

Energy Economics and Environment

Lecture 1



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



MINISTERSTVO ŠKOLSTVÍ,
MLÁDEŽE A TĚLOVÝCHOVY

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- Materials on:

**[https://goo.gl/
QXuJWw](https://goo.gl/QXuJWw)**

- Slides, readings, some literature, homeworks

Lecture	
	A. The system
1 02.14	Fundamentals of electricity: The system 1 (Blackouts, physics and synchronicity)
2 02.21	Fundamentals of electricity: The system 2 (Physics and Present challenges)
	B. Peak-load pricing and Transmission
3 02.28	Basics of peak-load-pricing Transmission: Investment and Pricing 1
4 03.07	Transmission: Investment and Pricing 2
	C. Generation
5 03.14	Fundamentals of electricity: Generation
	D. Peak-load pricing and Generation
6 03.21	Generation: Investment and Pricing

Lecture	
7 03.28	Generation: Investment and Pricing - Interactive session in the lab RB337 (lee-vse.cz)
8 04.04	Generation: optimal investment, screen curves, load duration curve
9 04.11	Missing money & capacity payments and subsidies
	E. Exchange Market Trading and Power Trading
10 04.25	Trading: Interactive session in the lab RB337 (lee-vse.cz)
	F. Climate policy for electricity
11 05.02	Renewable energy sources: - costs & benefits - the costs of intermittency - LCOE and its drawbacks - the utility dead-spiral
12 05.09	- The Green paradox - Disasters, myths and miracles

The electrical system 1

Transmission

Literature for today

- Shively Ch.1, 2, 5, 6, 7.
- Biggar Ch. 2
- *MIT: Appendix B*

















Power plants



A man in a dark suit and light-colored tie is standing outdoors next to a white electric vehicle charging station. He is holding a white card in his right hand, which is positioned near the charging port. The charging station has two charging ports with red cables. In the background, there is a building with a corrugated metal roof and a window. The ground is covered with dry leaves and some snow. A woman in a brown coat is partially visible on the left side of the frame.

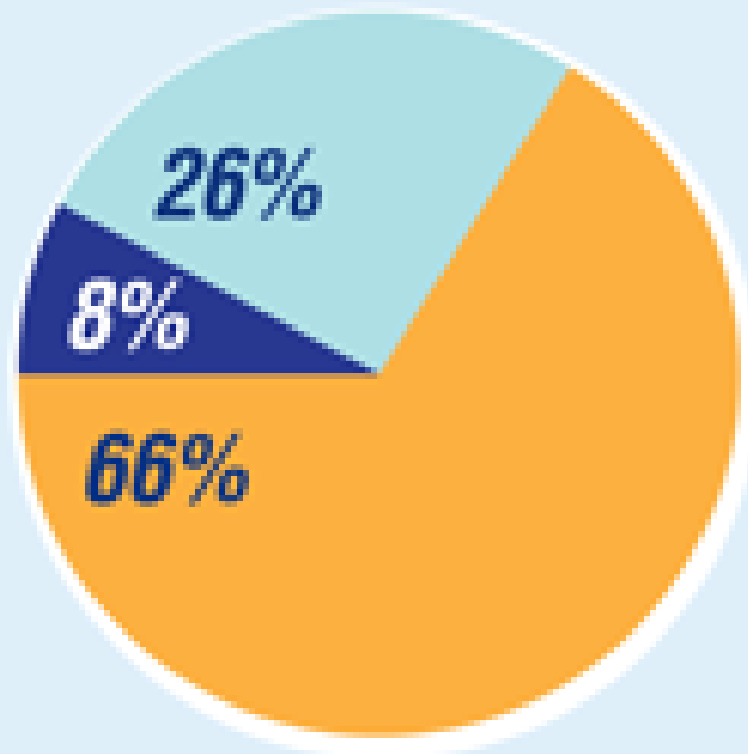
Distributors

Transmission

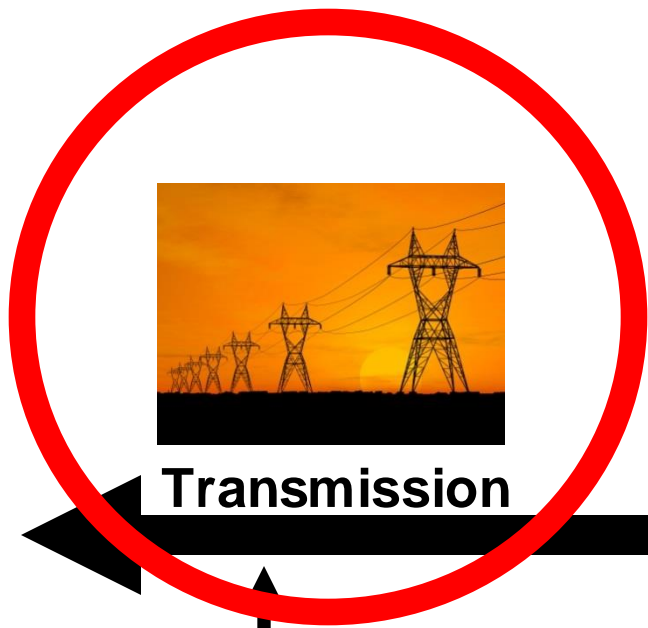


Cost of Transmission

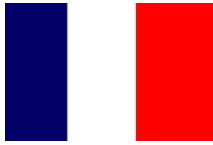
Cost of Transmission



-  **Generation**
-  **Distribution**
-  **Transmission**



Industrial consumers



Other countries

Power Plants



Distributors



**Residential consumers:
Households**



2. Transmission lines

September 28th, 2003

Huge blackout cripples Italy!



Rome's "white night"





110 trains stopped

Thousands of people stuck

Huge blackout cripples Italy!





Sils-Soazza

**Tree
flashover!**

**“Cross-border
transmission lines”**

**Mettlen-
Lavorgo**

“Interconnectors”

03:01

Sils-Soazza

**Tree
flashover!**



~~**Mettlen-
Lavorgo**~~

03:01

A map of Europe with a yellow background and blue outlines for rivers and coastlines. A black pushpin is placed in the northern part of the continent, with a white box containing the text 'Sils-Soazza' above it. To the west of the pushpin, there are two red pushpins. A white box with a red 'X' over it contains the text 'Mettlen-Lavorgo'. At the bottom of the map, a white box with a black border contains the date '03:01-03.16'.

Sils-Soazza

~~**Mettlen-
Lavorgo**~~

03:01-03.16

A man in a dark long-sleeved shirt is sitting at a desk in a control room. He is looking towards the camera with a serious expression. The desk is cluttered with multiple computer monitors, keyboards, and a mouse. The background shows more monitors and the dimly lit interior of the control room with overhead lights.

The Swiss TSO operator asks the Italian TSO for countermeasures

TSO= Transmission System Operator

03:11



Sils-Soazza

Tree
flashover!

~~Mettlen-
Lavorgo~~

**Italy reduces
import by -300 MW**

03:25

~~Sils-Soazza~~

Tree
flashover!

~~Mettlen-
Lavorgo~~

03:25



SWITZERLAND

All interconnectors are automatically disconnected



Line of separation from the European grid

03:26





1. Transmission lines limits

2. Dispatch

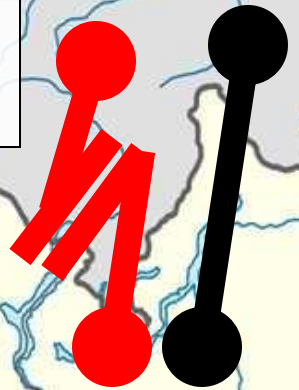
3. Frequency and synchronicity

4. Transmission shortage in the EU

Transmission lines limits

Sils-Soazza

Tree
flashover!



~~Mettlen-
Lavorgo~~

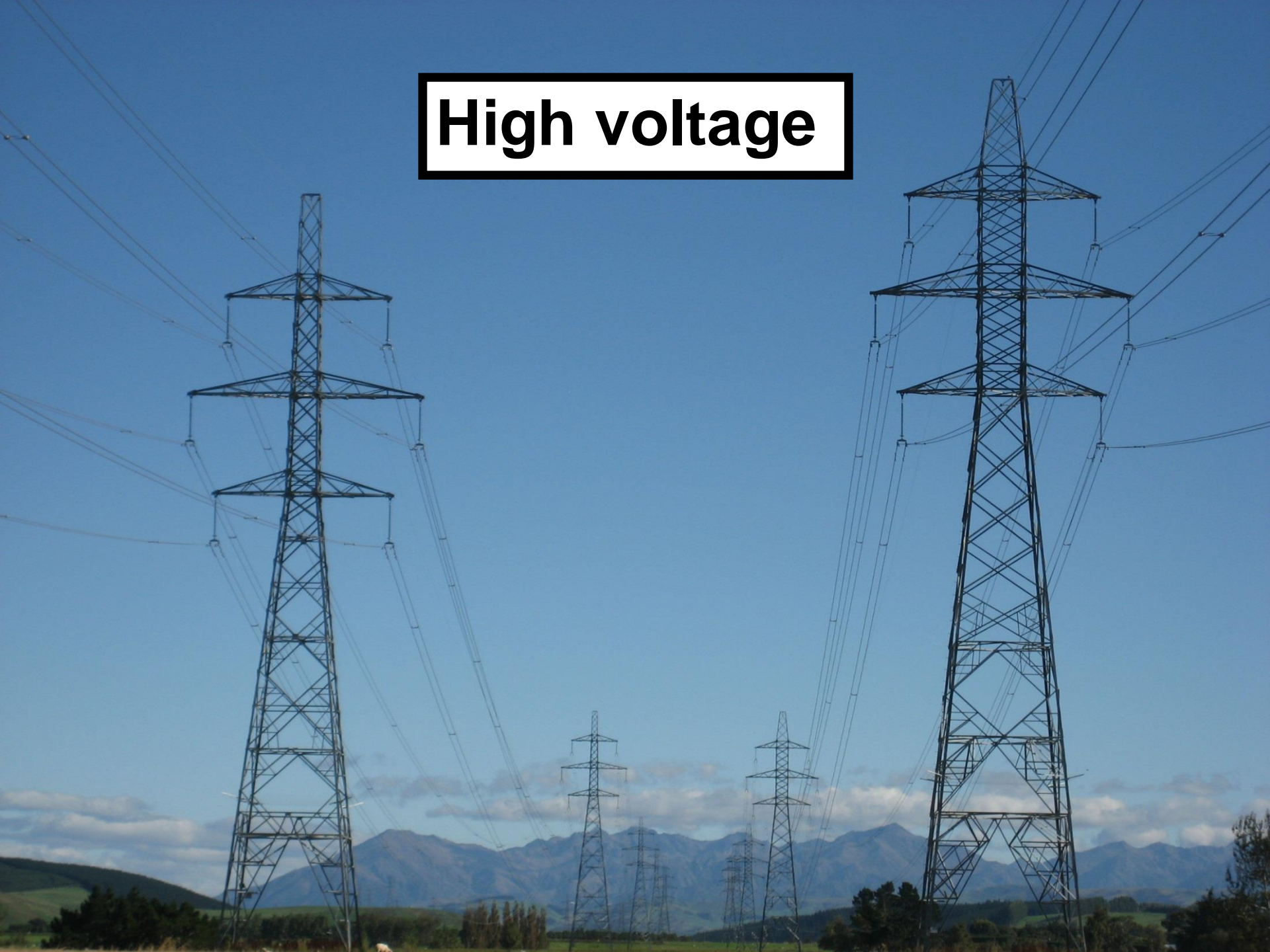
03:01

Transmission lines limits

flashover



High voltage



High voltage

Dramatically lowers losses to resistance

1 KV-> 10KV

Loss falls to 1%

Factor 100

Transmission lines limits

1 KV-> 100KV

Loss falls to 0.01%

Factor 10.000

Why?

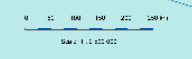
$$E = I \cdot V^2$$

Current (or flow)

Voltage (or pressure)

Loss a function of current, not of voltage

01.07.2003



Legend

Plants and stations:

- Hydro Power Plant
- Thermal Power Plant
- Substation
- Control Center
- Transmission Line
- Interconnector
- DC Converter

Lines:

- 100 kV transmission line
- 220 kV transmission line
- 330 kV transmission line
- 500 kV transmission line
- 765 kV transmission line
- 1000 kV transmission line
- DC line
- Interconnector

Special status of UCTE:

- UCTE member
- Non-UCTE member

Boundary of UCTE:

- Operational UCTE boundary
- UCTE boundary of UCTE
- UCTE boundary of UCTE
- UCTE boundary of UCTE

The network:

1998-2003

Year	Length of AC circuits (km)	Length of DC circuits (km)	Total length (km)
1998	141 359	0	141 359
1999	141 359	0	141 359
2000	141 359	0	141 359
2001	141 359	0	141 359
2002	141 359	0	141 359
2003	141 359	0	141 359

ENTSO-E Overview circuit

Length of AC circuits

220 – 285 kV	141 359
330 kV	9 141
380/400 kV	151 272
750 kV	471
Sum	302 243

Percentage losses by transmission in %?

2013: 1.6 %

https://www.entsoe.eu/Documents/Publications/ENTSO-E%20general%20publications/2013_ENTSO-E_Statistical_Factsheet_Updated_19_May_2014_.pdf

Table 1. Length of high-voltage lines, year 2000.

Voltage, kV	Length, thousand km	Share
1150	1.0	2.4%
800	0.4	1.0%
750	2.8	6.7%
500	30.5	72.8%
400	0.01	0.02%
330	7.2	17.2%
Total	41.91	100.0%

Source: State Council of the Russian Federation (2001).

The electricity market is based on nodal pricing

- Like many regional markets in US (PJM, ERCOT)
- EU mostly zonal system

Transmission lines limits

High load

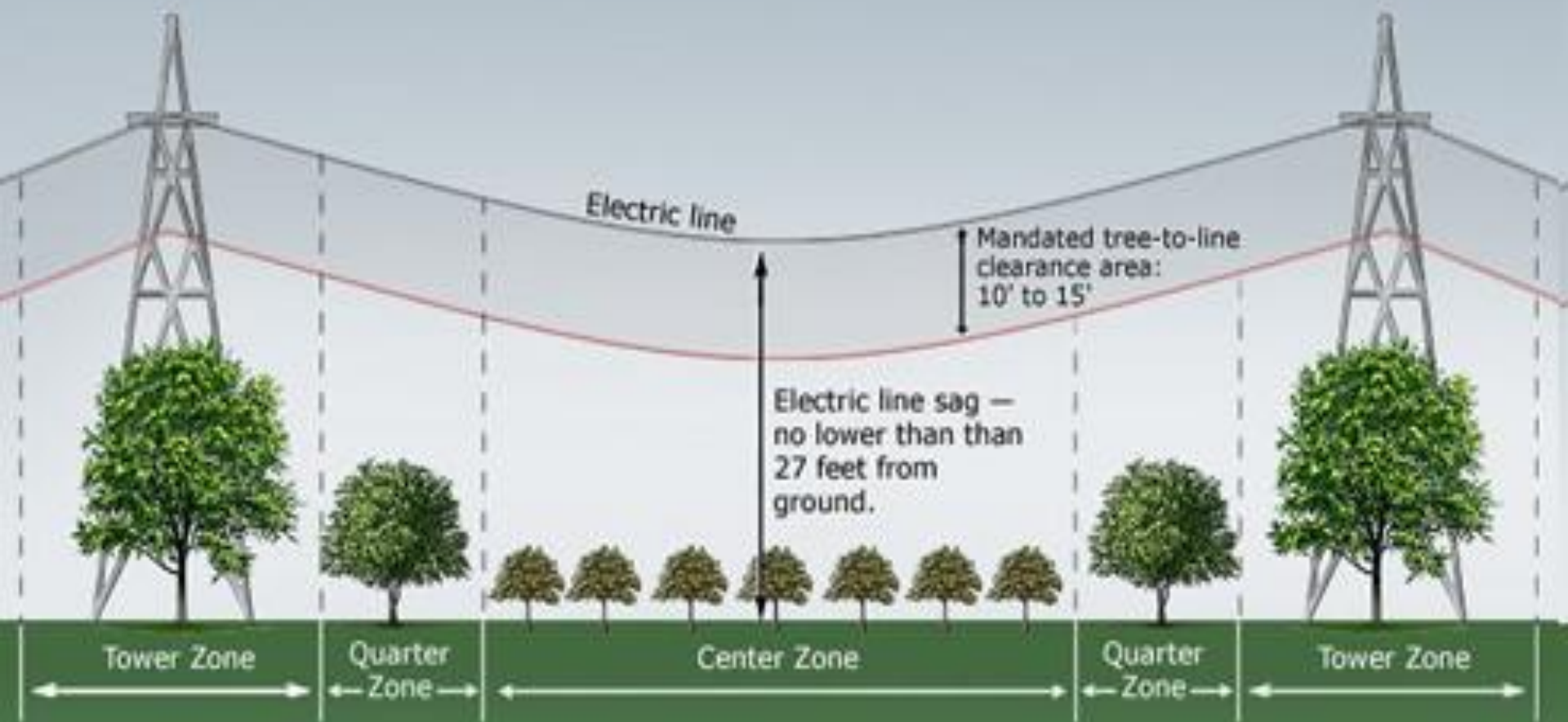
SAG

Sagging of the line

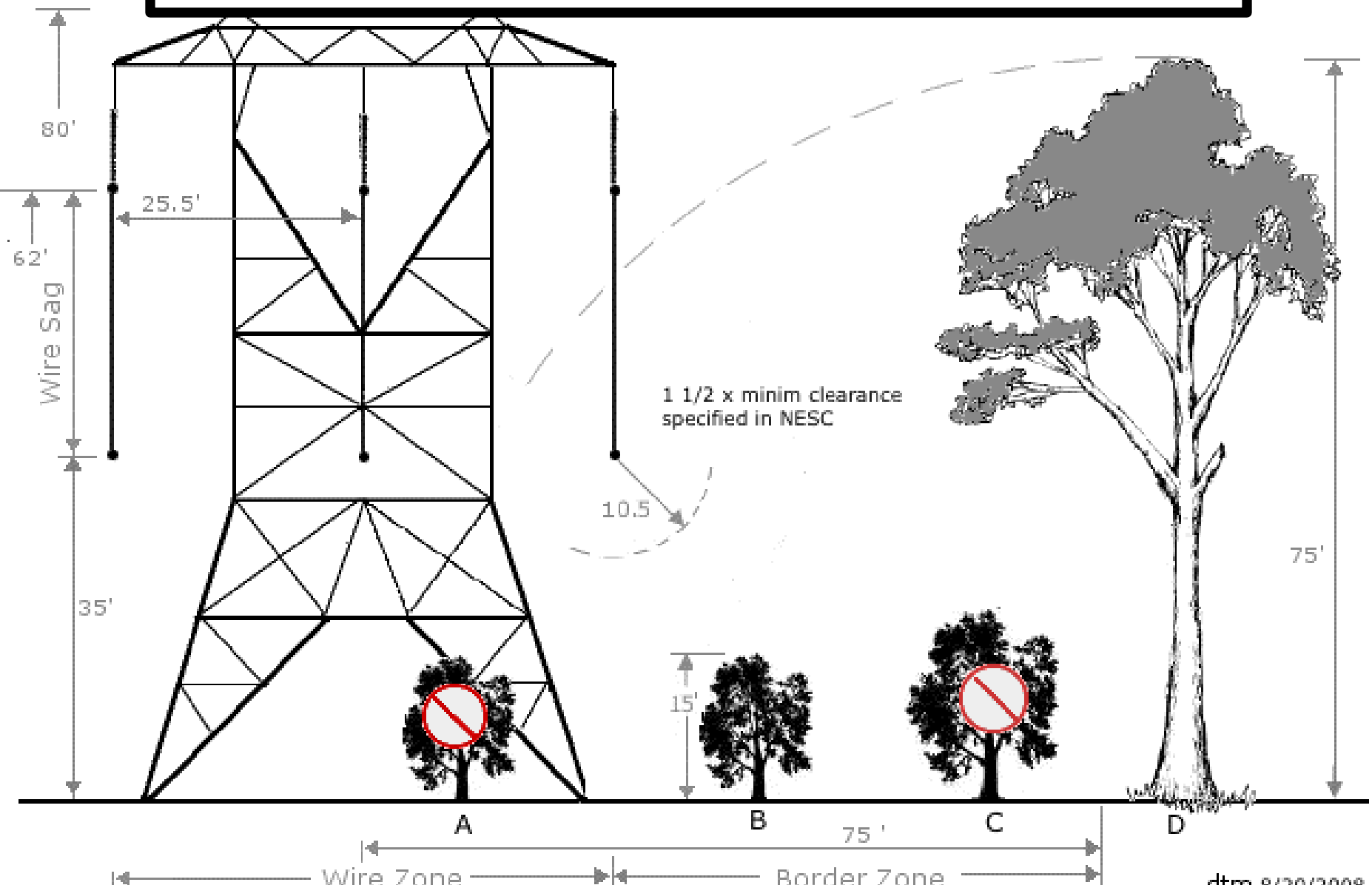


Power Line Clearance Zones

Commercial Orchards



Clearance: Trees below transmission lines must be kept short enough



- Limit of a line varies...
 - The line itself
 - Maximum allowed sagging
 - Air temperature & wind
 - For example, Increase in temperature from 30C to 40C can lower the limit with 10%

VIDEO

“1. Tree Flashover
10.03.09 (hq)”

Line flashover

3 risk factors for line flashover

Factor 1: High voltage

Factor 2: High load

Factor 3: proximity to other objects (trees)

1. Transmission lines limits



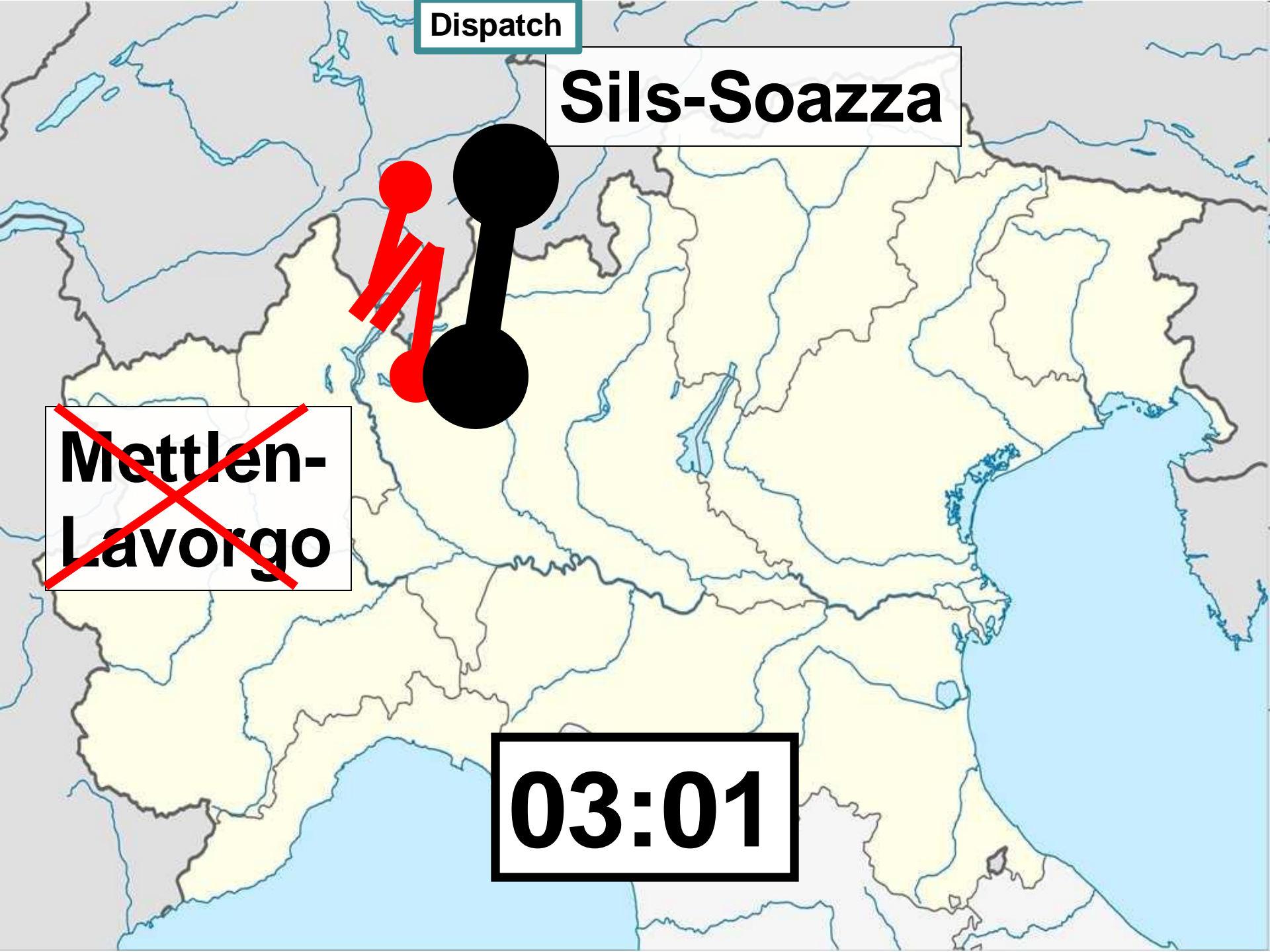
2. Dispatch

Dispatch

Sils-Soazza

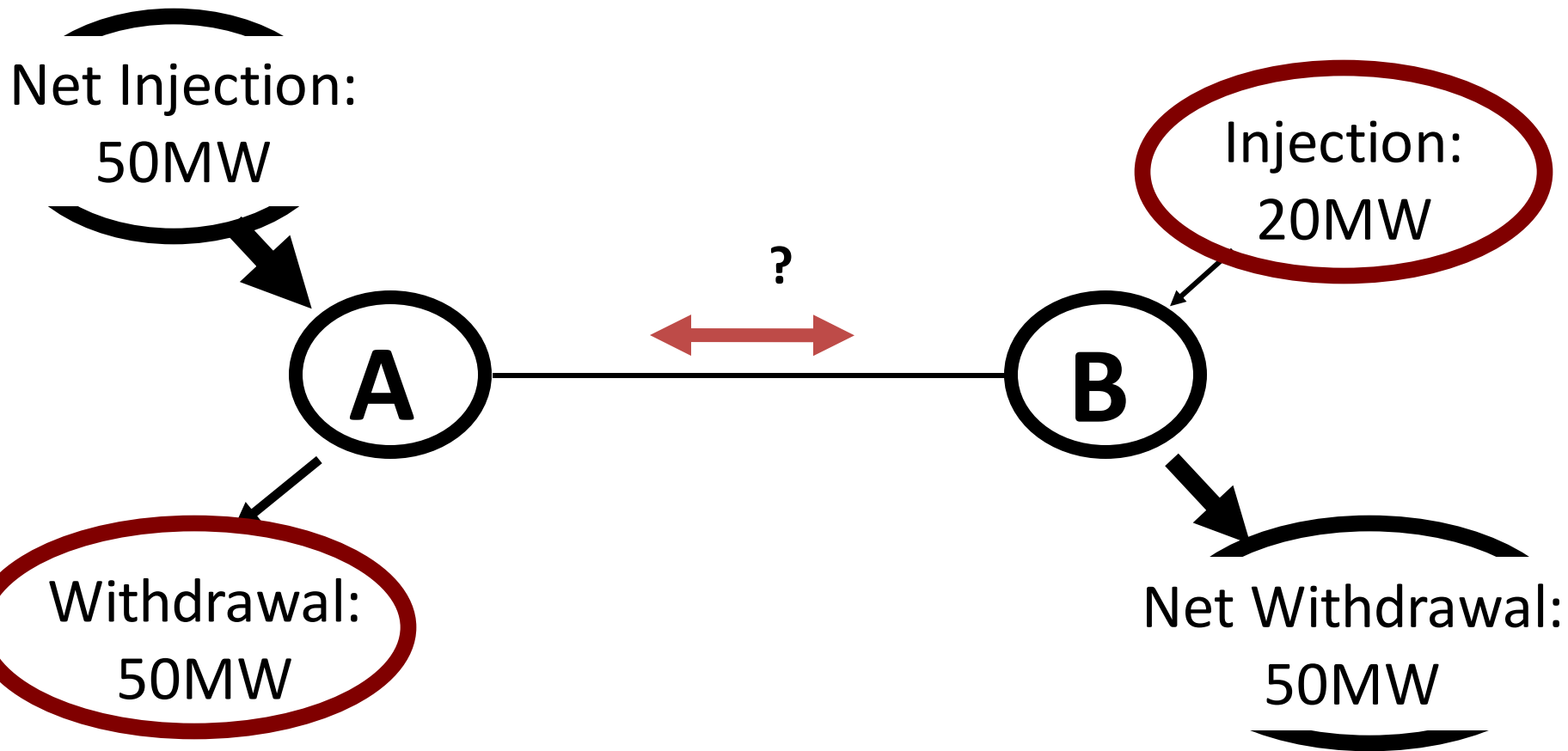
~~Mettlen-Lavorgo~~

03:01



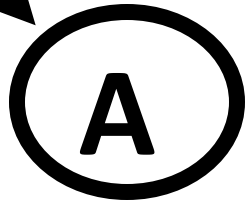
2 node AC network

Dispatch

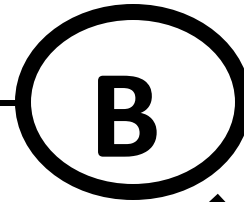


Dispatch

Net Injection:
50MW

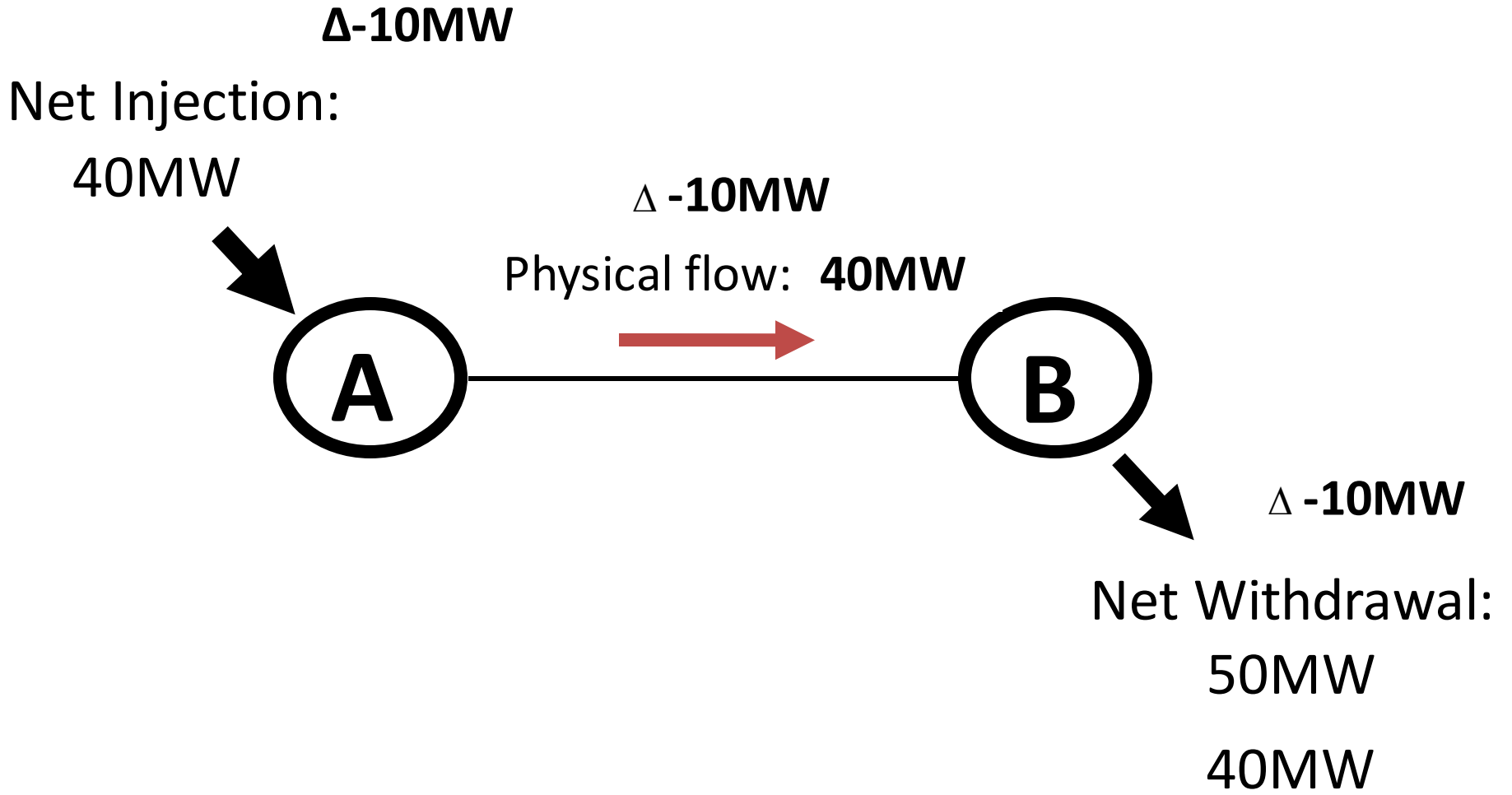


Physical flow: 50MW



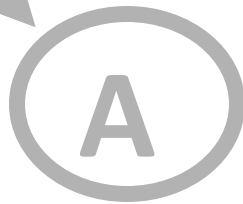
Net Withdrawal:
50MW

Dispatch



Dispatch

Net Injection:
40MW



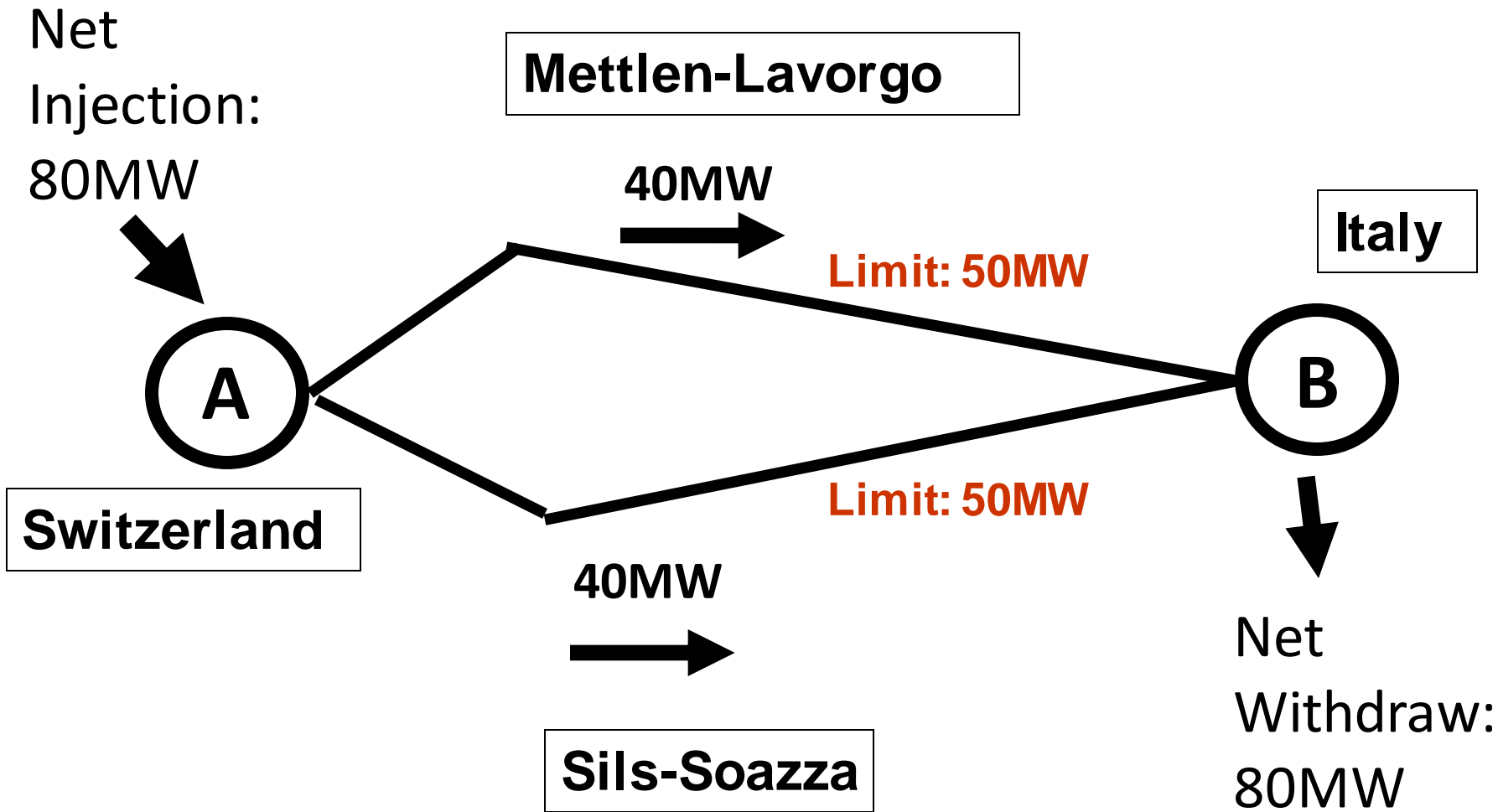
Physical flow: 40MW



Net Withdrawal:
40MW

**Electricity cannot just be “send”
somewhere on AC lines**

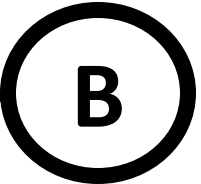
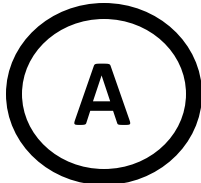
**Any flow is the RESULT of the
injection and withdrawals**



Net
Injection:
80MW

Mettlen-Lavorgo

Italy



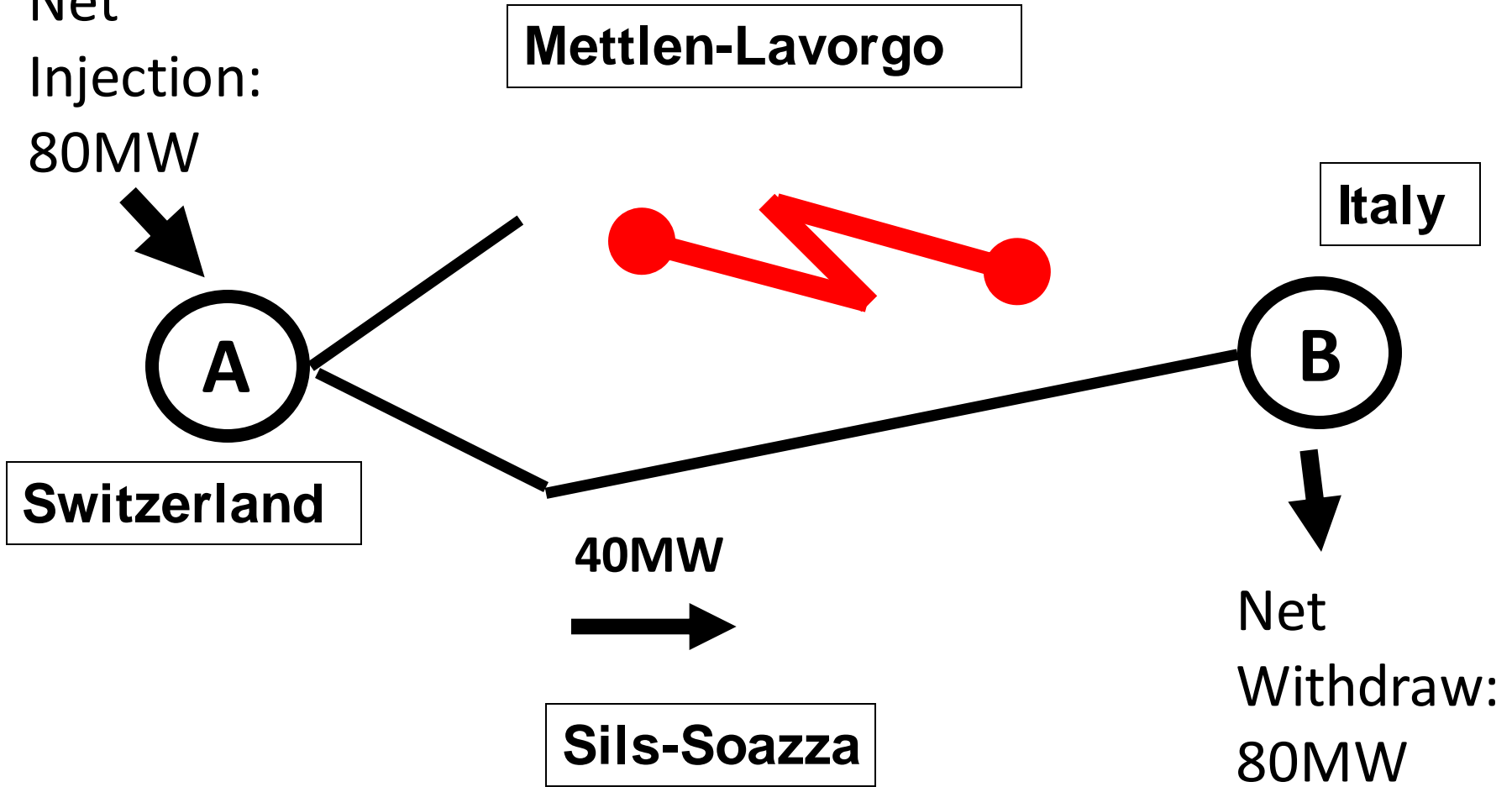
Switzerland

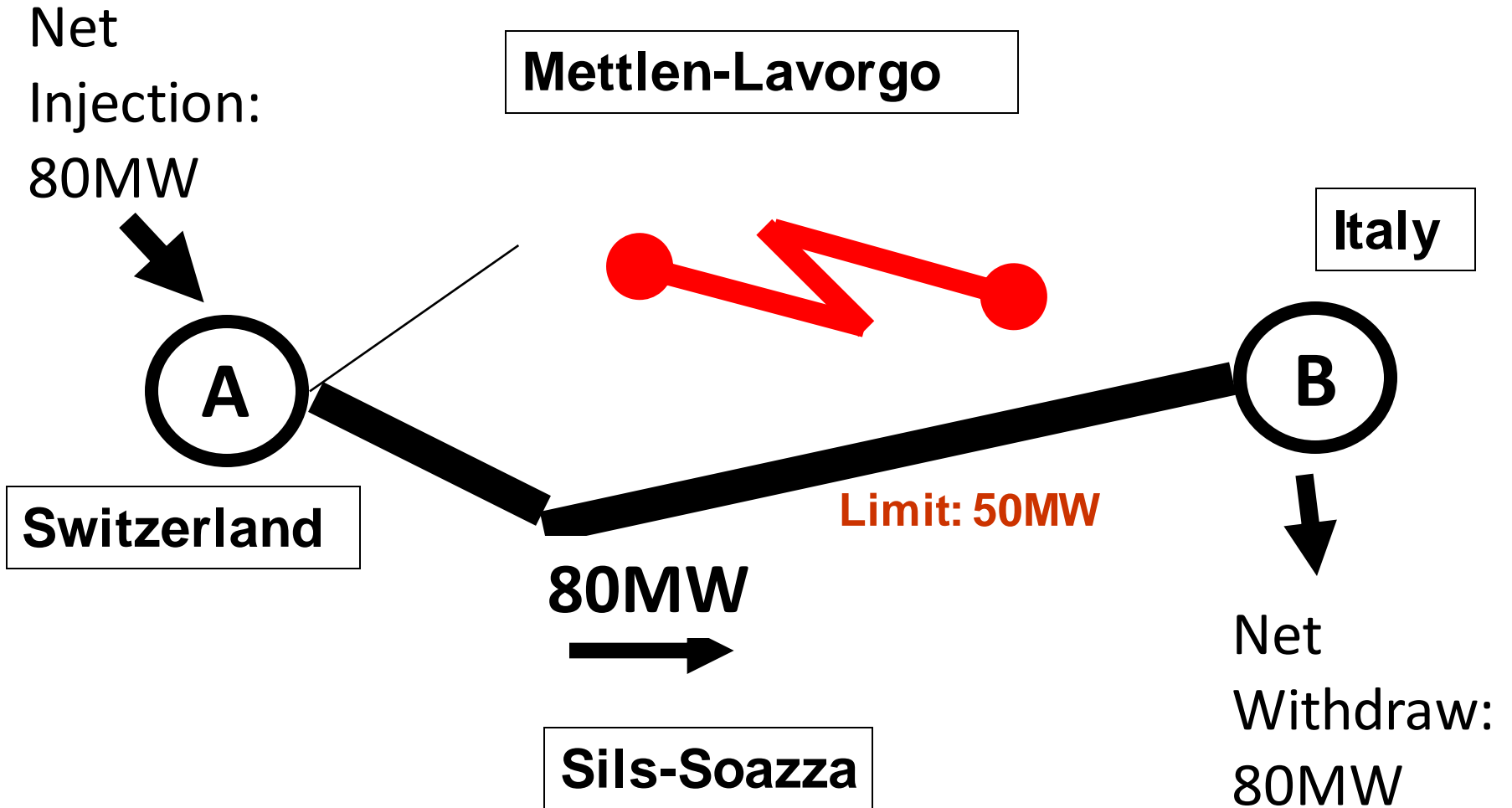
40MW



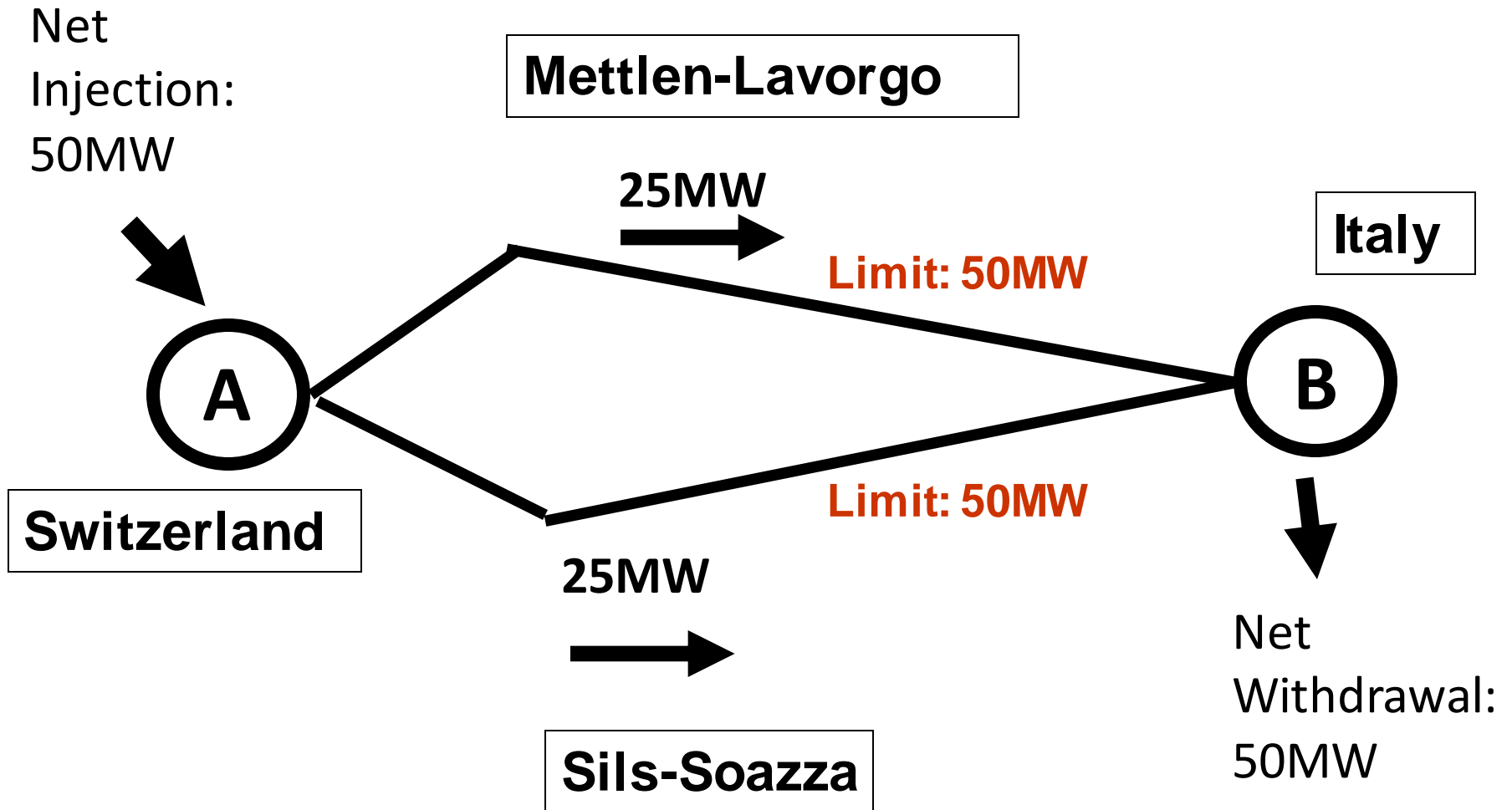
Sils-Soazza

Net
Withdraw:
80MW





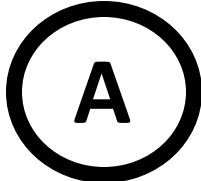
Apply N-1 security standards



Fulfills (a weaker form) of N-1 security standards

Net
Injection:

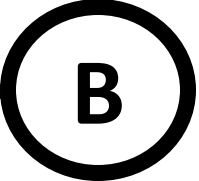
80MW



40MW



Limit: 50MW



Limit: 50MW

40MW



Both lines can
have 80MW
(15 minuts)

Decrease in
withdrawal of 30MW
available
(within 15 min)



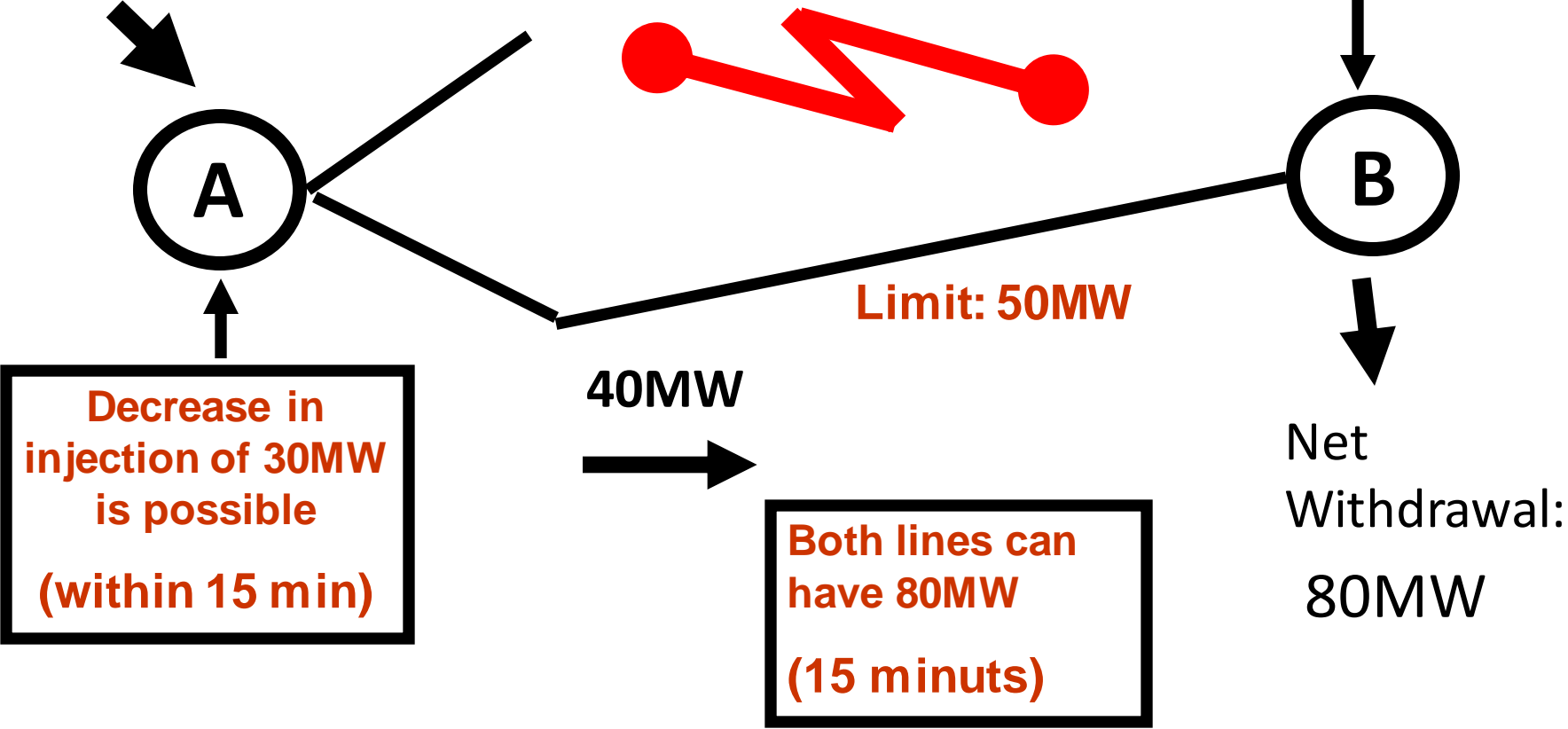
Net
Withdrawal:
80MW

Decrease in
injection of 30MW
is possible
(within 15 min)

Fulfills (a weaker form) of N-1 security standards

Net
Injection:
80MW

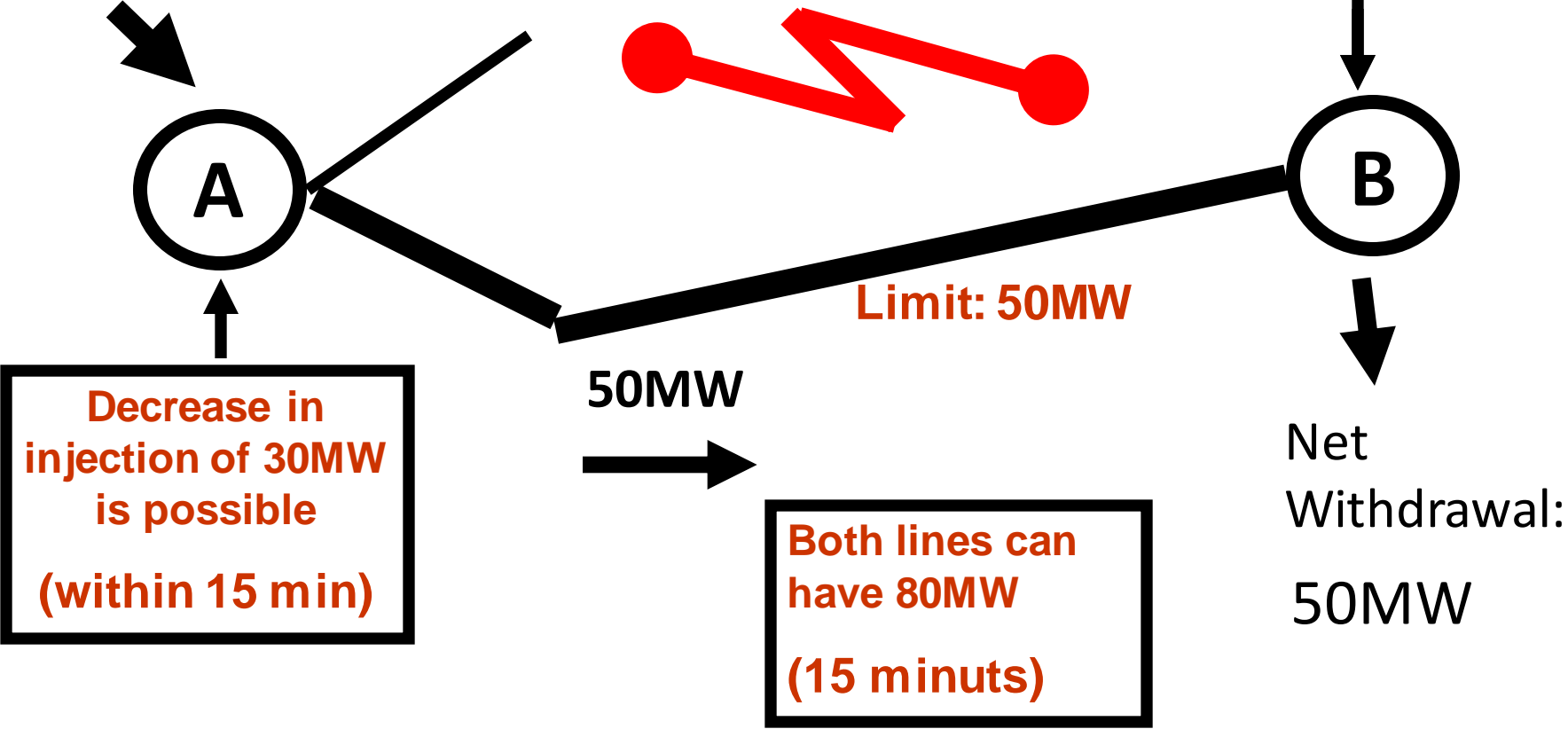
Decrease in
withdrawal of 30MW
available
(within 15 min)



Fulfills (a weaker form) of N-1 security standards

Net
Injection:
50MW

Decrease in
withdrawal of 30MW
available
(within 15 min)



A man in a dark long-sleeved shirt is sitting at a desk in a control room. He is looking towards the camera with a serious expression. The desk is cluttered with multiple computer monitors, keyboards, and papers. The background shows more monitors and the dimly lit interior of the control room with some overhead lights.

The Swiss TSO operator asks the Italian TSO for countermeasures

Dispatch is done by national TSOs

03:11

Dispatch

Sils-Soazza

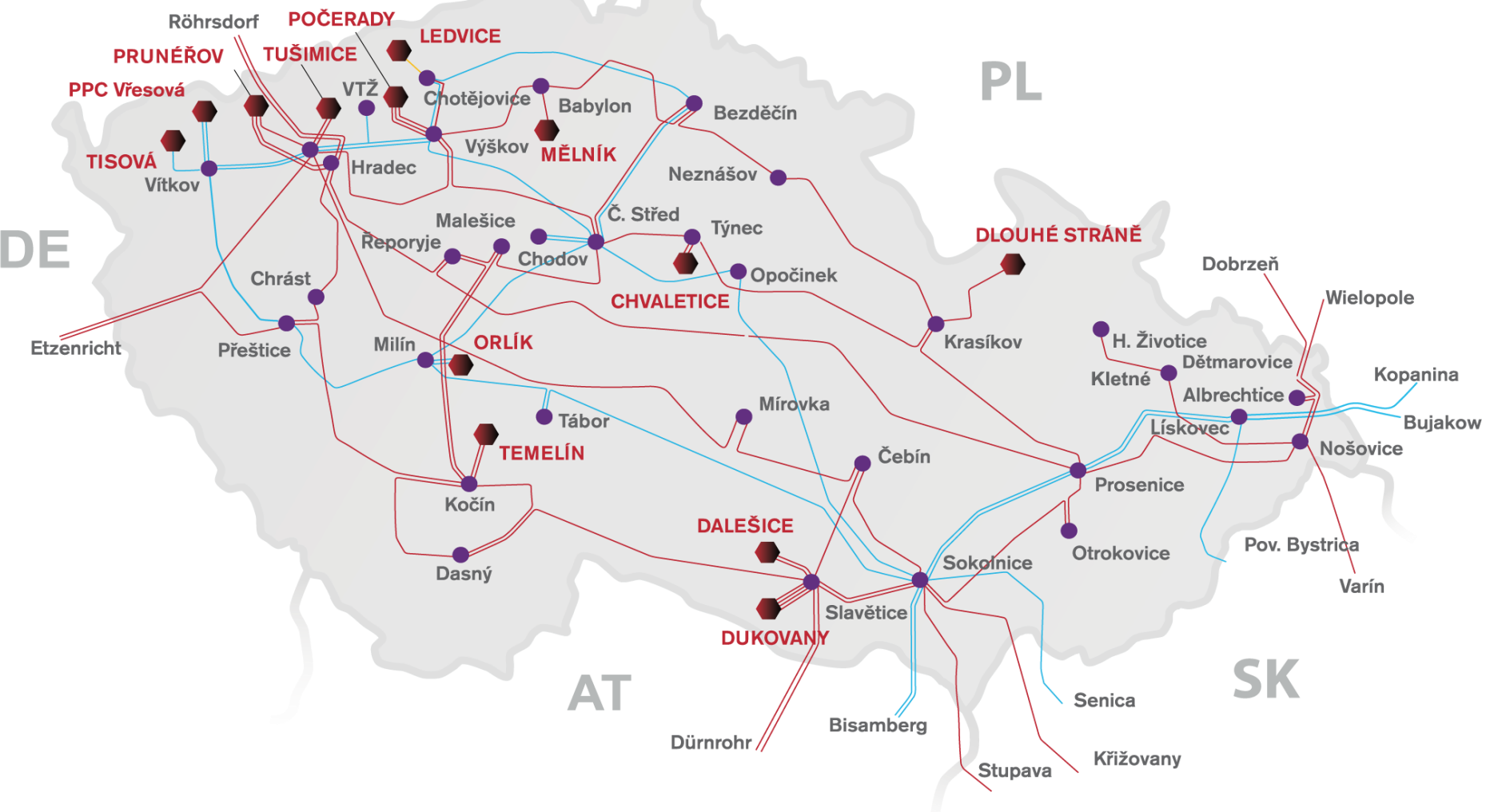


~~Mettlen-
Lavorgo~~

**Italy reduces
import by -300 MW**

03:25

Map of Interconnected Network - 400 and 220kV



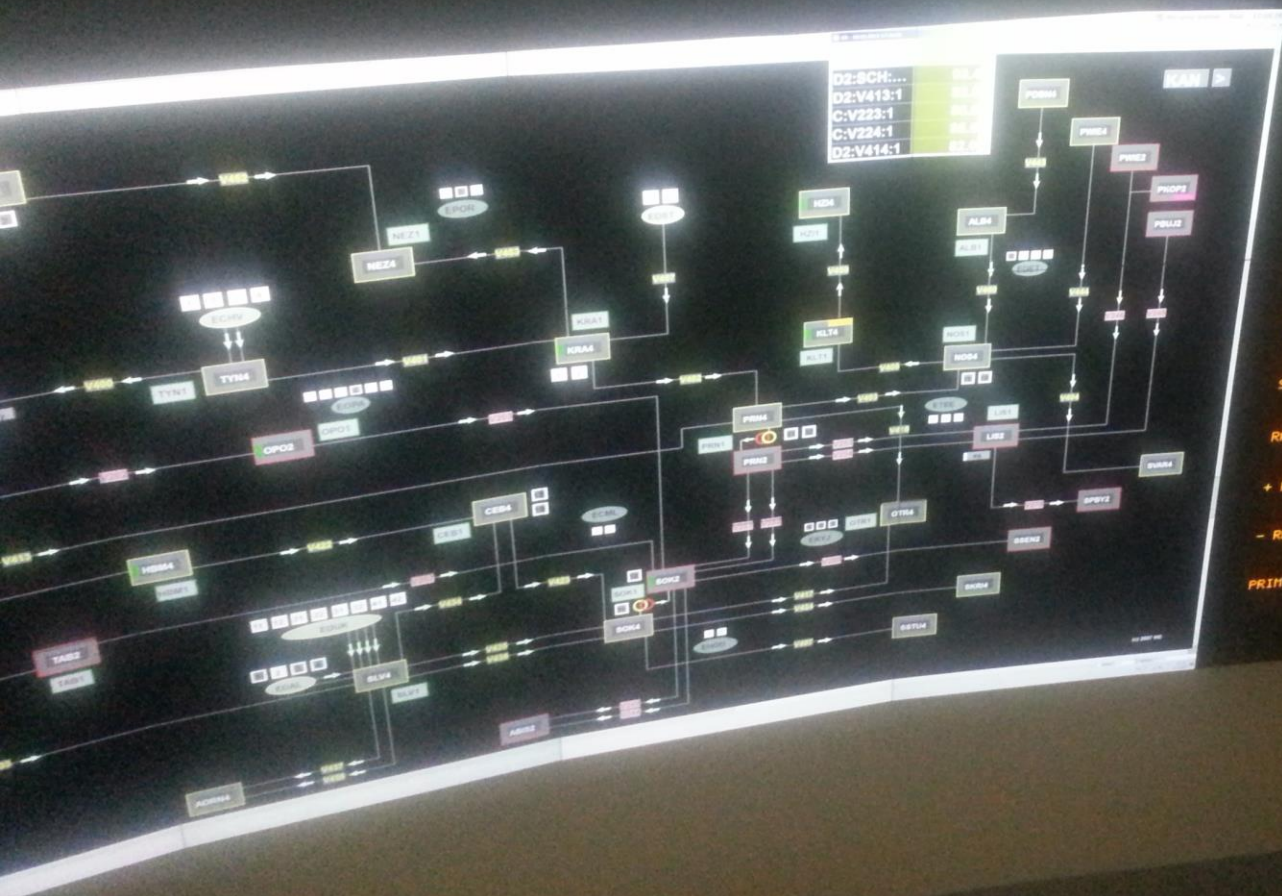
- Line 400 kV
- Line 220 kV
- Power plant
- Substatiin



ČEPS



D2: SCH:...	83.4
D2: V413:1	88.6
C: V223:1	88.6
C: V224:1	88.6
D2: V414:1	82.6



02.01.2014 17:24

UT 10 ONOR 17:24

UT	0	6CC	0
f	49993	SALDO plan	- 2984
f str.	50003	SALDO	- 2955
UVRABA	12973	ODCHYLKA salda	31
SPOTREBA	10112	SACE	48
RACE PE	121	SACE str. bezne	- 189
+ REZ PE	447	SACE str. nin	38
- REZ PE	373	SALDO rozdil ner	- 16
PRIH. REGULACE	92	SALDO 110 kV	90

1. Transmission lines limits

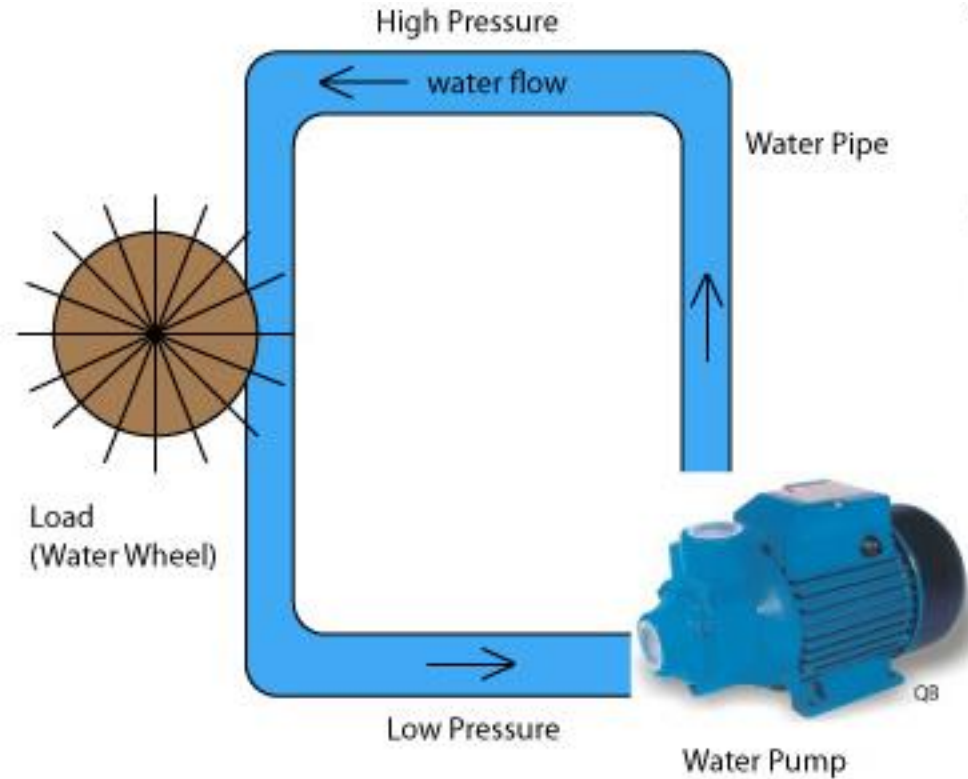
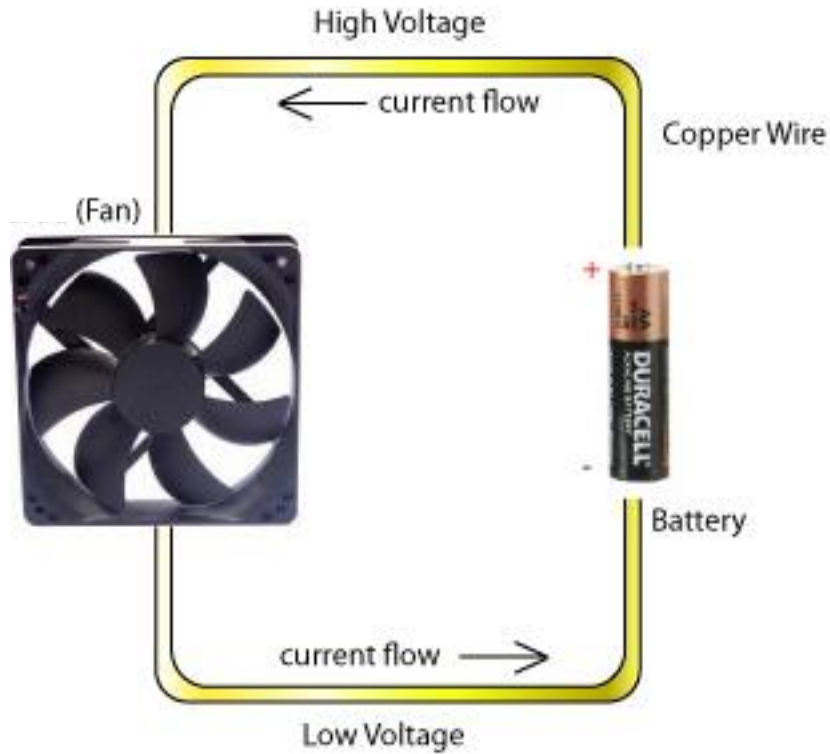


2. Dispatch



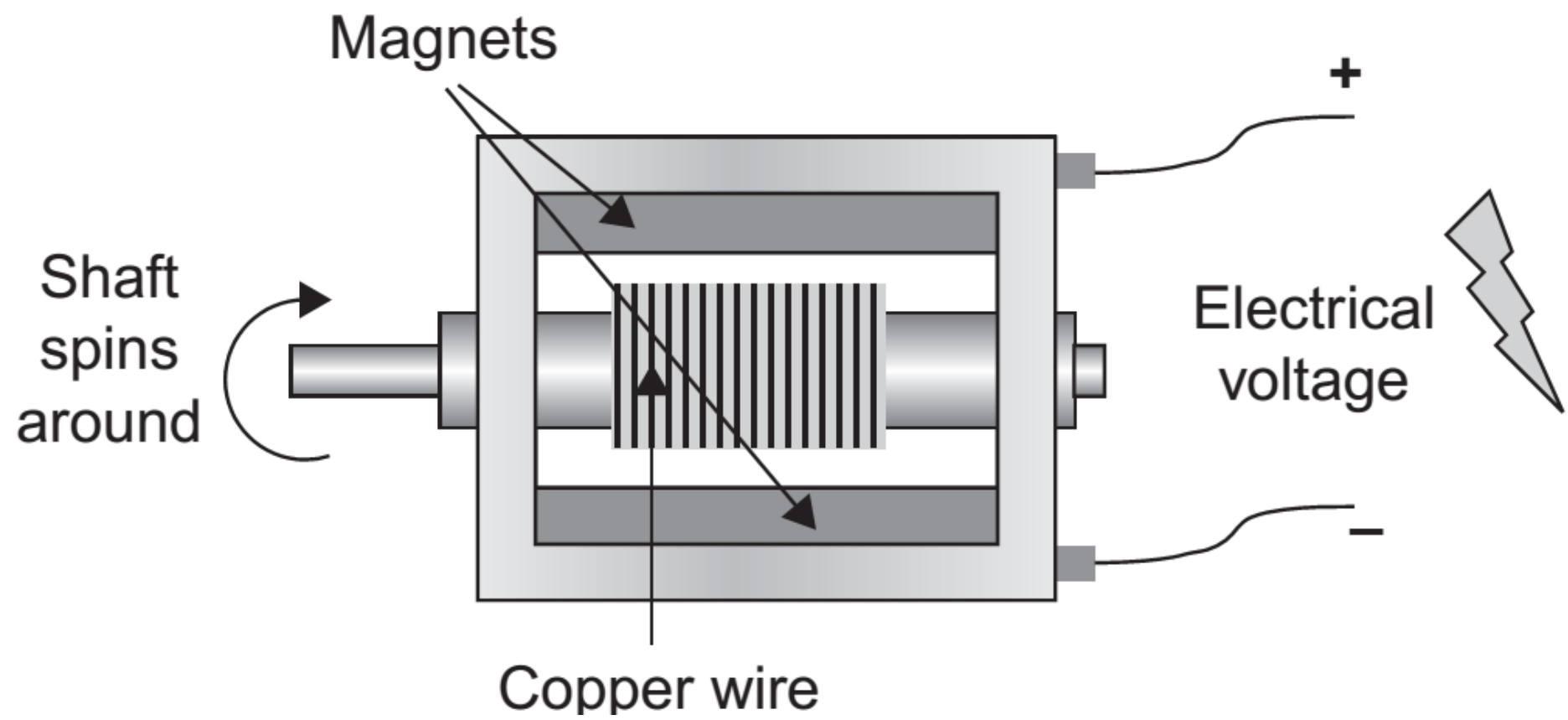
3. Frequency and synchronicity

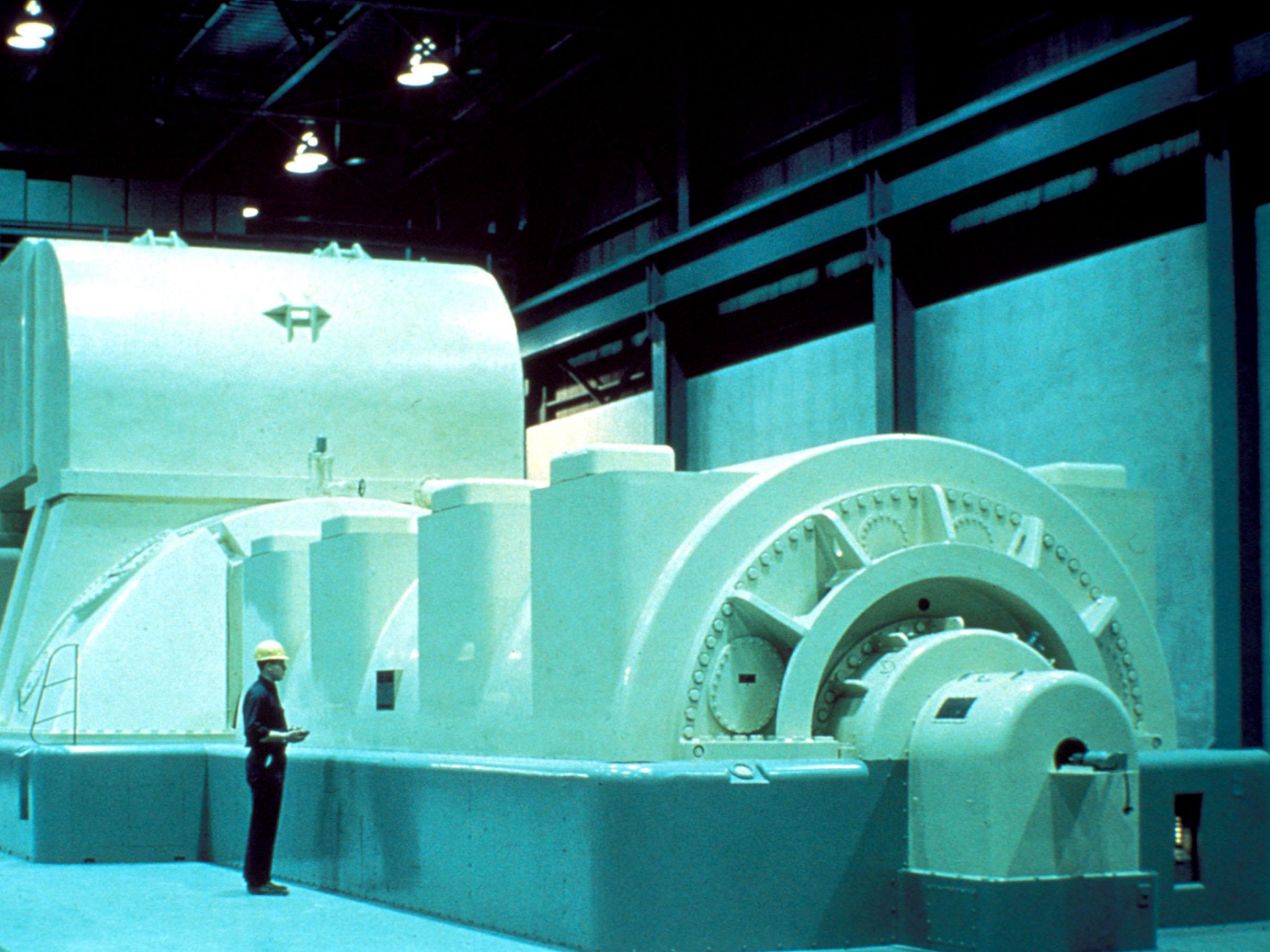
Frequency and Synchronicity



Direct Current (DC)

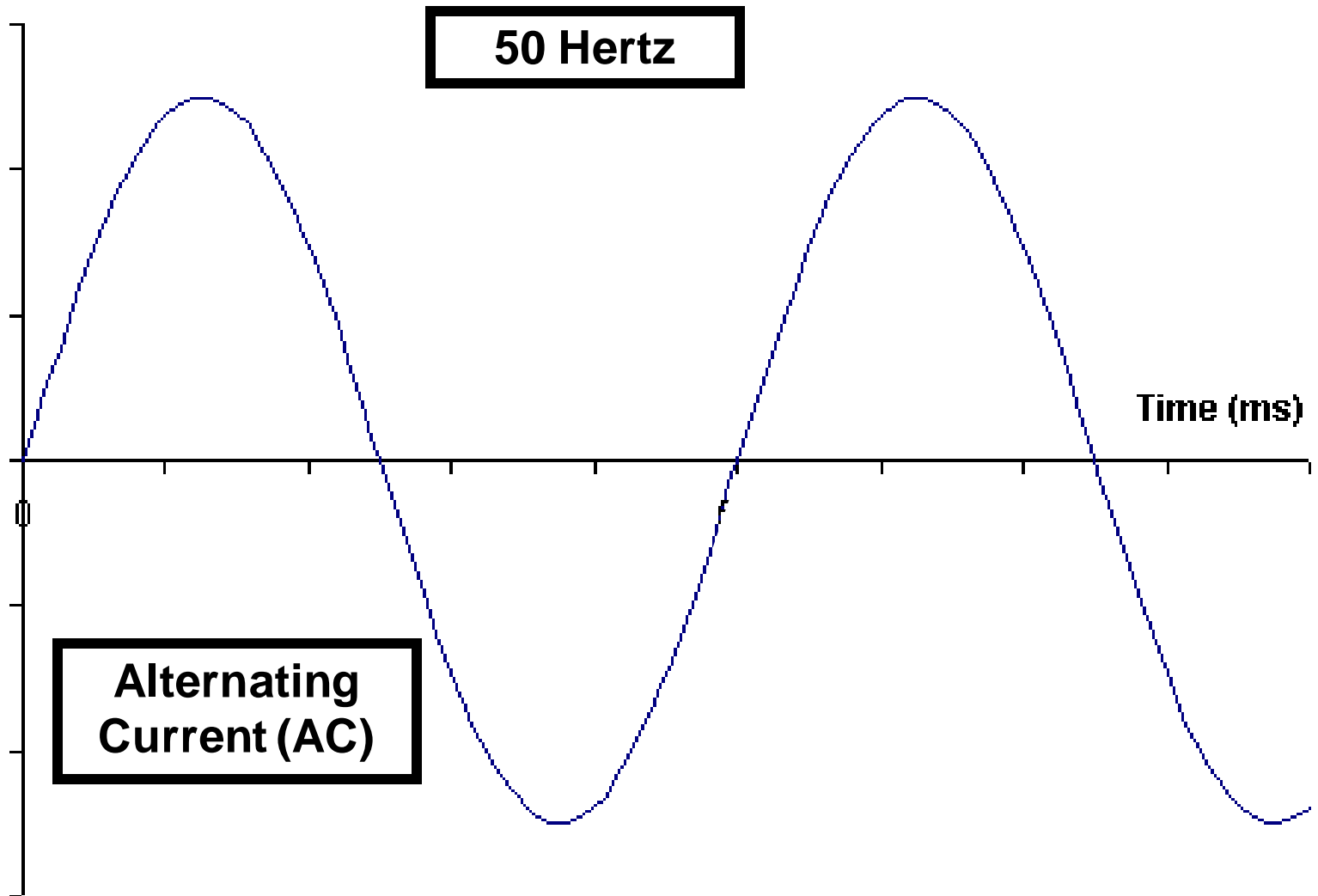
Alternating Current (AC)



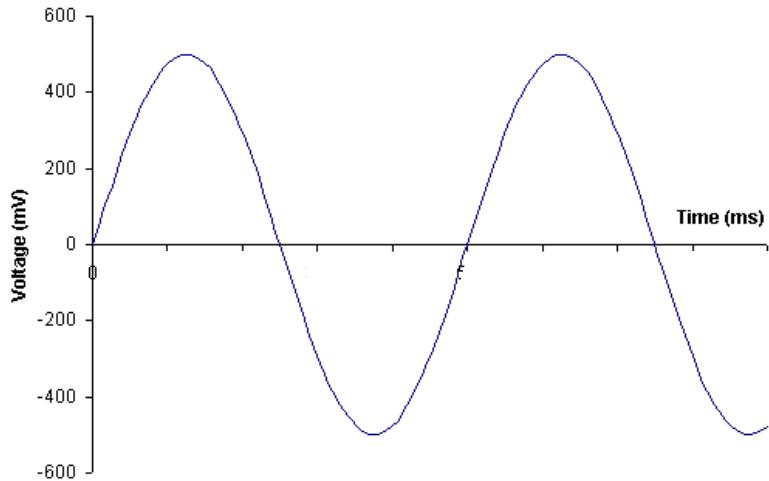




Frequency and Synchronicity



Frequency and Synchronicity



Does a lamp in your house receive zero energy 100 times a second and is thus blinking?

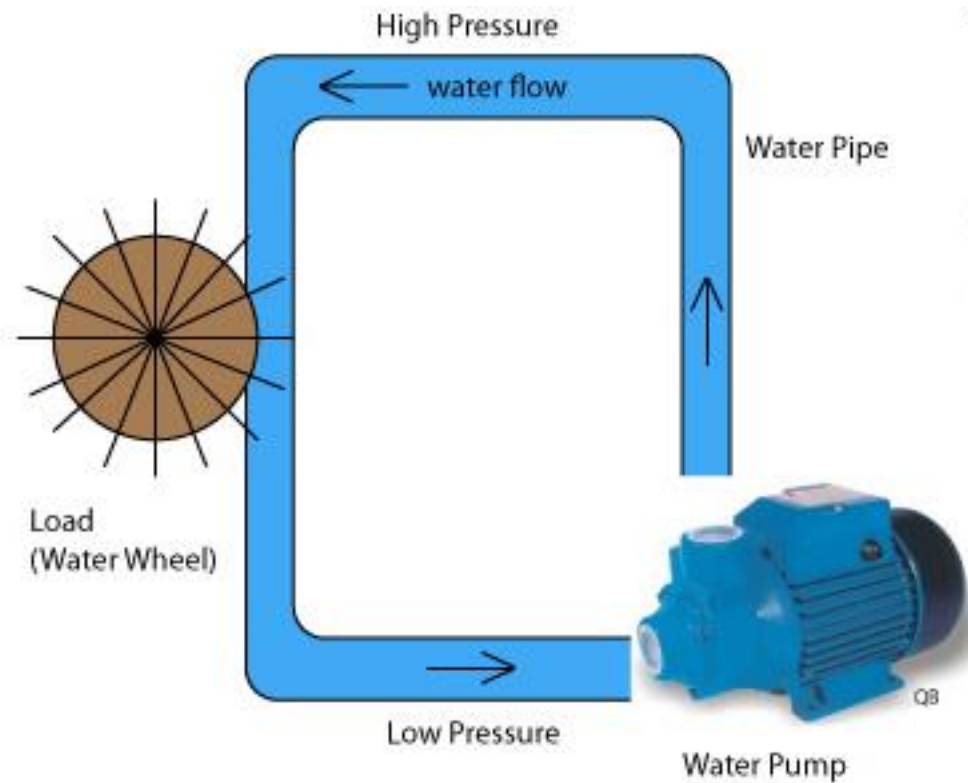
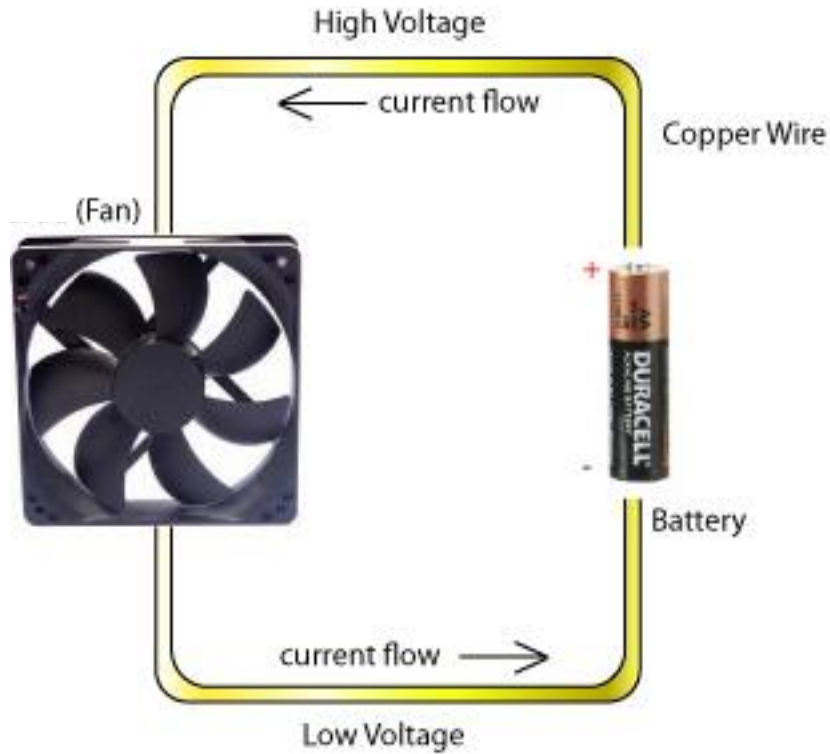
- **VID**

- Wednesday 1_ light bulb.divx

Alternating Current lines (AC)



Frequency and Synchronicity



Direct Current (DC)

Alternating Current (AC)

HVDC Light: underground and underwater power link

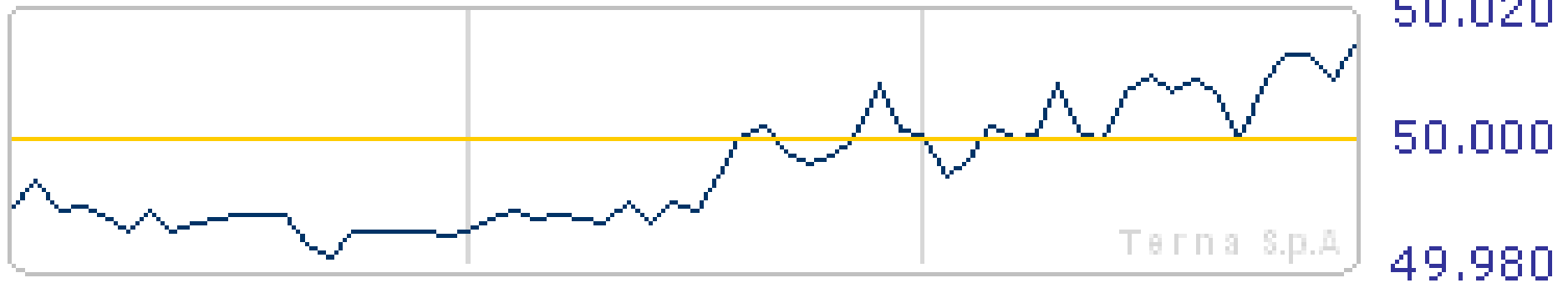
Direct Current lines (DC or HVDC)



Lightweight, oil-free design

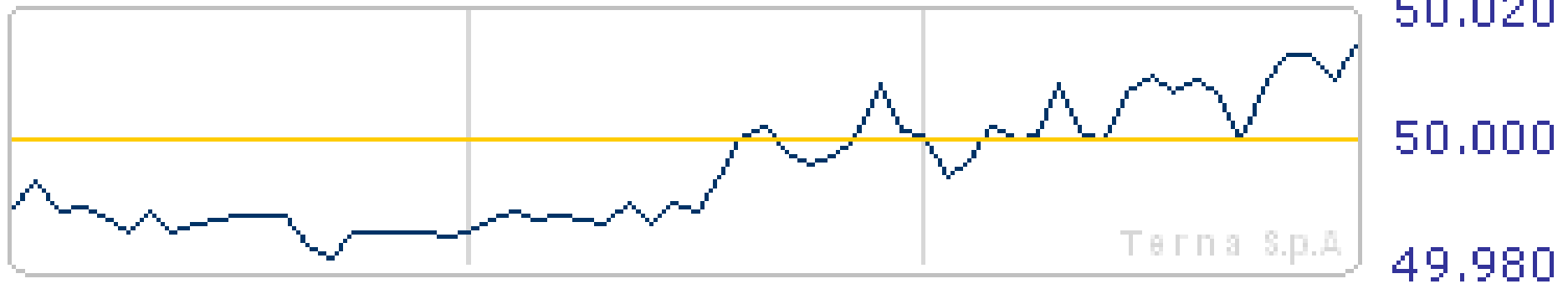
Frequency and Synchronicity

50 Herz is the frequency in Europe



Frequency and Synchronicity

A shortage of generation makes the frequency fall

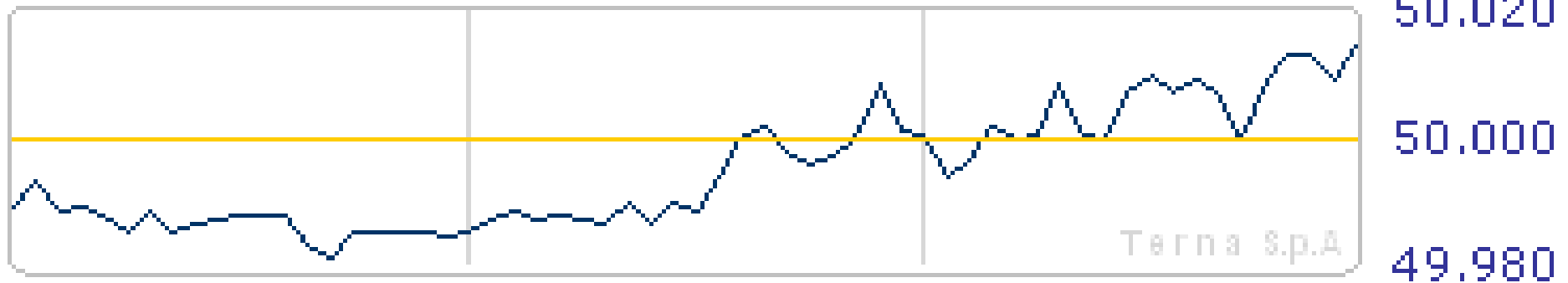


Slight shortage

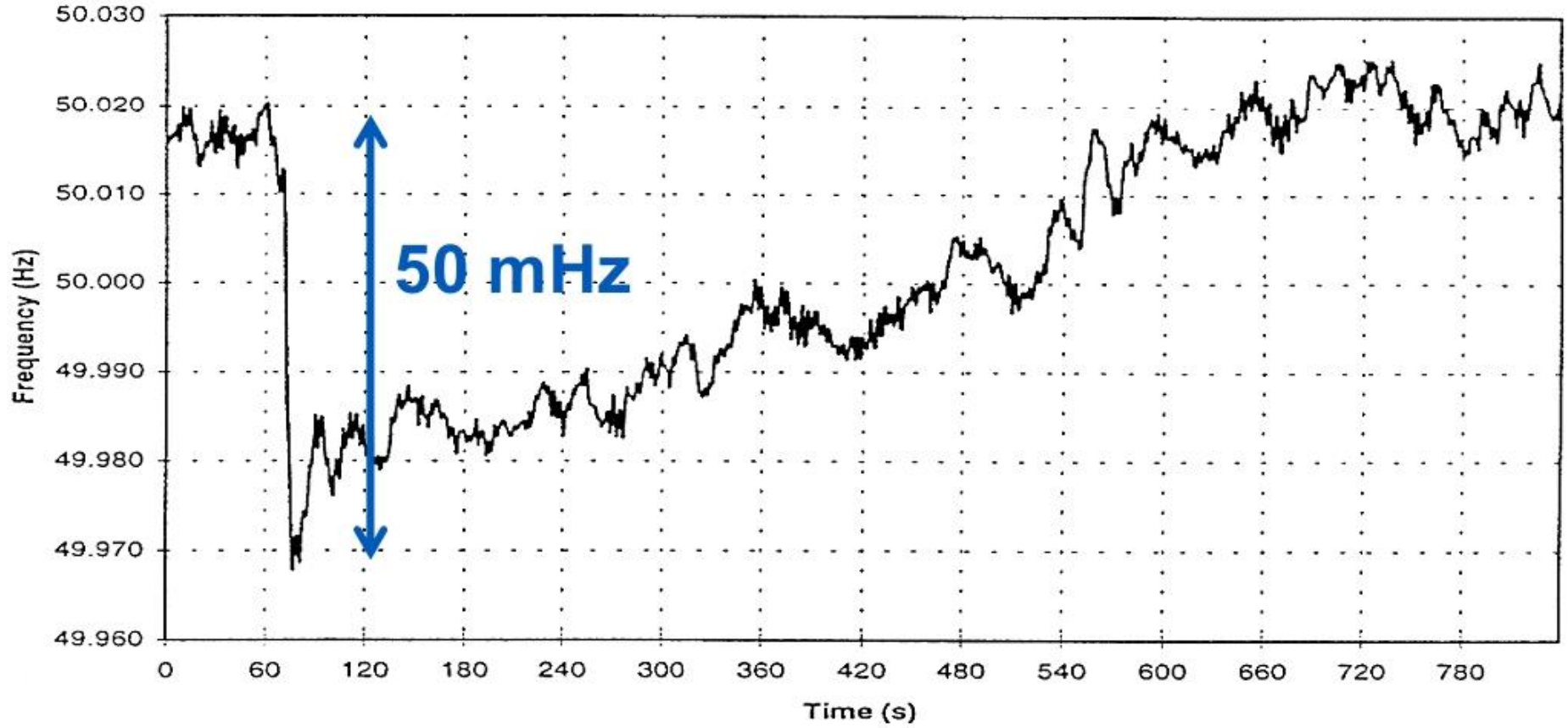
Frequency and Synchronicity

**A surplus of generation
makes the frequency rise**

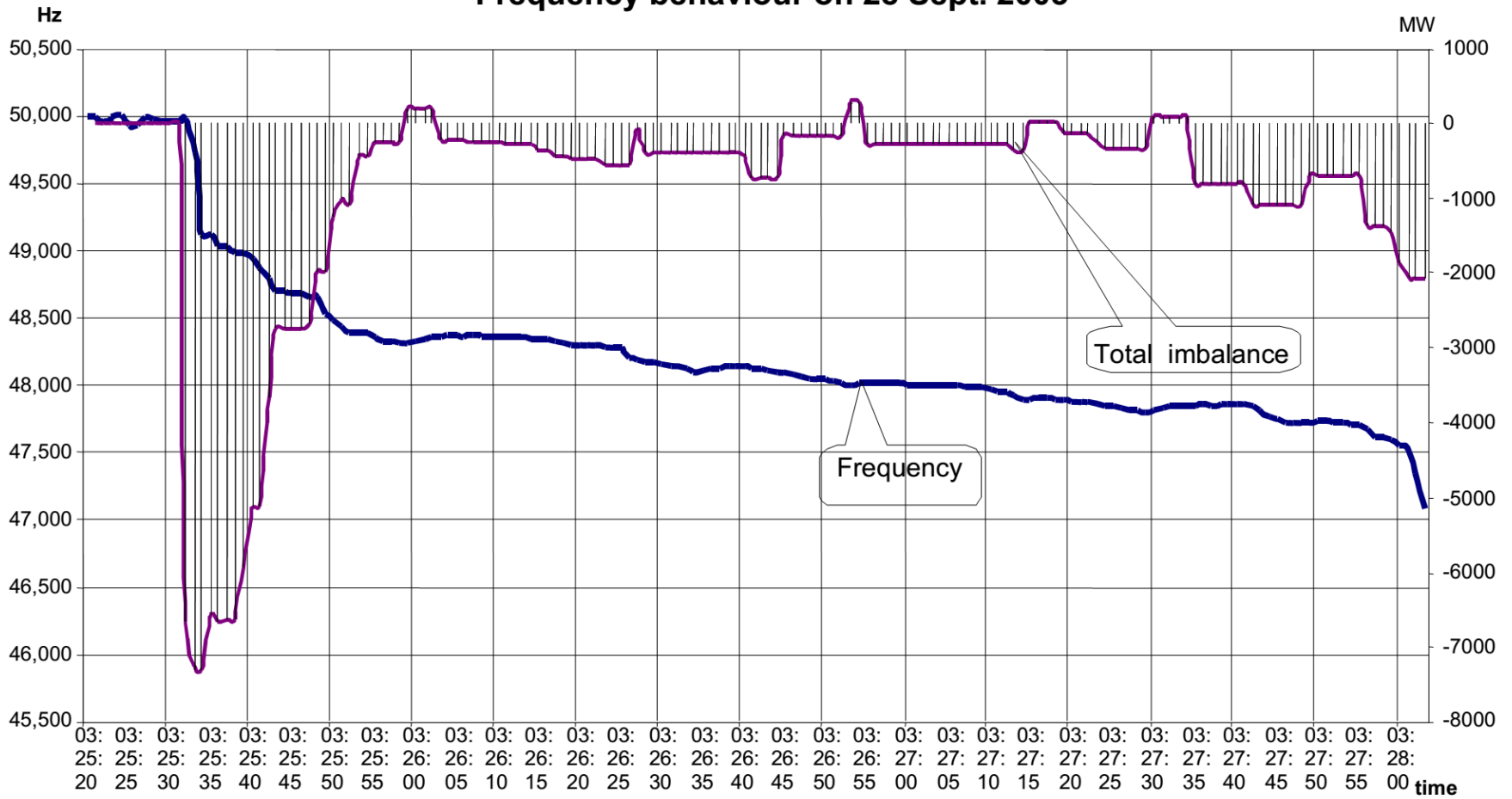
Slight surplus



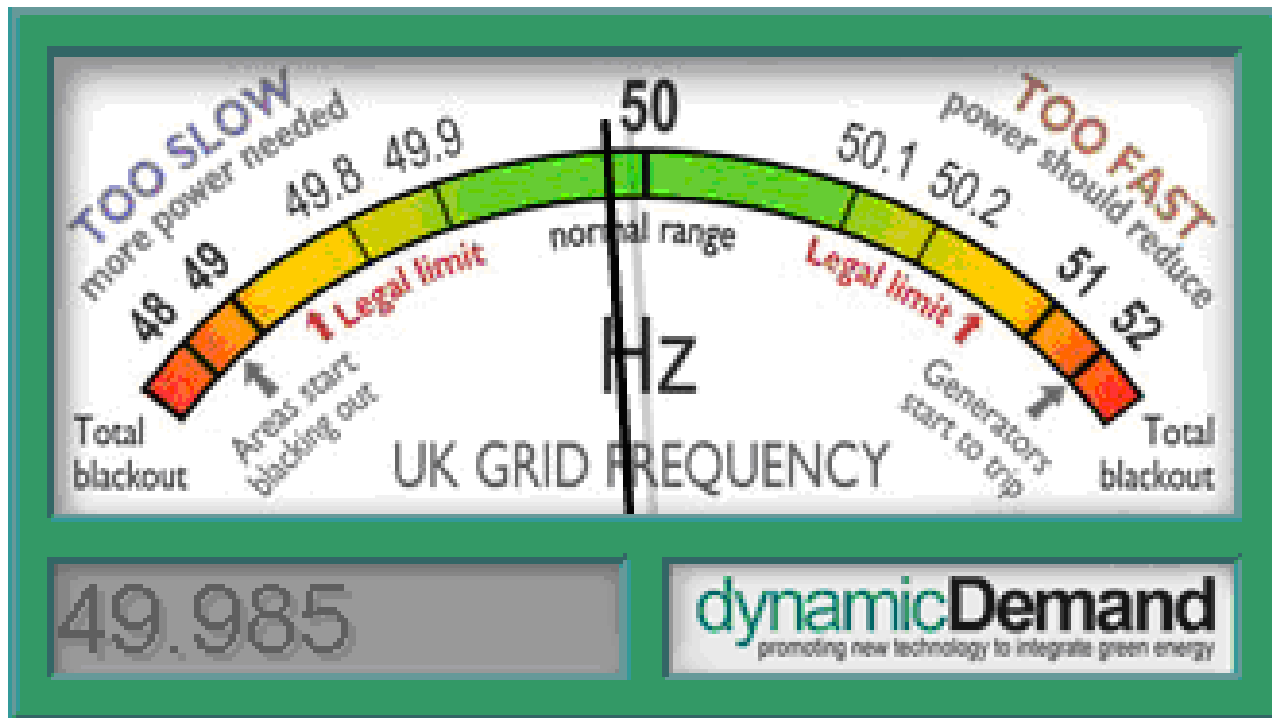
Lost of a nuclear unit (1300 MW) within the UCTE system



Frequency behaviour on 28 Sept. 2003



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



- What is (one of) the biggest challenges for the British TSO?



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Sources

- This presentation is modernized version of Kotev, S. Principles of transmission, applied to the eu transmission network. Presentation. 2011.



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Národohospodářská fakulta VŠE v Praze



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