'S BEST PRODUCTION

The use of the ELECTRIC is rapidly increasing,—it has a field of usefulness all its own. For the busy business man, in going to and from his home, office, bank, etc., or for making business calls; or for the lady in her shopping, calling, pleasure riding, the theatre, etc.—the “ELECTRIC” is just the right type of car,—and the BAILEY ELECTRIC is invariably chosen by the discriminate.

It is a dependable car,—always ready to use,—easily managed,—speed under perfect control,—noiseless, safe, clean, convenient and comfortable.

The RELIABILITY of service from the BAILEY ELECTRIC can, to a great degree, be traced to the

## EDISON STORAGE BATTERY

with which the BAILEY ELECTRIC is equipped. It runs the BAILEY 150 miles under good conditions, and 100 miles under any conditions. Has range to satisfy every need.

In *easa* of operation, in simplicity of construction, in efficiency and reliability of its motive power, the BAILEY ELECTRIC VICTORIA PHAETON stands alone,—the proven perfect electric car.

**PRICES,—\$2400 to \$2600**

Correspondence solicited

1911: Add for electric car





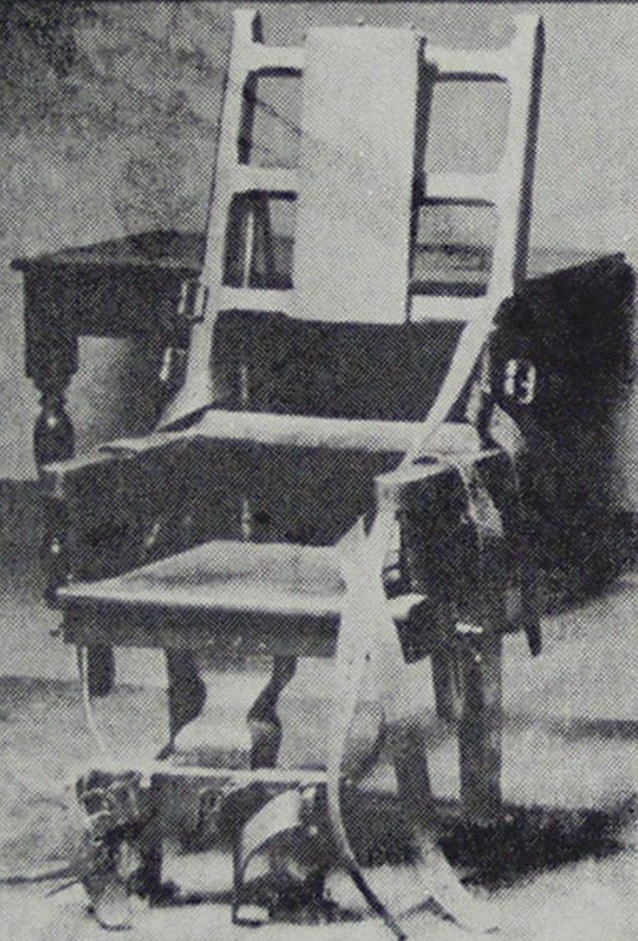
**1908-1927: Henry Ford's model T**





1888: Thomas Edison has series of experiments done killing animals with electricity  
Using AC!

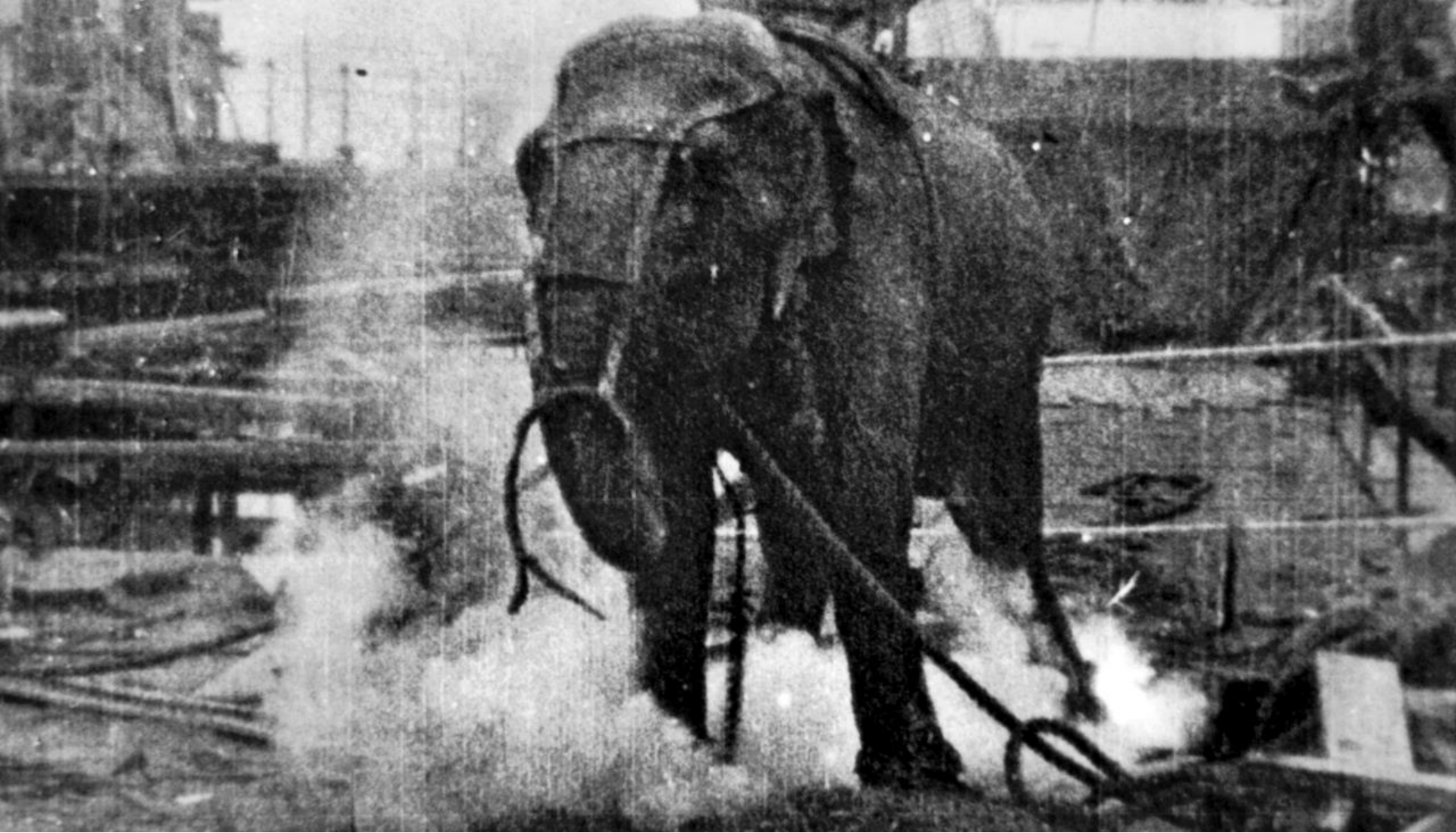




**1890: Thomas Edison has electric chair built  
Using AC! (“Westinghoused”)**

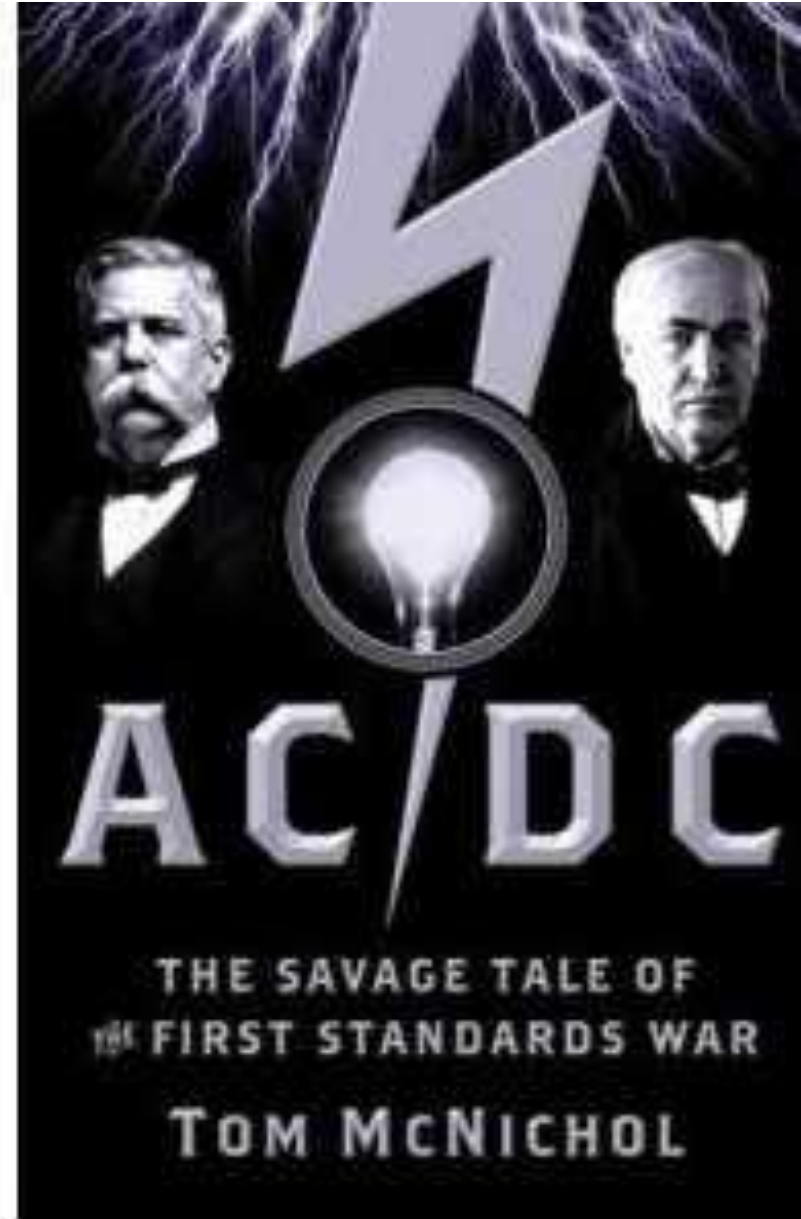
- AC won over DC round 1892~1893
- 1893: **Westinghouse** wins contract to build the first large-scale **hydroelectric generating plant at Niagara Falls.**
- 1892, **General Electric** merged with Thompson-Houston and immediately invested heavily in AC power





1903: Edison ordered documentary film *Electrocuting an Elephant* with AC?

Maybe yes ([http://en.wikipedia.org/wiki/War\\_of\\_Currents](http://en.wikipedia.org/wiki/War_of_Currents), McNichol), maybe no (<http://edison.rutgers.edu/topsy.htm>)



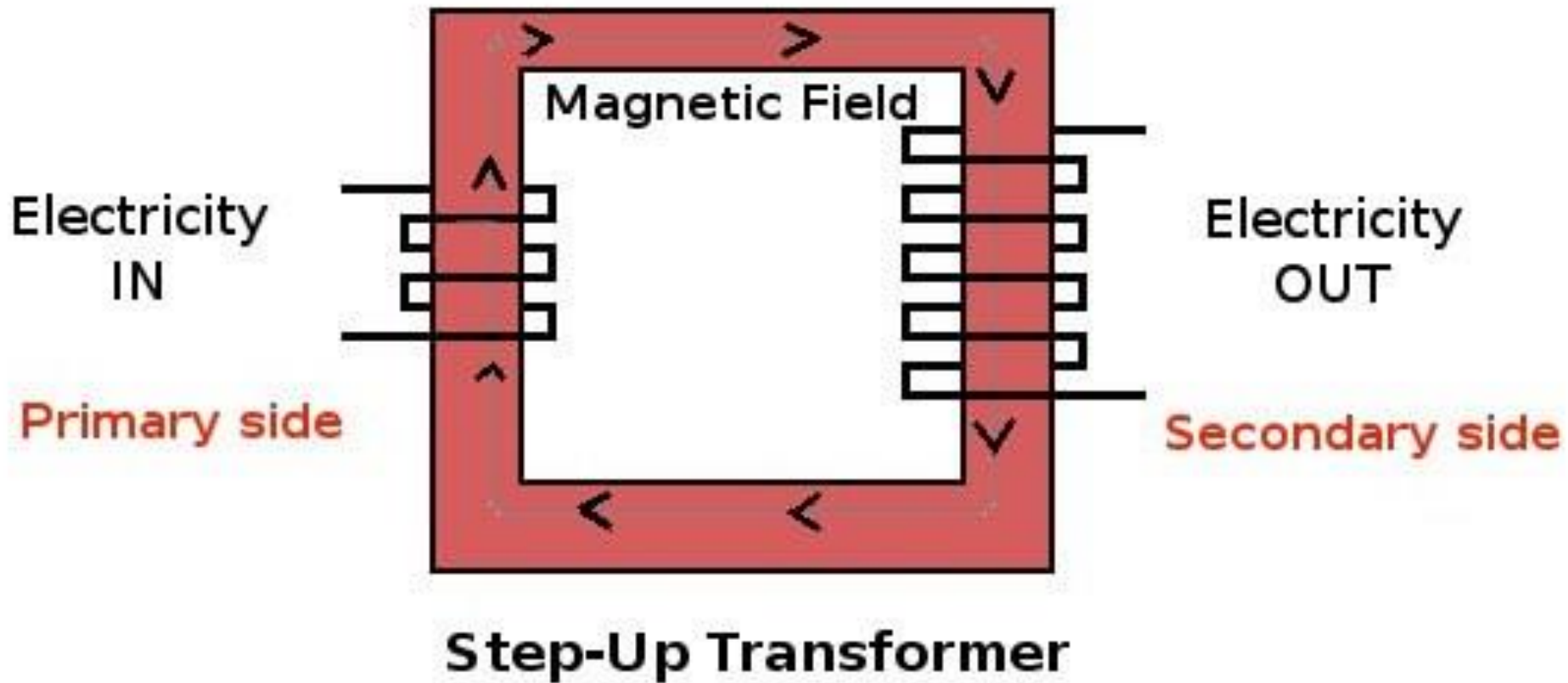


# Why AC?

Especially given that DC  
was first!



# Easy & cheap transformation



- 1. Transmission lines limits** ✓
- 2. Dispatch** ✓
- 3. Frequency and synchronicity** ✓
- 4. Transmission shortage in the EU**

SWITZERLAND

# Interconnectors very high loaded at night!



Line of separation from the European grid

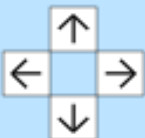
**03:26**



## The future of the EU transmission network

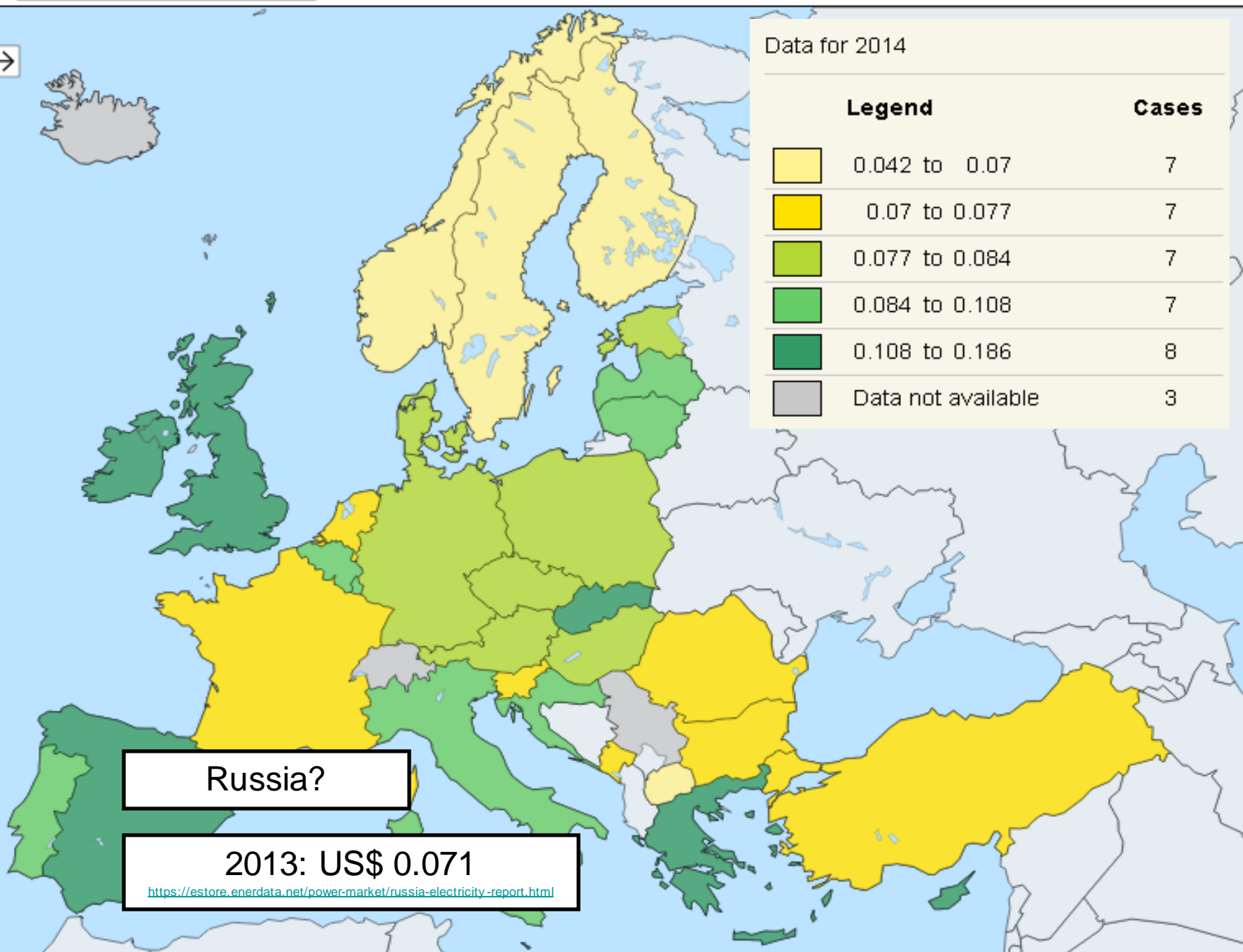


Internal EU market induces increase  
in cross-border trading



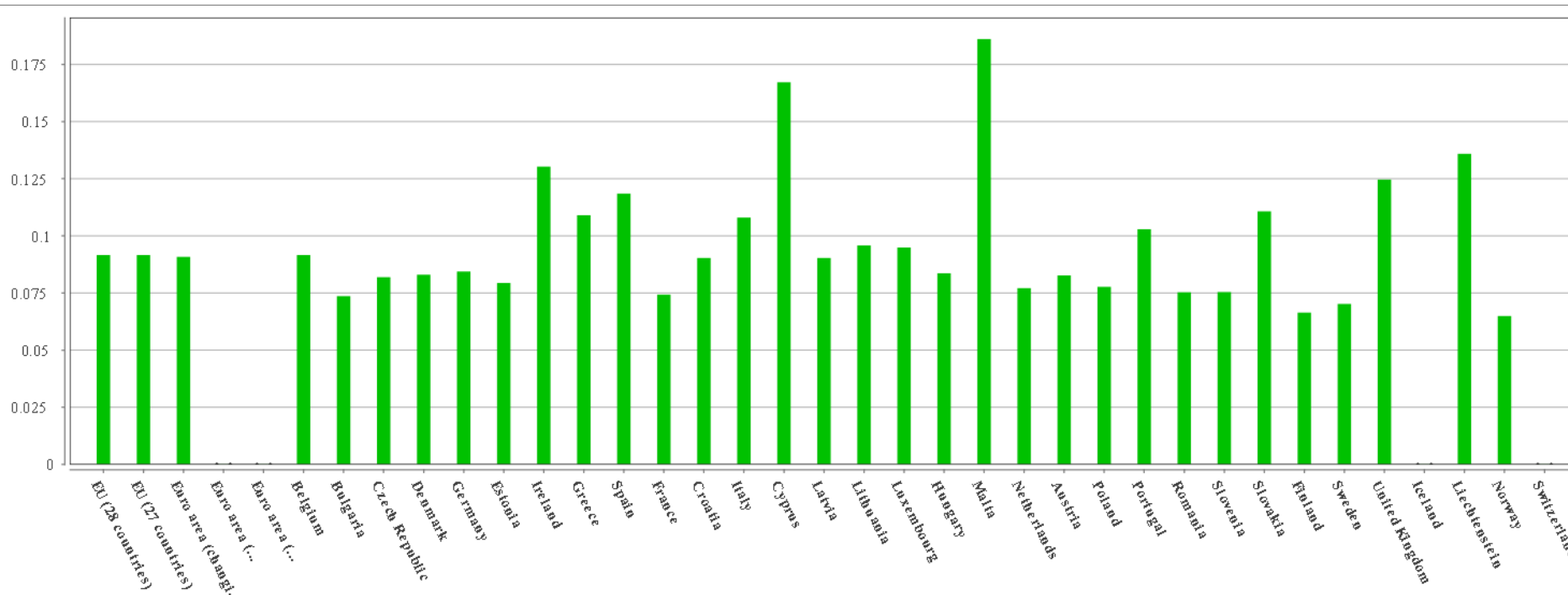
Data for 2014

Legend	Cases
0.042 to 0.07	7
0.07 to 0.077	7
0.077 to 0.084	7
0.084 to 0.108	7
0.108 to 0.186	8
Data not available	3

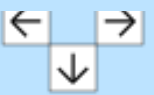


Russia?

2013: US\$ 0.071  
<https://estore.enerdata.net/power-market/russia-electricity-report.html>



Medium size households ▾



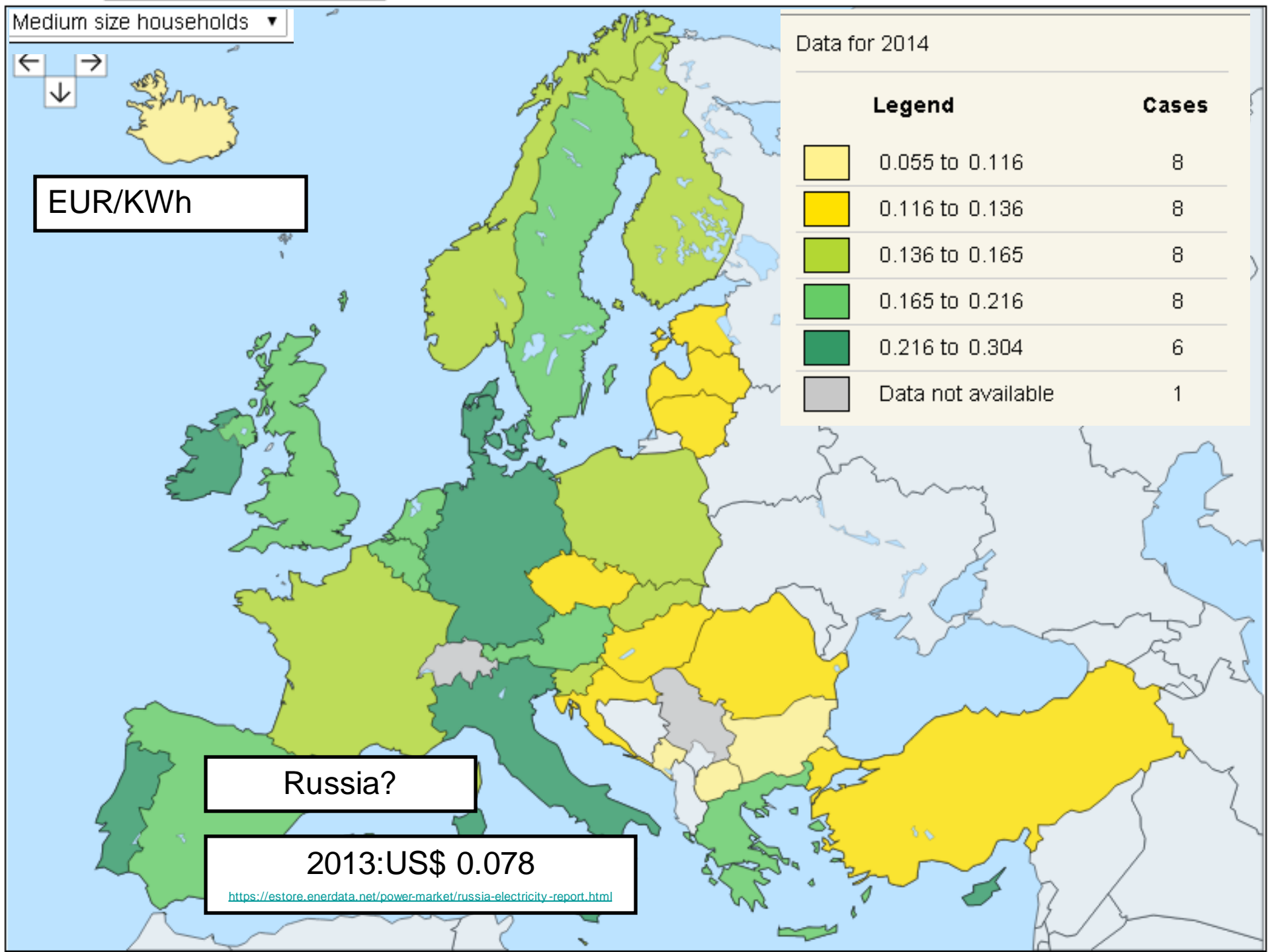
EUR/KWh

Data for 2014

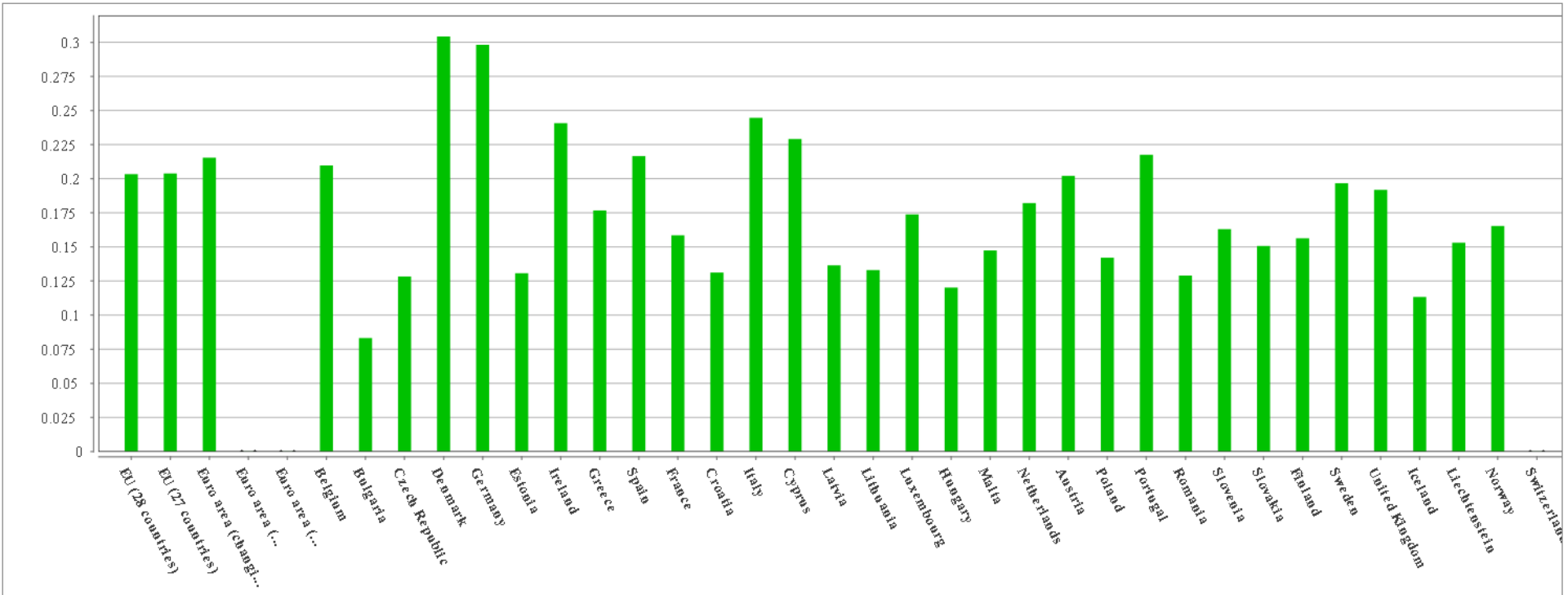
Legend		Cases
	0.055 to 0.116	8
	0.116 to 0.136	8
	0.136 to 0.165	8
	0.165 to 0.216	8
	0.216 to 0.304	6
	Data not available	1

Russia?

2013:US\$ 0.078  
<https://estore.enerdata.net/power-market/russia-electricity-report.html>

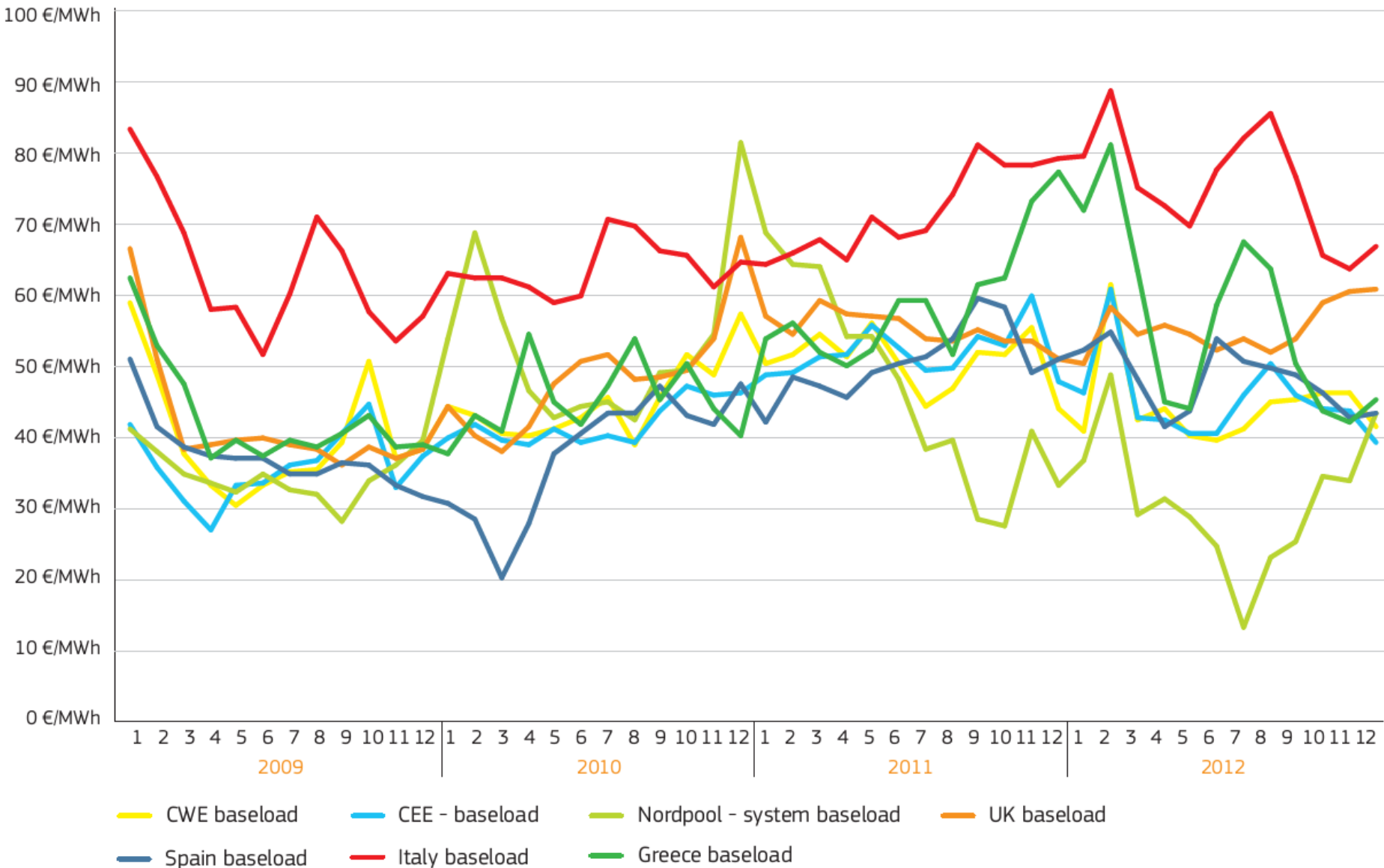








**FIGURE 9 - COMPARISONS OF MONTHLY ELECTRICITY BASELOAD PRICES IN REGIONAL ELECTRICITY MARKETS**





Massive deployment of wind and solar energy

What new renewable resource is most prevalent presently in Germany?





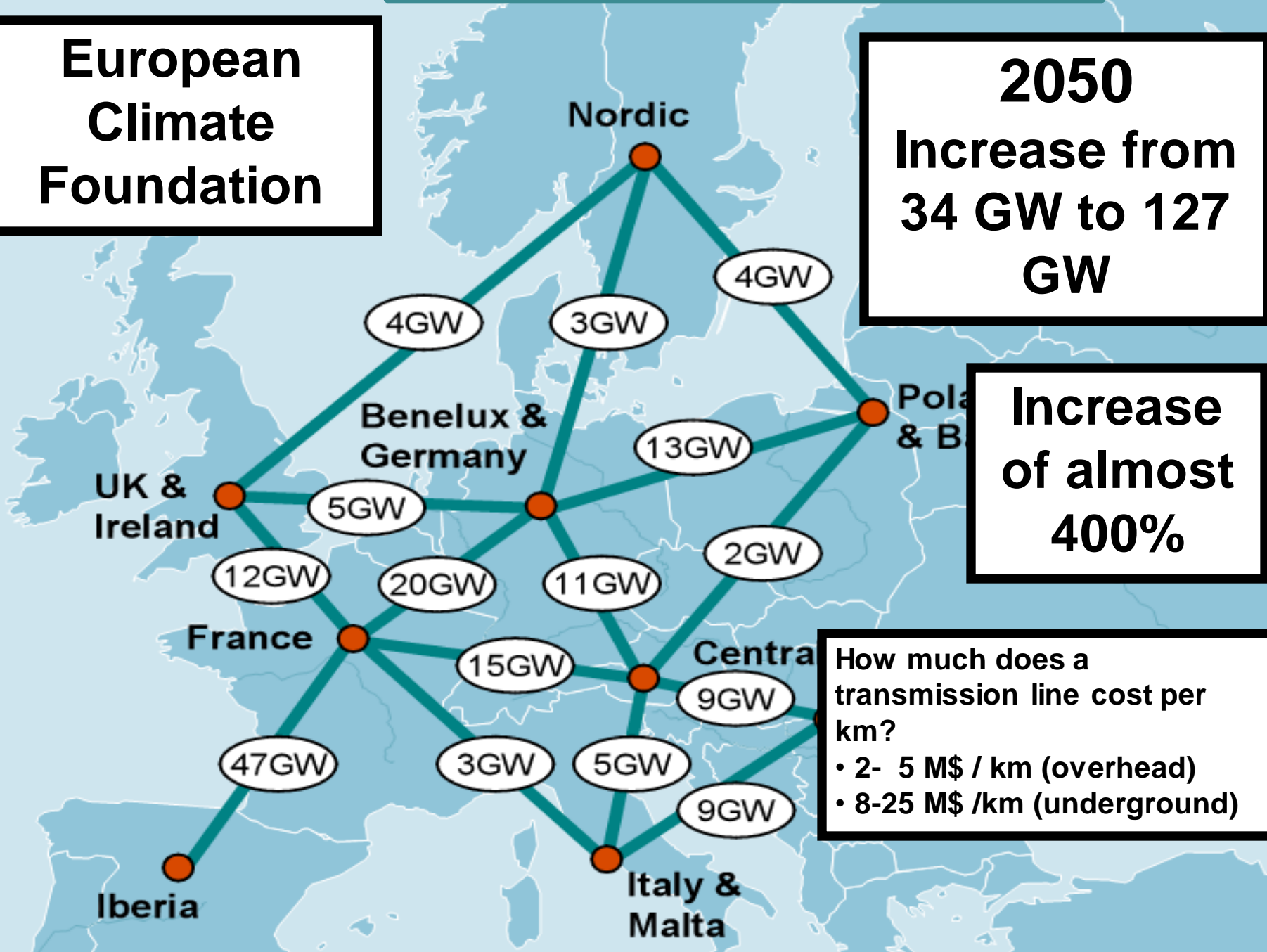
# The future of the EU transmission network

European  
Climate  
Foundation

**2050**  
Increase from  
34 GW to 127  
GW

Increase  
of almost  
400%

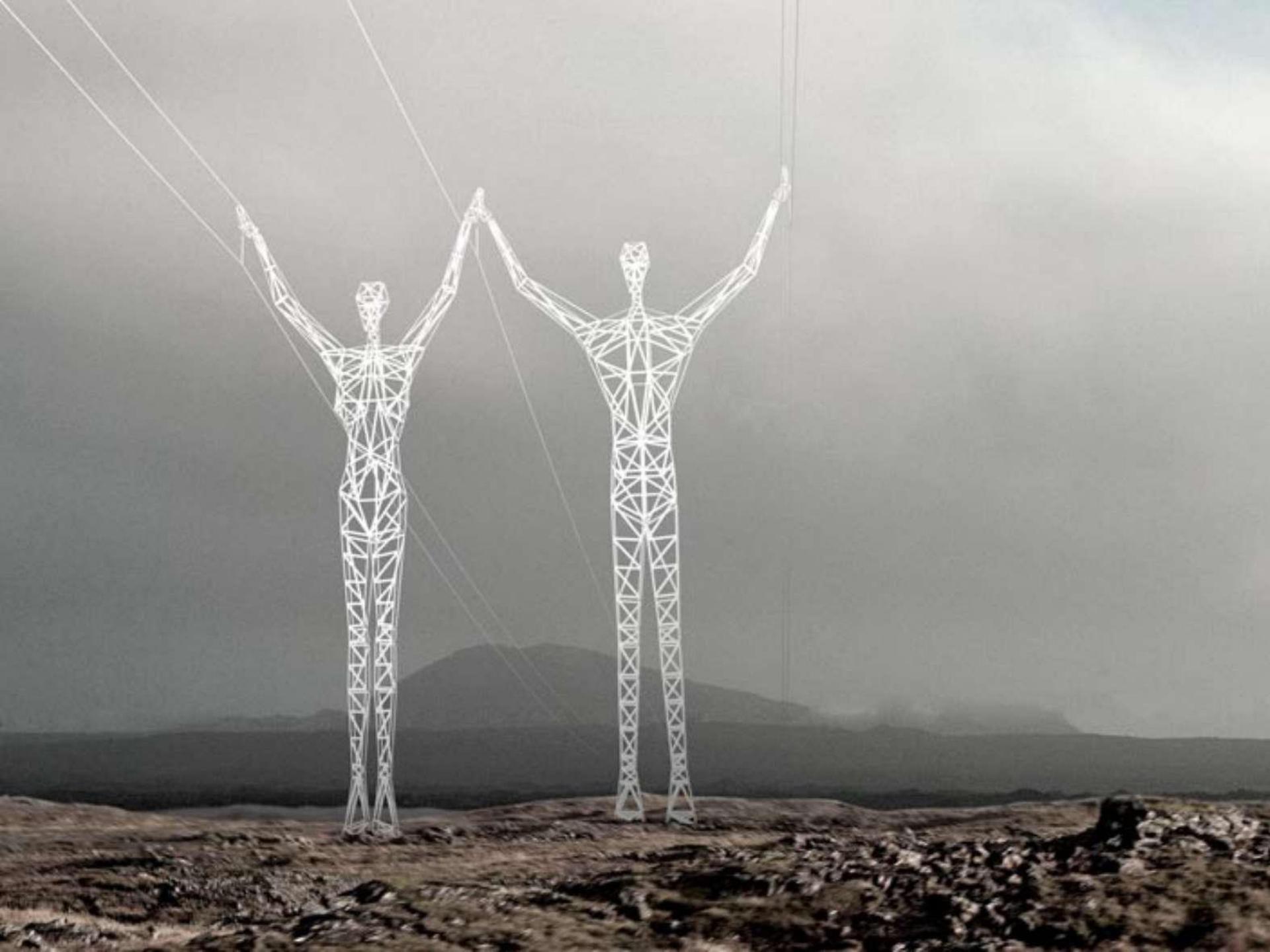
How much does a  
transmission line cost per  
km?  
• 2- 5 M\$ / km (overhead)  
• 8-25 M\$ /km (underground)



- Resistance against transmission



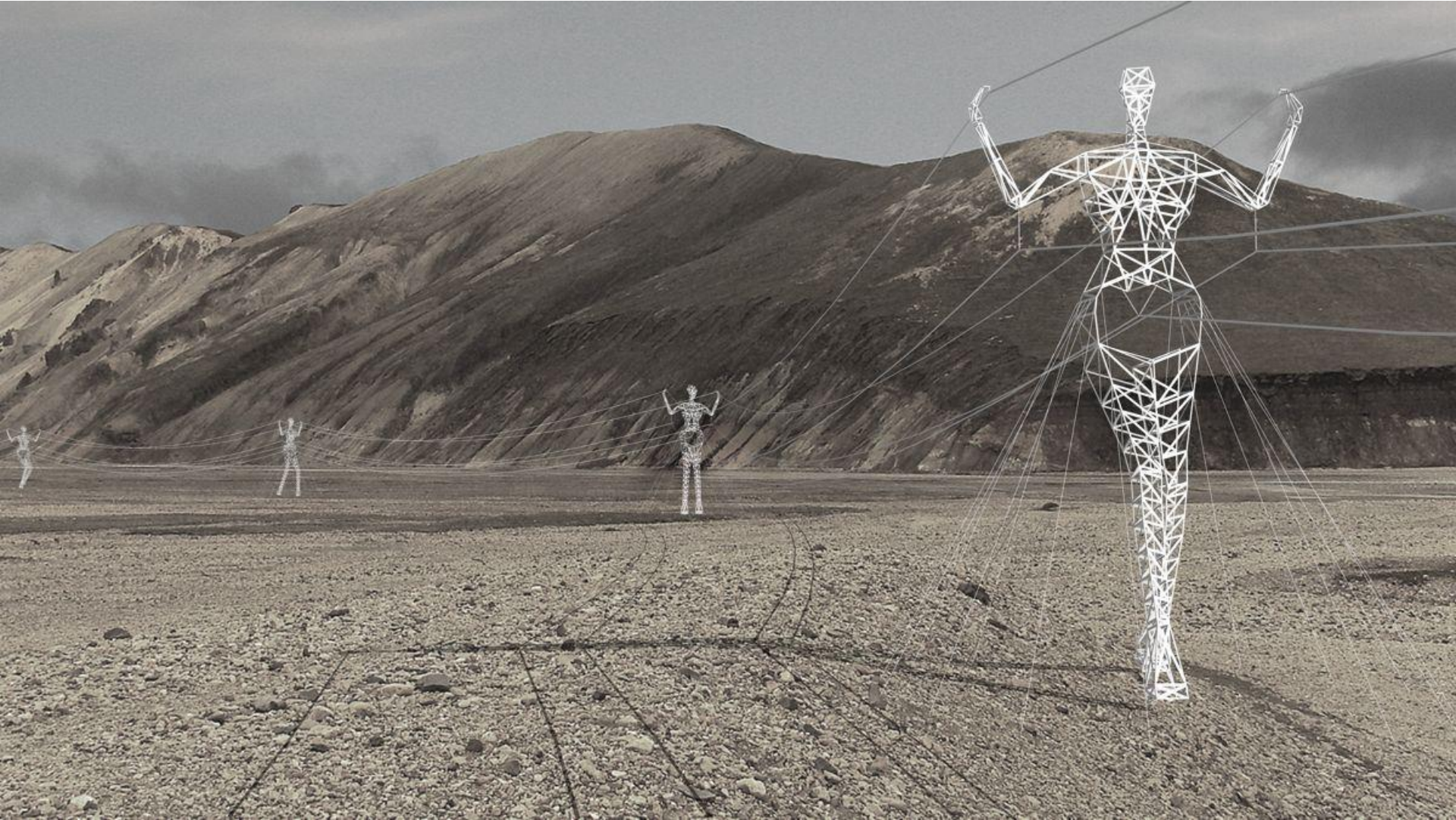






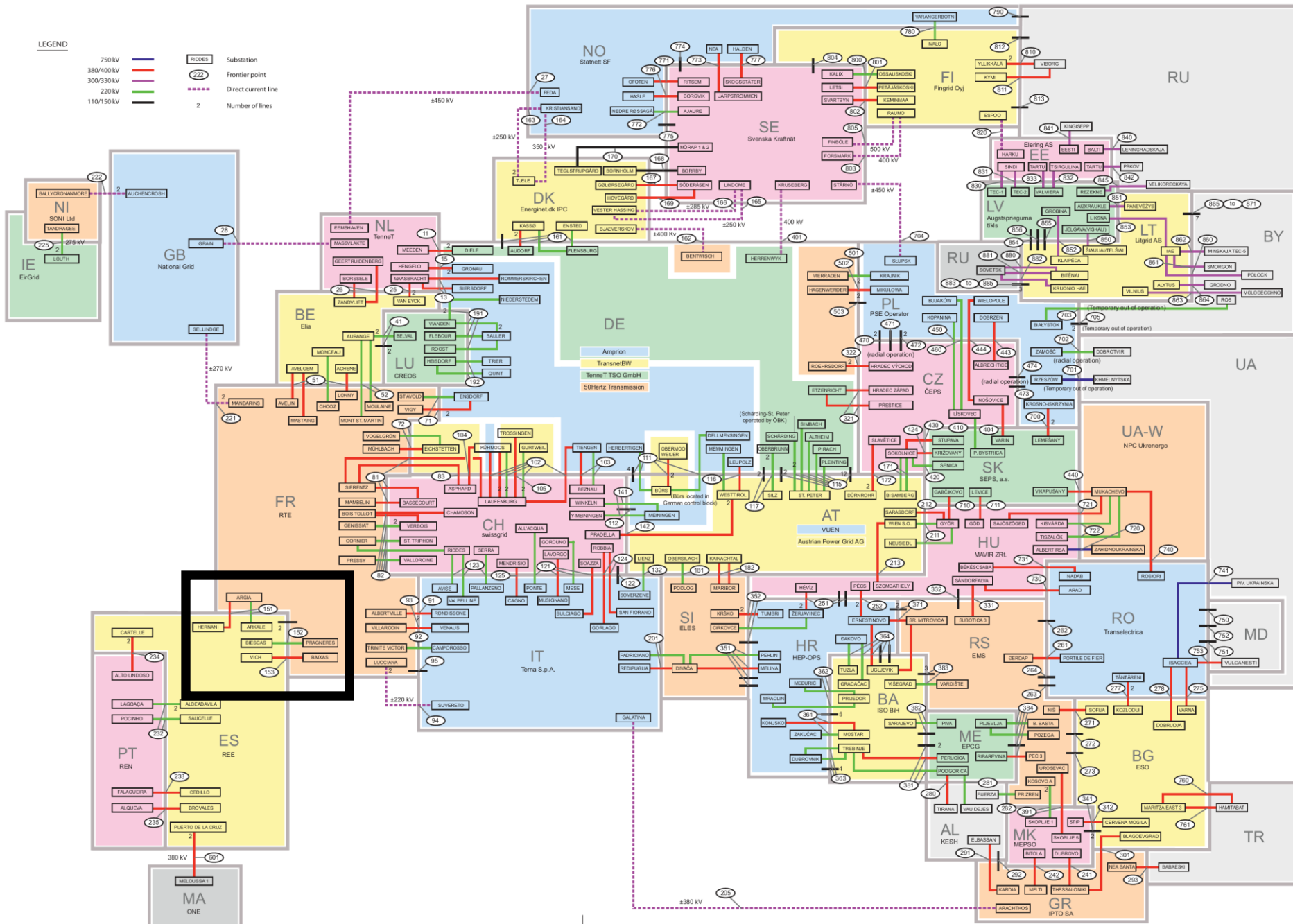











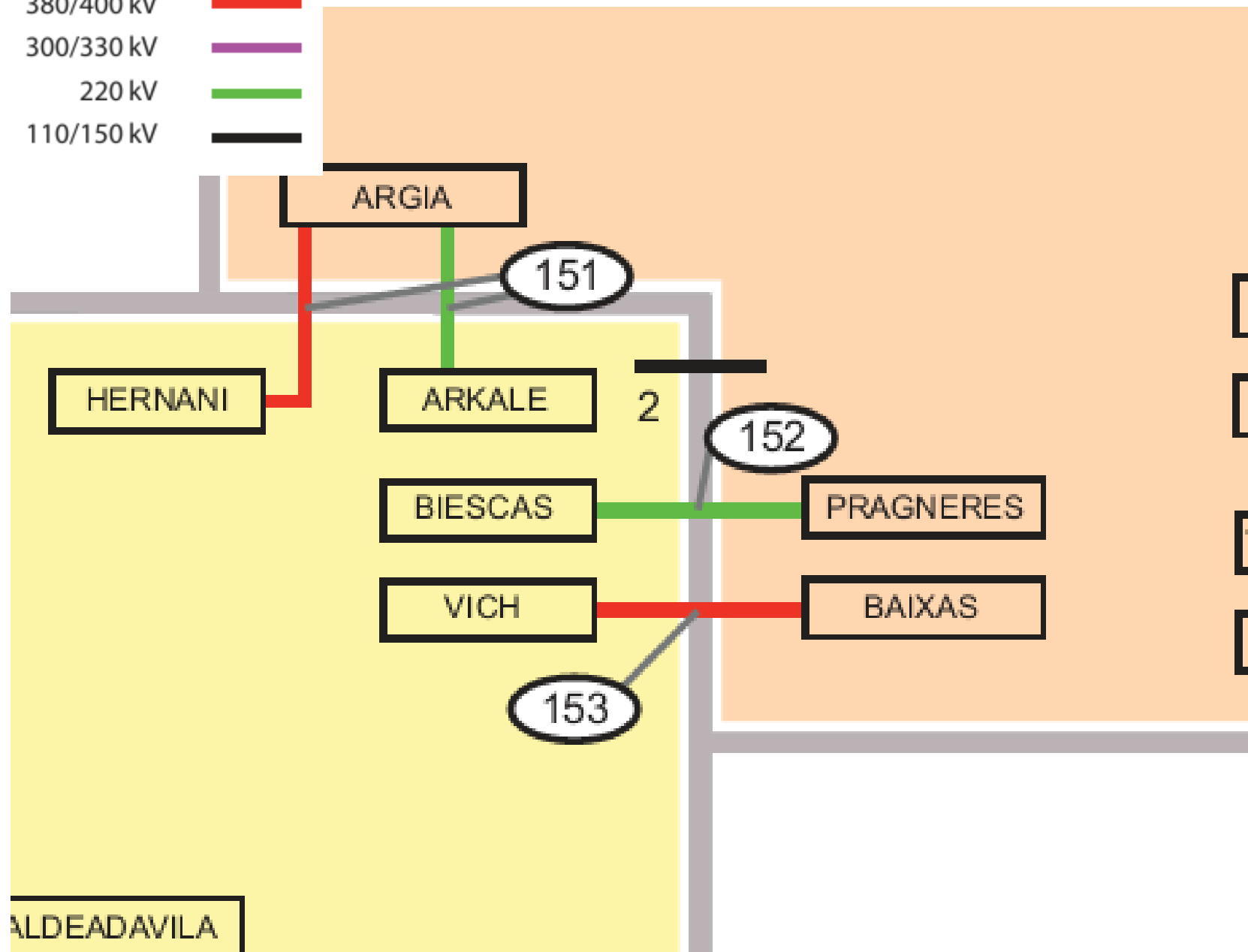
LEGEND

- 750 kV (Blue line)
  - 380/400 kV (Red line)
  - 300/330 kV (Purple line)
  - 220 kV (Green line)
  - 110/150 kV (Black line)
  - 2 (Number of lines)
- |       |                     |
|-------|---------------------|
| ROZES | Substation          |
| 222   | Frontier point      |
| ---   | Direct current line |









# LEGEND


- 750 kV 
- 380/400 kV 
- 300/330 kV 
- 220 kV 
- 110/150 kV 









### DESERTEC-EUMENA

	Concentrating Solar Power		Hydro
	Photovoltaics		Biomass
	Wind		Geothermal



### CSP collector areas for electricity

	World 2005
	EU-25 2005
	MENA 2005
	TRANS-CSP Mix EUMENA 2050









**Sils-Soazza**

**Tree  
flashover!**

**“Cross-border  
transmission lines”**

**Mettlen-  
Lavorgo**

**“Interconnectors”**

**03:01**

- 1. Transmission lines limits** ✓
- 2. Dispatch** ✓
- 3. Frequency and synchronicity** ✓
- 4. Transmission shortage in the EU** ✓



**September 28<sup>th</sup>, 2003**

**Huge blackout cripples Italy!**



# Transmission



**1. Transmission lines limits** ✓

**2. Dispatch** ✓

- Meshed networks

**3. Frequency and synchronicity** ✓

**4. Transmission shortage in the EU** ✓



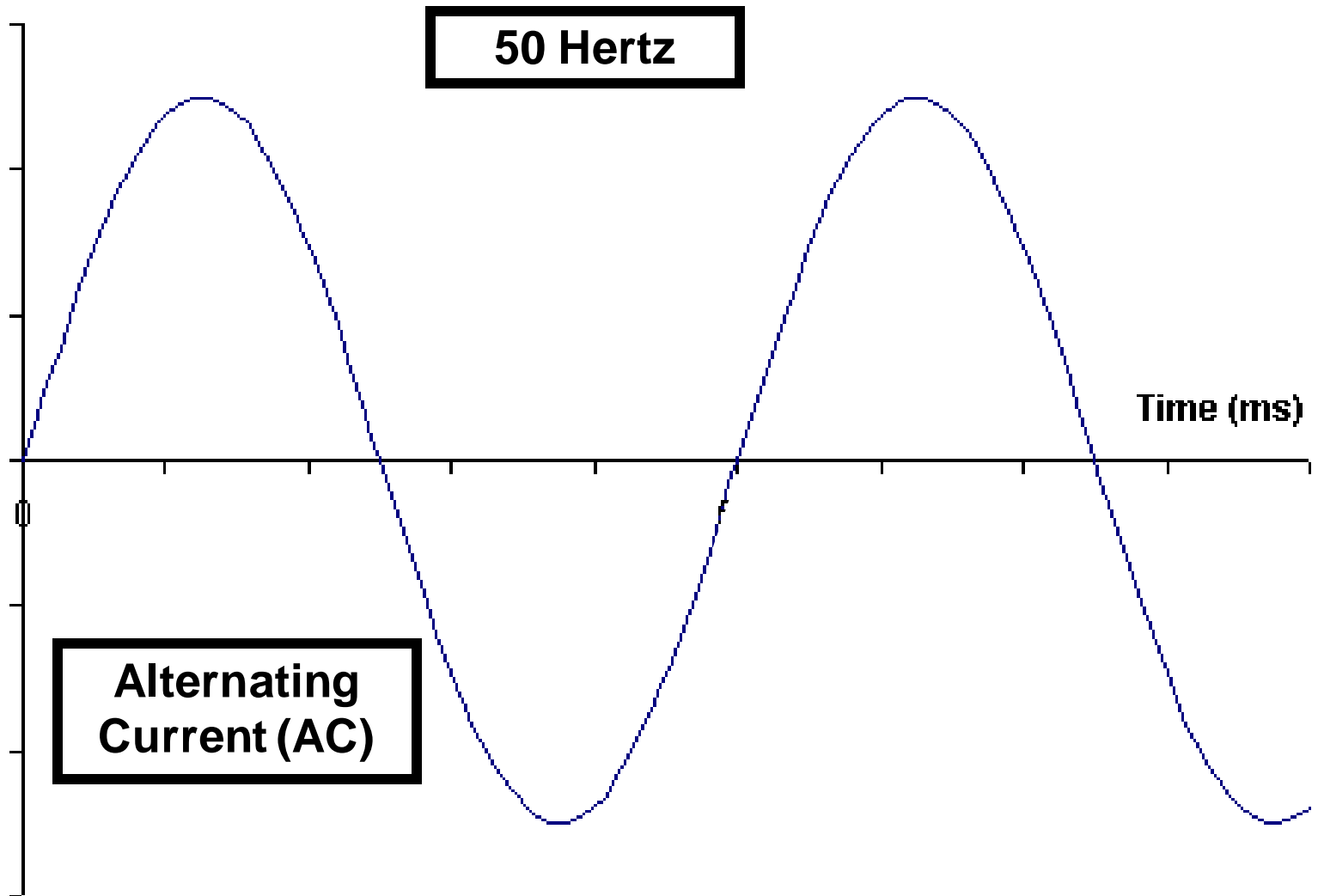
- *Final Report of the Investigation  
Committee on the 28 September 2003  
Blackout in Italy*  
[Final Report](#)
- ([https://www.entsoe.eu/fileadmin/user\\_upload/\\_library/publications/ce/otherreports/20040427\\_UCTE\\_IC\\_Final\\_report.pdf](https://www.entsoe.eu/fileadmin/user_upload/_library/publications/ce/otherreports/20040427_UCTE_IC_Final_report.pdf))

- Additional topics
  - Reactive power
  - Commercial flows versus actual flows

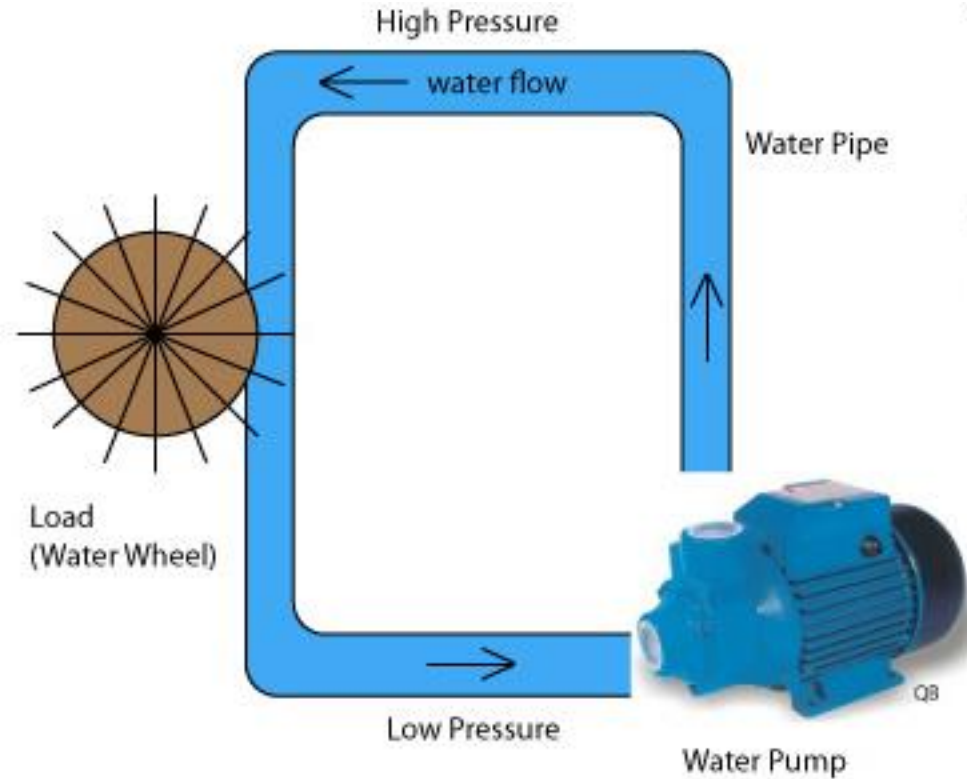
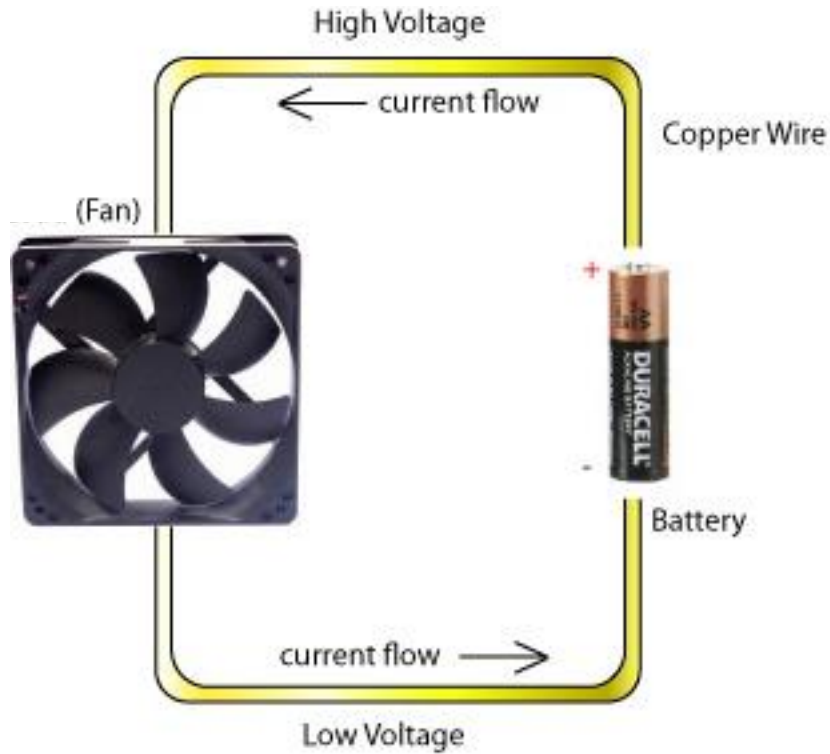
- Reactive power



# Frequency and Synchronicity



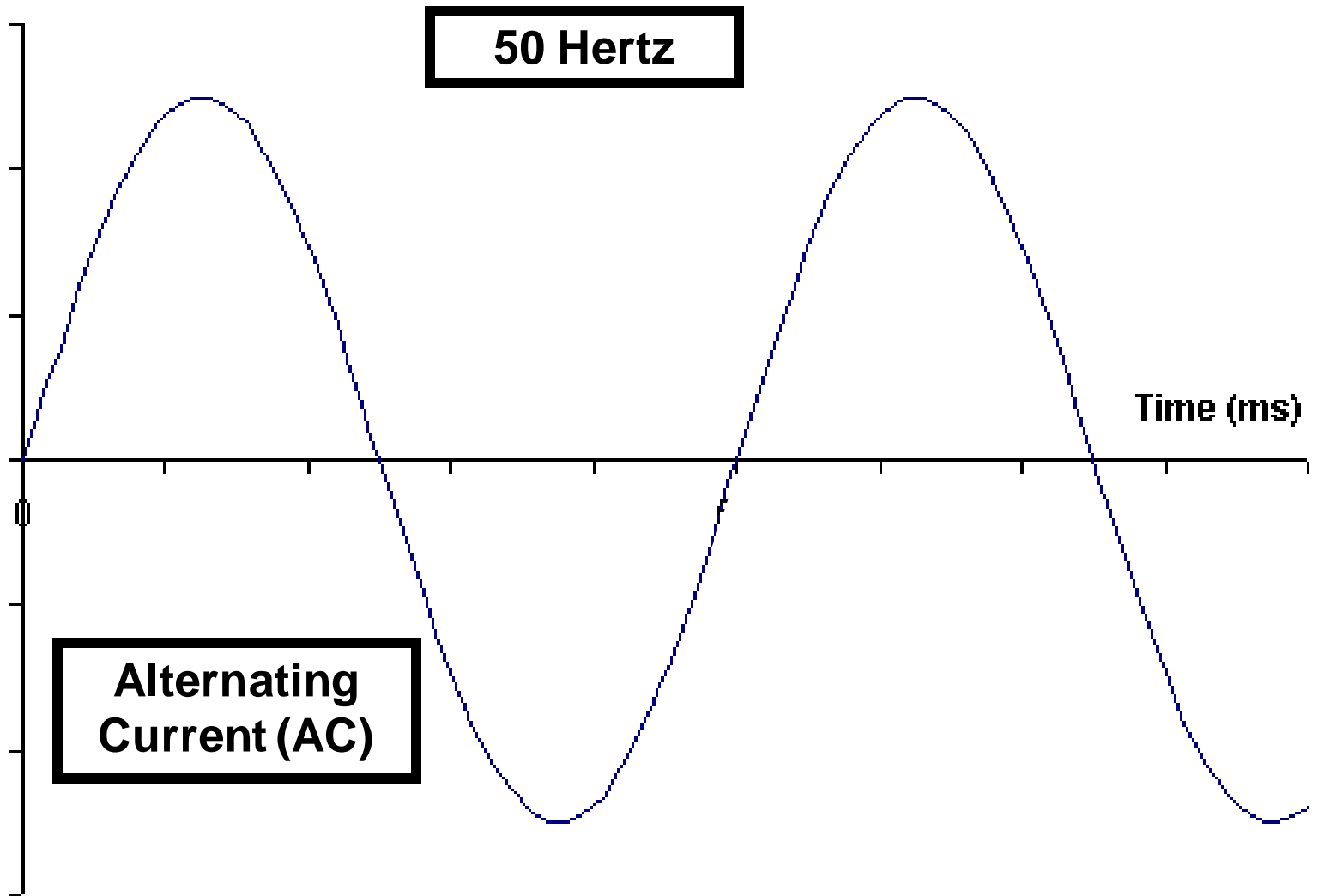
# Frequency and Synchronicity



**Direct Current (DC)**

**Alternating Current (AC)**

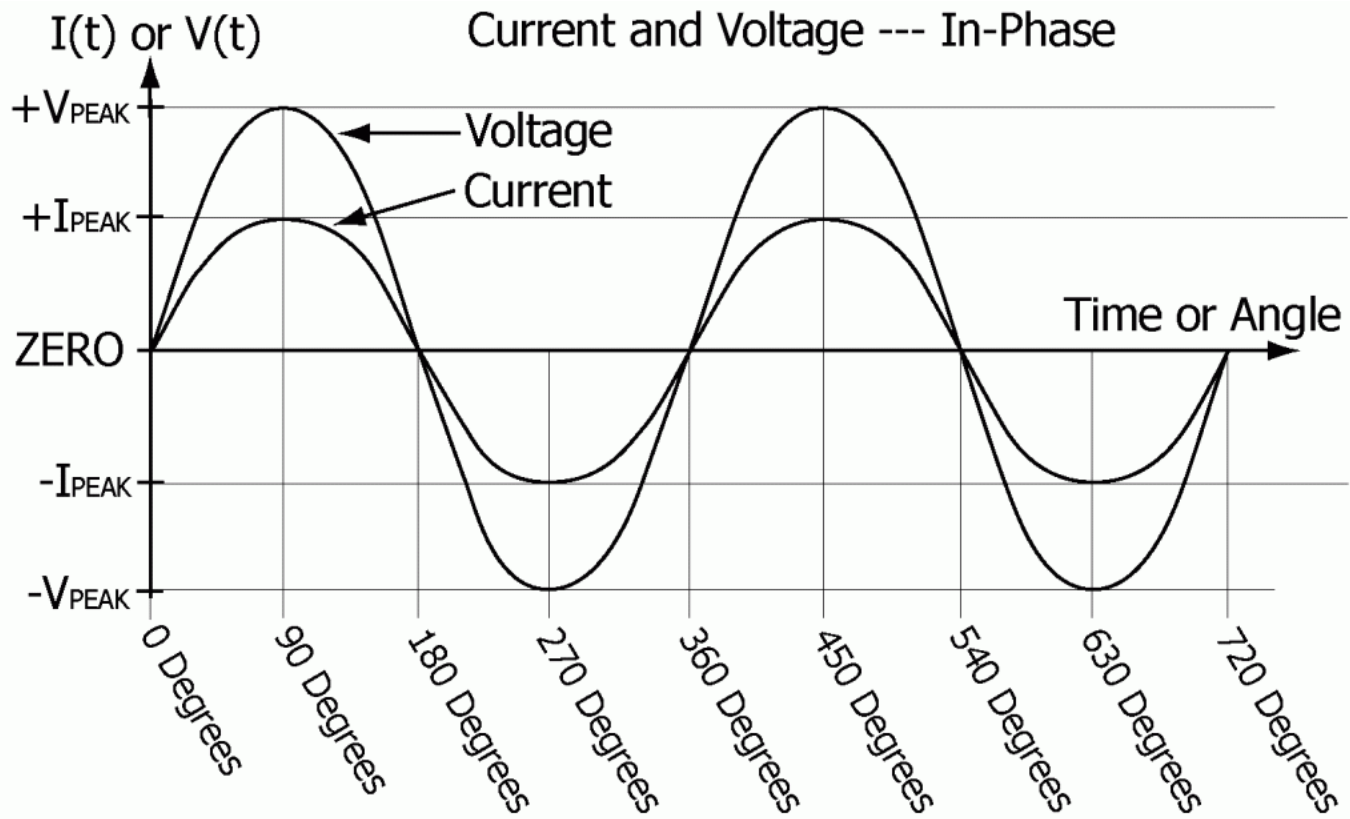
# Frequency and Synchronicity



**50 Hertz**

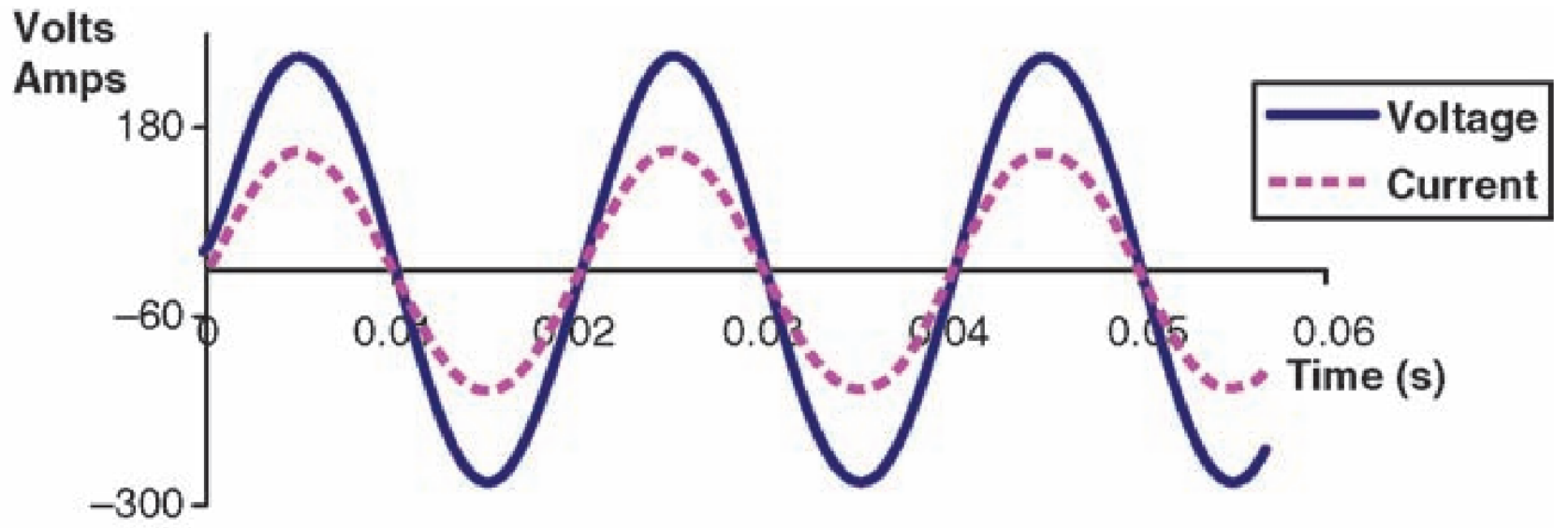
**Time (ms)**

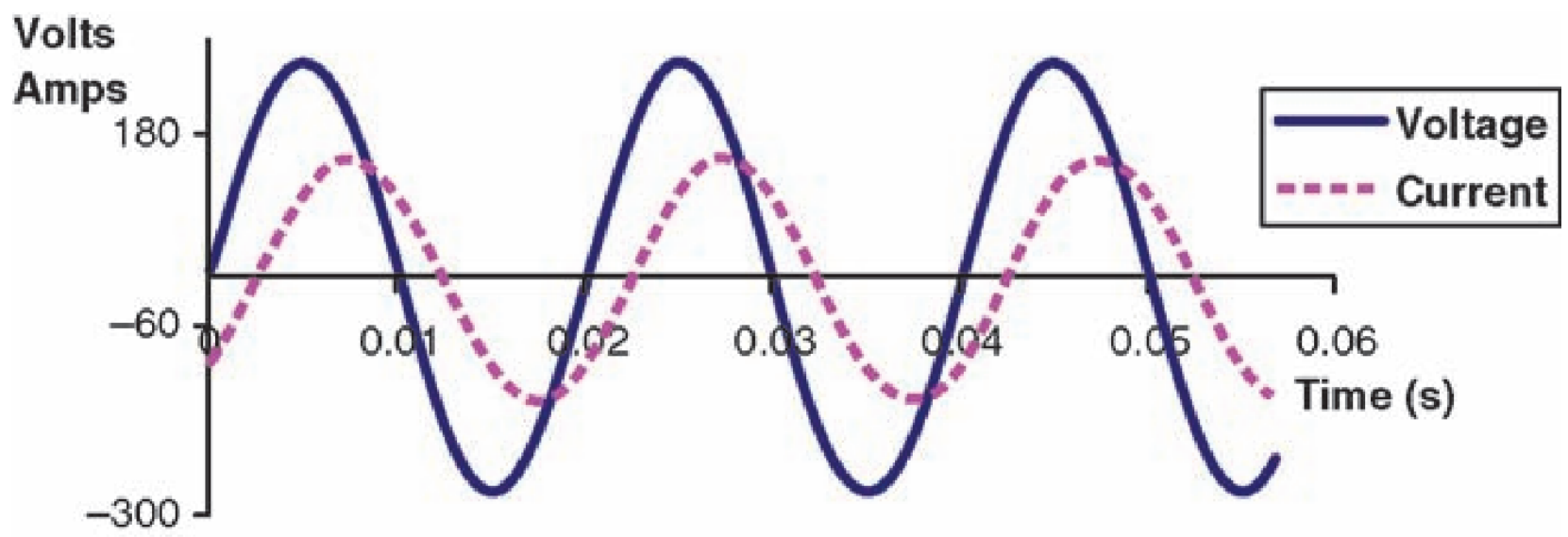
**Alternating  
Current (AC)**

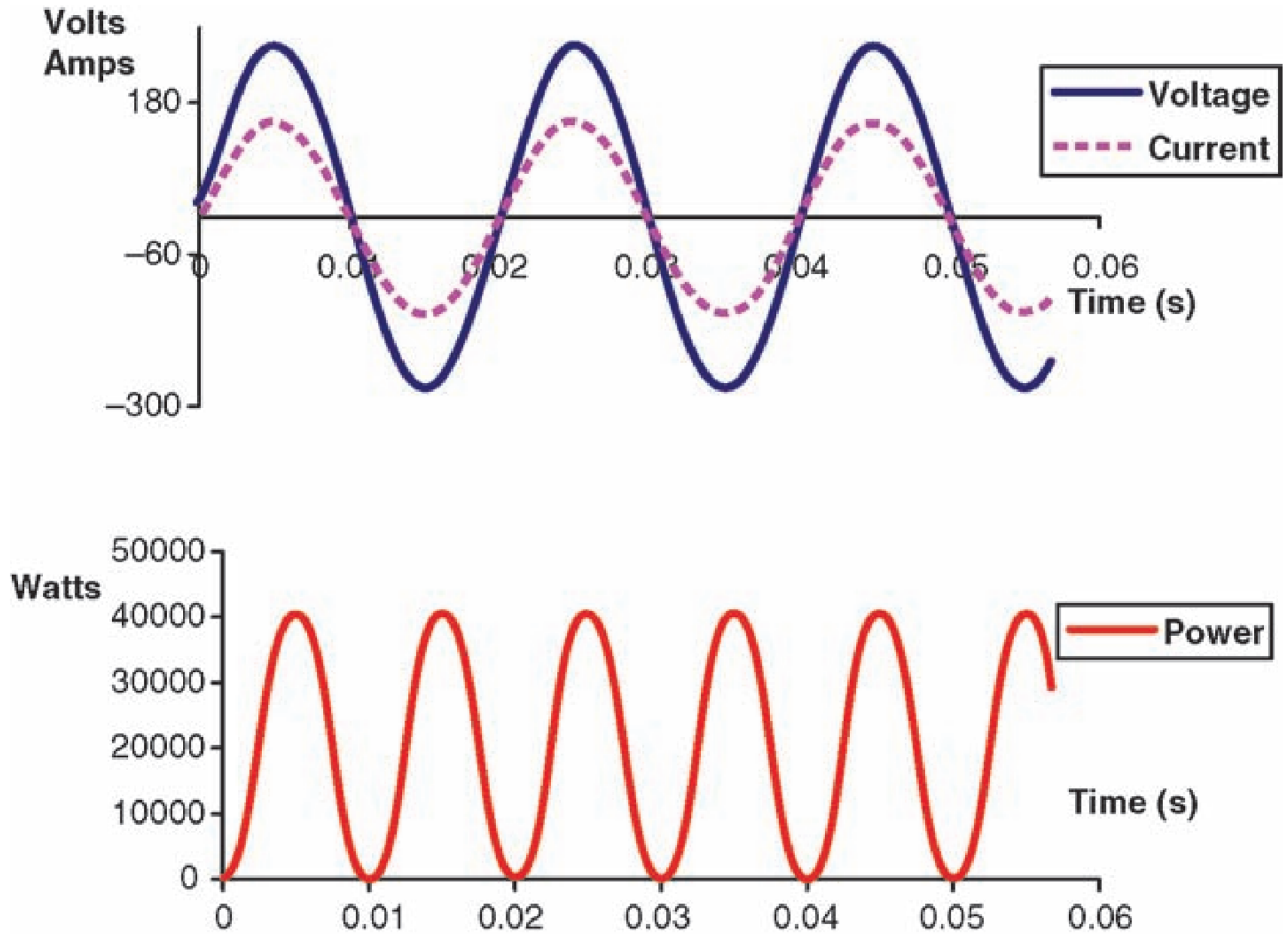


Out of phase possible?

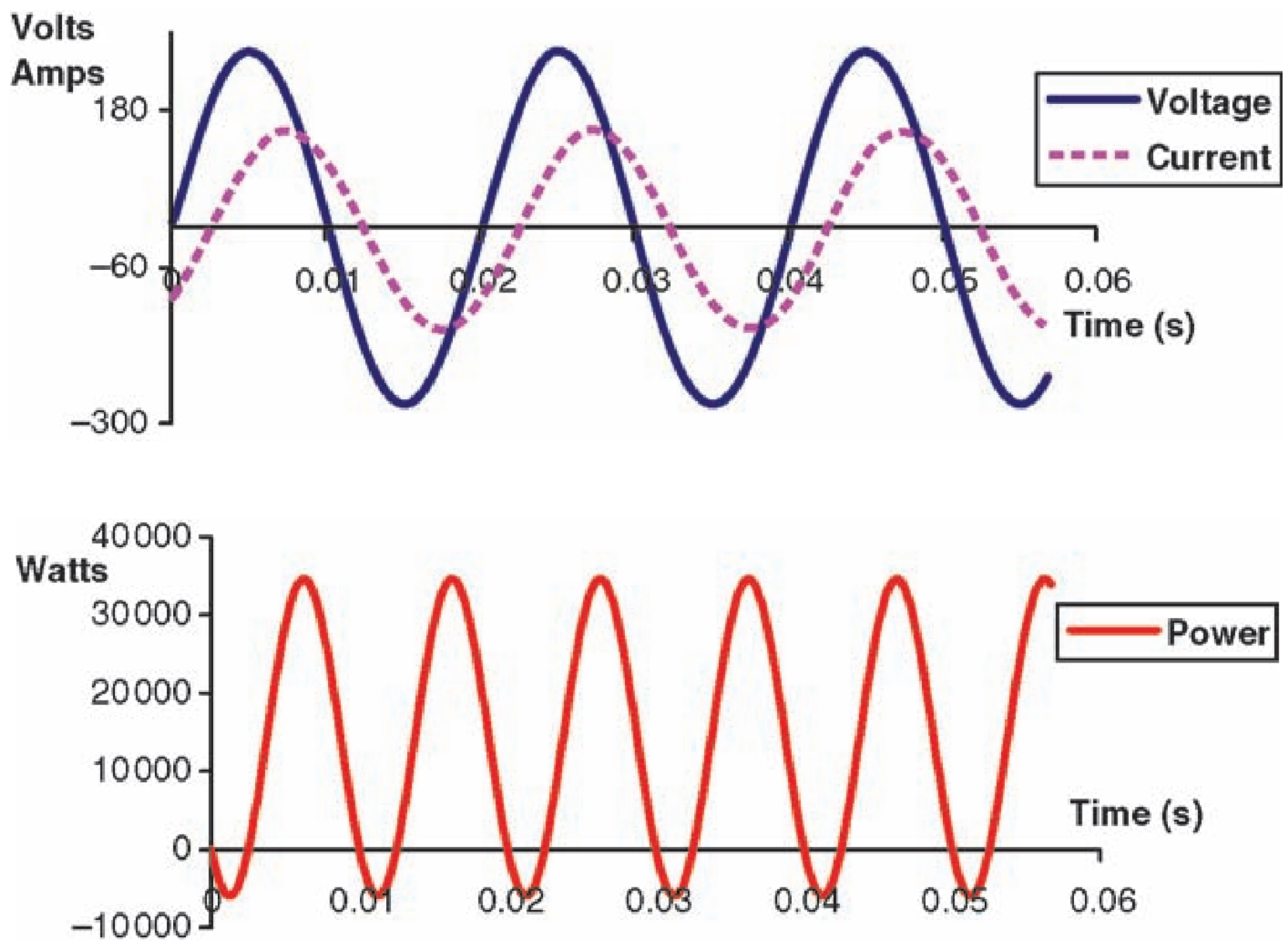








**Figure 2.7** An AC network with voltage and current perfectly in phase



**Figure 2.8** An AC network with current leading voltage by  $45^\circ$



## Out of phase possible?

- Yes, loads can be inductive (mostly) or capacitive
- Inductive: lags current relative to voltage (shifts current leftwards)
- Capacitive: lags voltage relative to current (shifts voltage leftwards)
- Need to restore this is called a need for **reactive power**.
- Can be done by generators or devices (often capacitors)

- Many loads on the power system – especially large motors – consume reactive power.
- Distribution often require large customers to maintain a power factor close to one
  - to provide their own devices (usually capacitors) to offset the reactive power induced by their electrical equipment.

EE\_2015\_PhD - Goo... FNET/GridEye Server... fnetpublic.utk.edu/anglecontour.html

# FNET/GridEye Web Display

About FNET/GridEye | Table Display | Angle Contour Map | U.S. Frequency Gradient Map | World-Wide Frequency Map | Sample Events | Partners | Contact Us | Future Applications

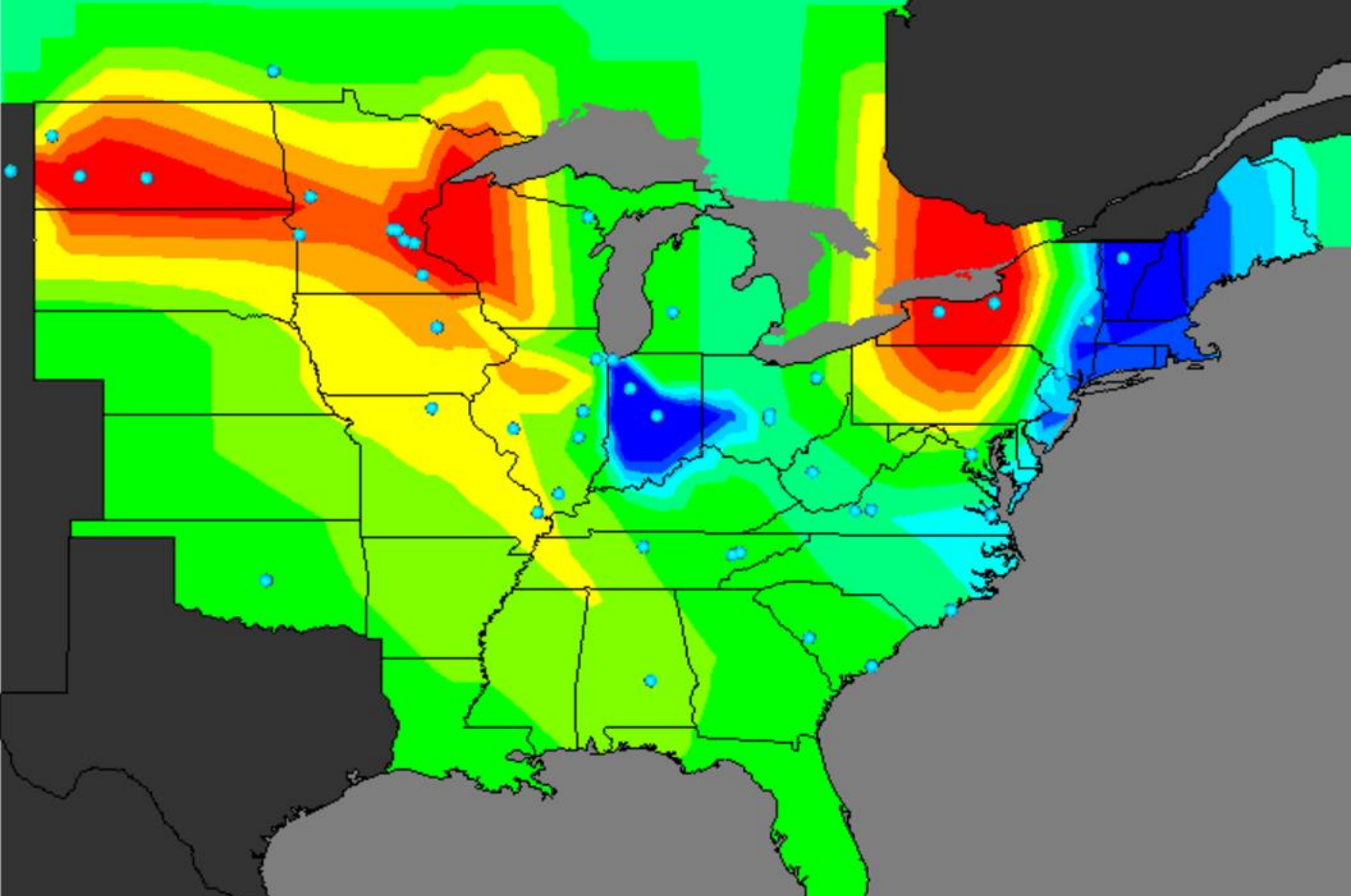
FNET Angle Contour Map  
2015/10/28 11:34:24.0 UTC Time

Ang(deg)  
-60.00 -30.00 0.00 30.00 60.00 90.00

Real-Time Angle Contour Map Developed by FNET

Start | ... | EN | 12:34 PM

- <http://fnetpublic.utk.edu/anglecontour.html>



FNET Angle Contour Map

2015/10/28 11:36:08.0 UTC Time



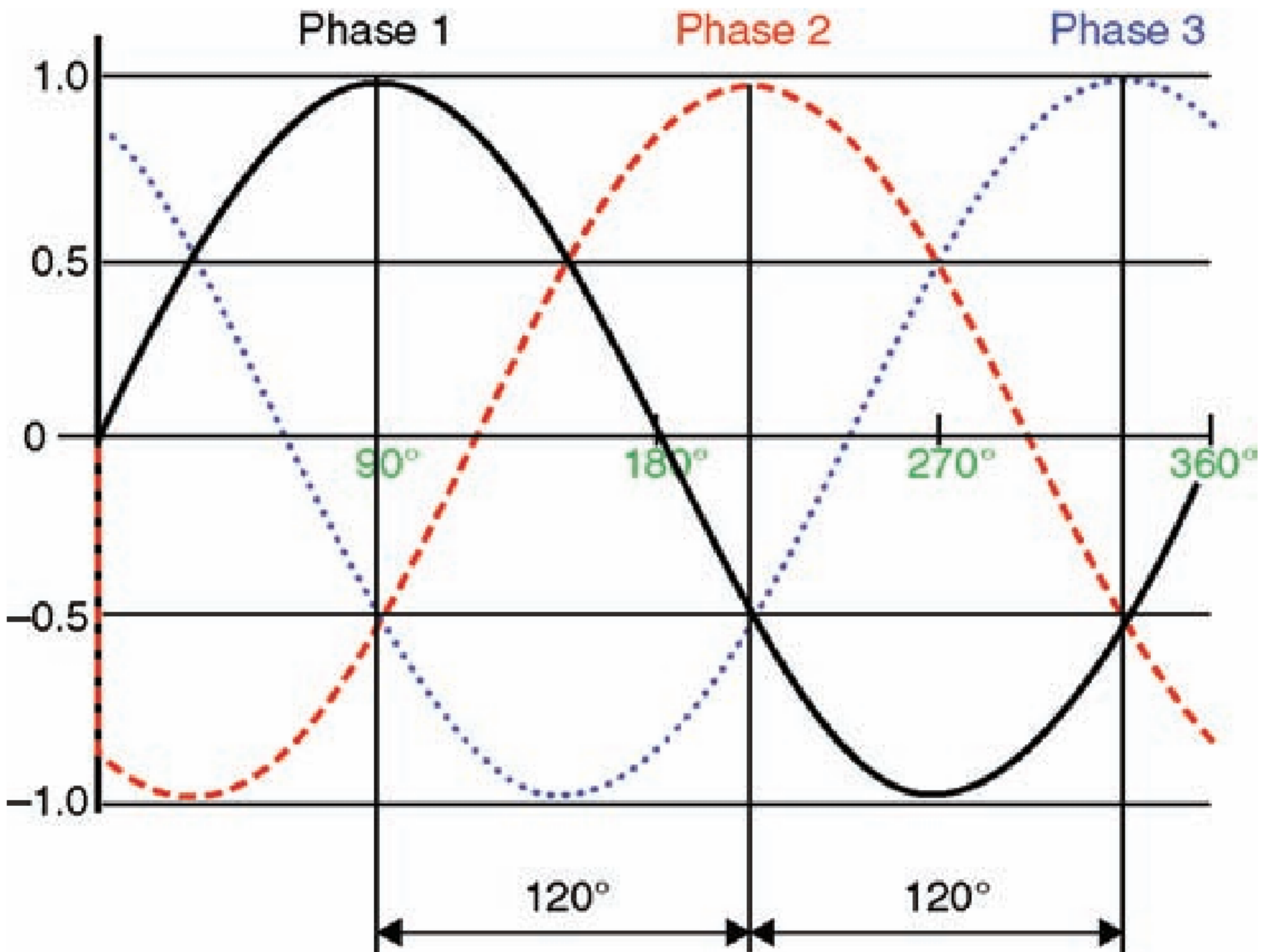


- **Why in “trinity” in transmission conductors?**







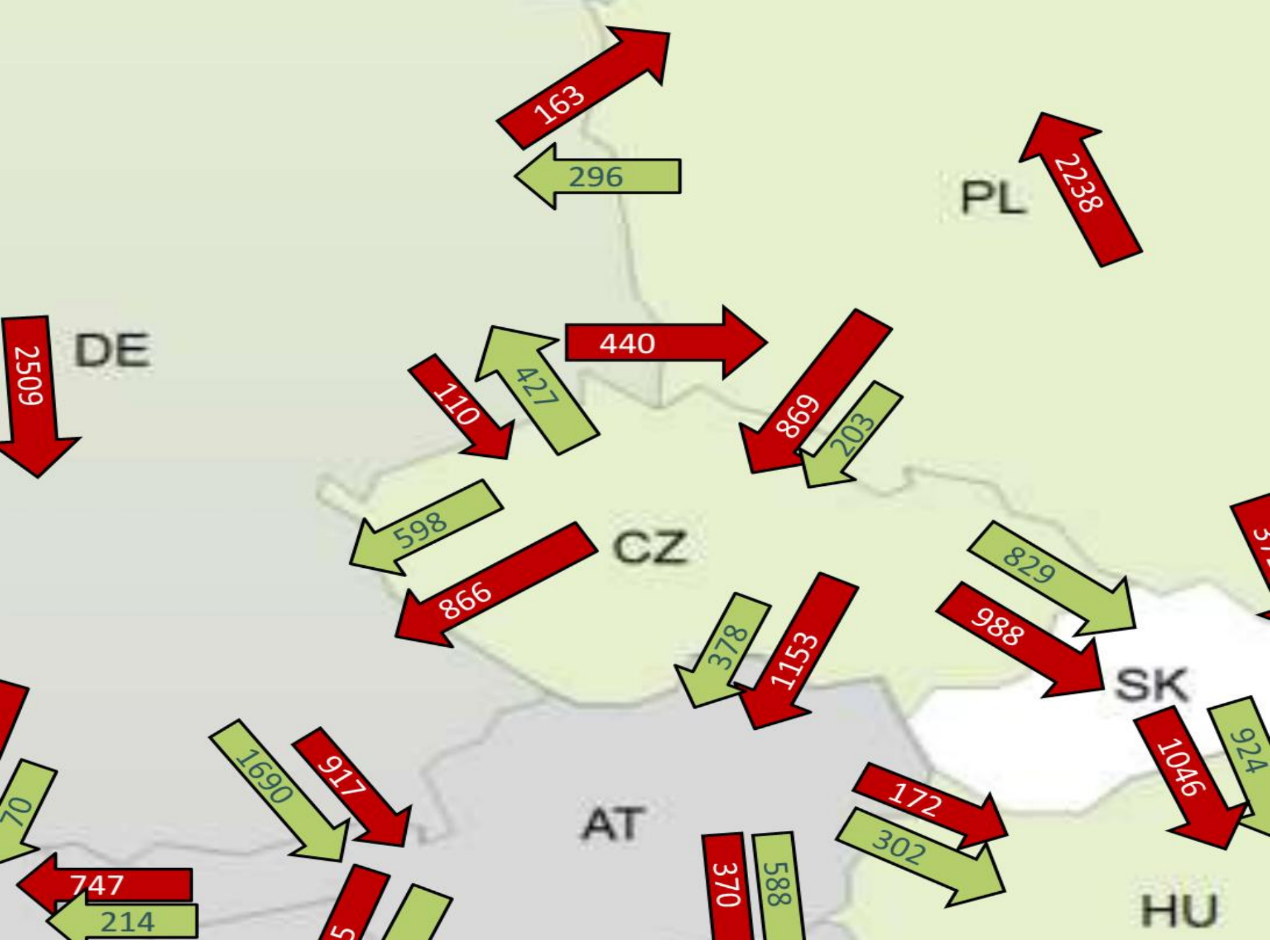




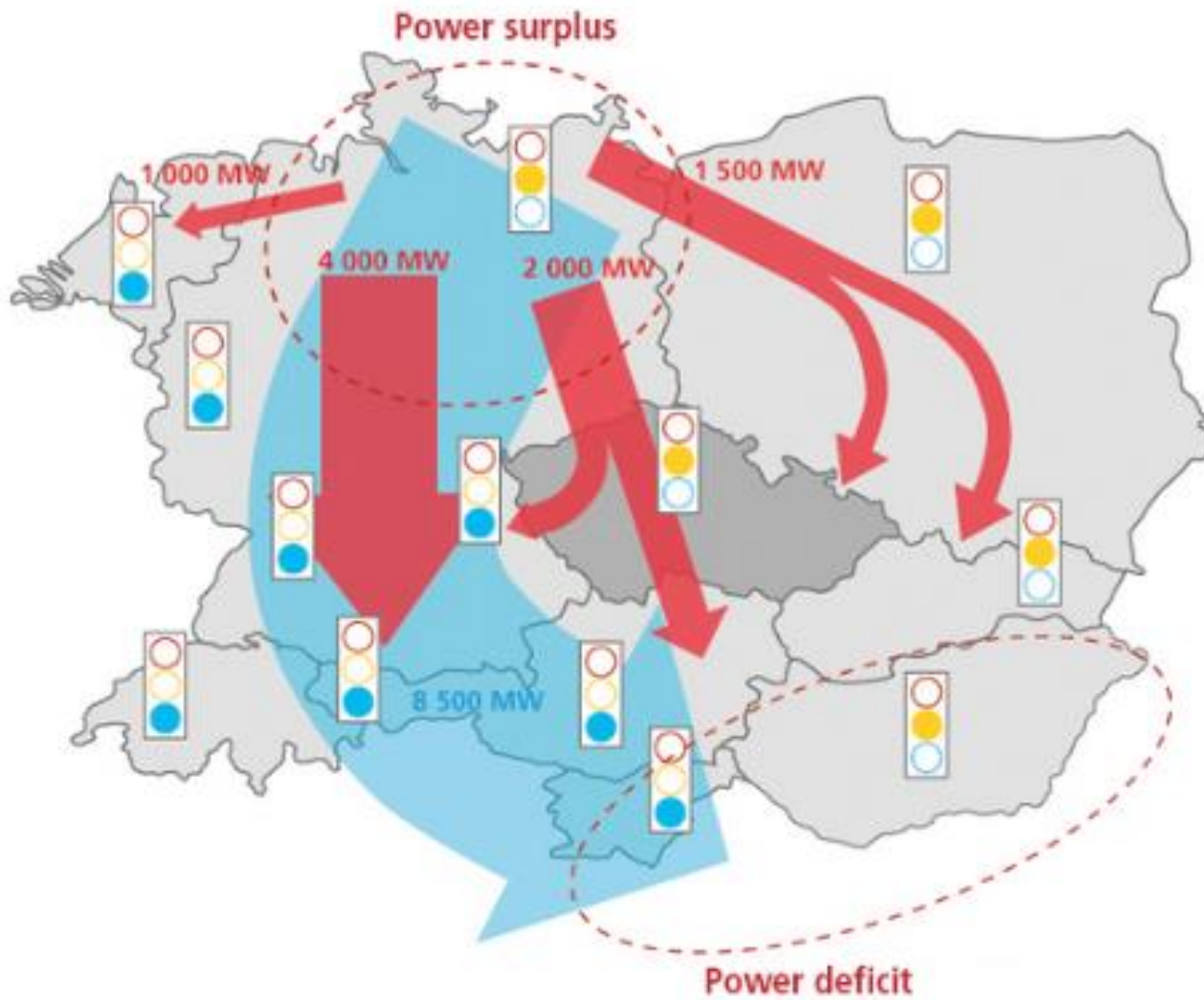
- We can achieve a constant power flow over time using three conductors carrying alternating currents that are exactly  $120^\circ$  out of phase with one another.

- Commercial flows versus actual flows









Source: CEPS (2014)



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Operační program Výzkum, vývoj a vzdělávání



MINISTERSTVO ŠKOLSTVÍ,  
MLÁDEŽE A TĚLOVÝCHOVY



EVROPSKÁ UNIE  
Evropské strukturální a investiční fondy  
Operační program Výzkum, vývoj a vzdělávání



## Národohospodářská fakulta VŠE v Praze



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