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Interconnessioni elettriche: nuovi scenari e tecnologie

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Milano, 17.04.2014

Trino-Lacchiarella – 400 kV double circuit line

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Summary

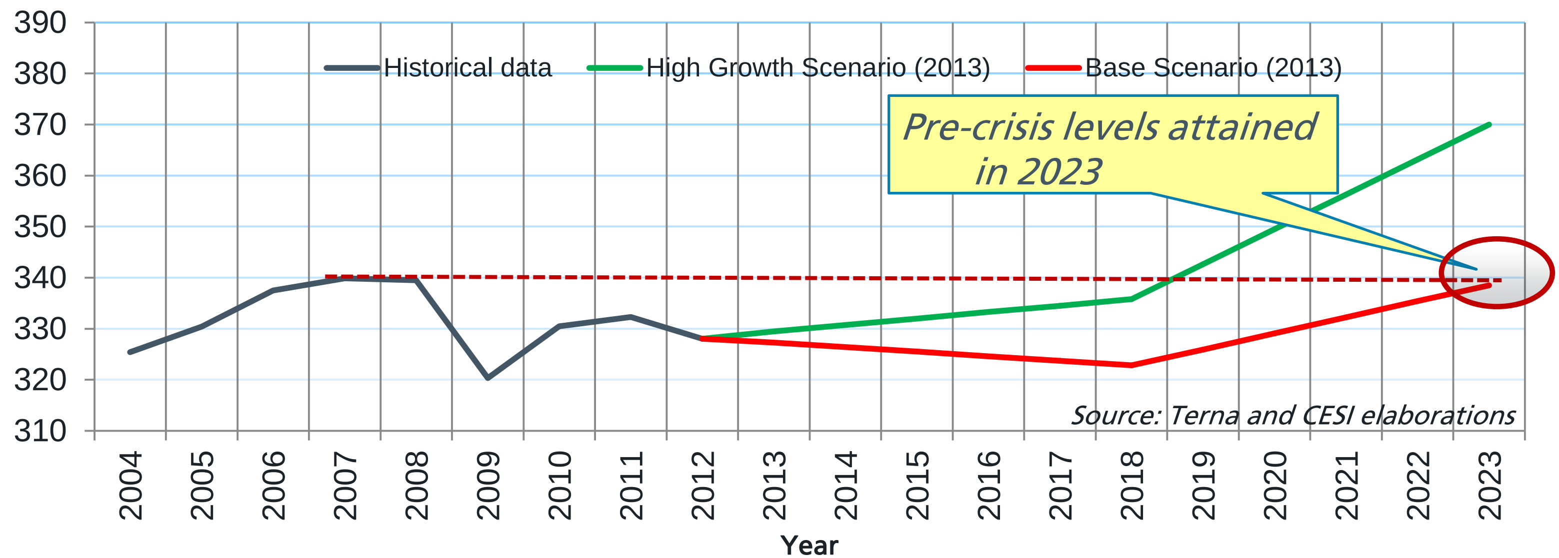
- Power system security: the increasing concerns
- Measures ensuring power system security margins
- New paradigms and complexity of the planning process
- Examples of interconnection studies among large systems
  - Tunisia-Libya interconnection
  - Europe-Turkey interconnection
- Technologies of links and development of complex grids
- Conclusions and key messages

Power system security: the increasing concerns

Load demand trend: demand stagnation across Europe, negative in some countries

	ELECTRICITY CONSUMPTION [TWh]		
	2010	2011	2012
ENTSO-E	3 360	3 339	3 336

Electricity demand projection 2013-2023 in Italy [TWh]



Peak demand evolution: slow growth in the next decade. Compound Annual Growth Rate of January peak load ≈1% per year.

Power system security: the increasing concerns

Load and peak demand trends

Conflicting effects

+

- ✓ Switch by end-uses from fossil fuel to electricity
- ✓ Increased use of electronic devices
- ✓ Possible massive deployment of electric vehicles (?)

−

- ✓ European economic downturn, especially in the peripheral countries
- ✓ Efficiency measures

Apparently, the demand is not the driver towards network strengthening

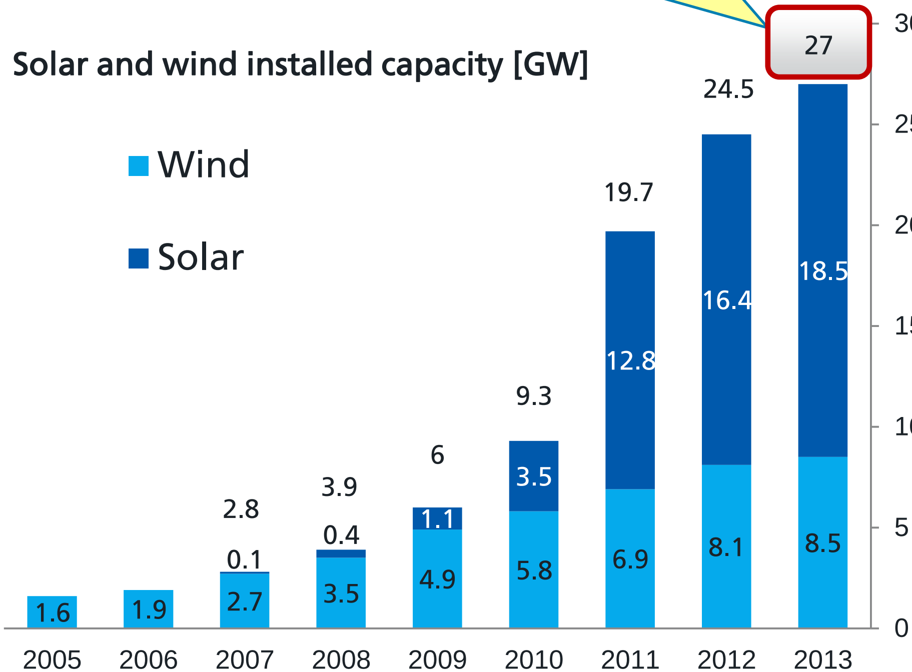
Power system security: the increasing concerns

RES generation: non-programmable RES power plants installations are exploding

Situation in Italy

20% connected to HV
60% connected to MV
20% connected to LV

(*)



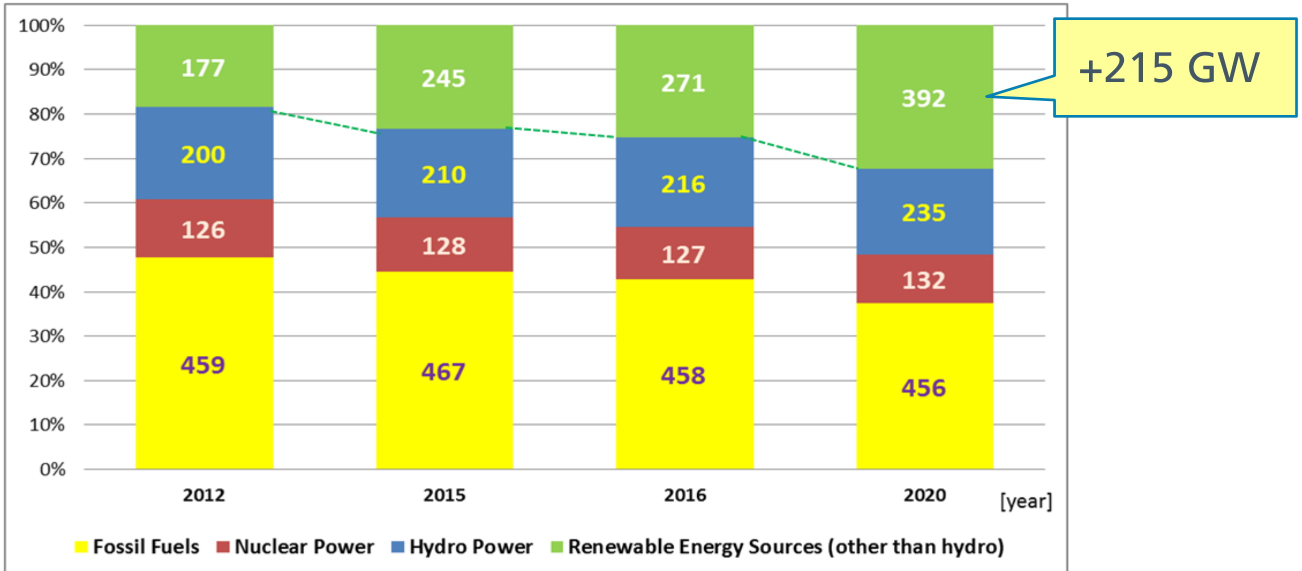
Source: Terna and CESI elaborations

Range of load variation in Italy:
- peak: ~50 GW
- minimum: 20 GW

(*) more challenging system controllability

Power system security: the increasing concerns

RES generation: continuous trend towards an increasing share of non-programmable RES generation



Source: ENTSO-E

EU targets

Full decarbonisation of the power sector

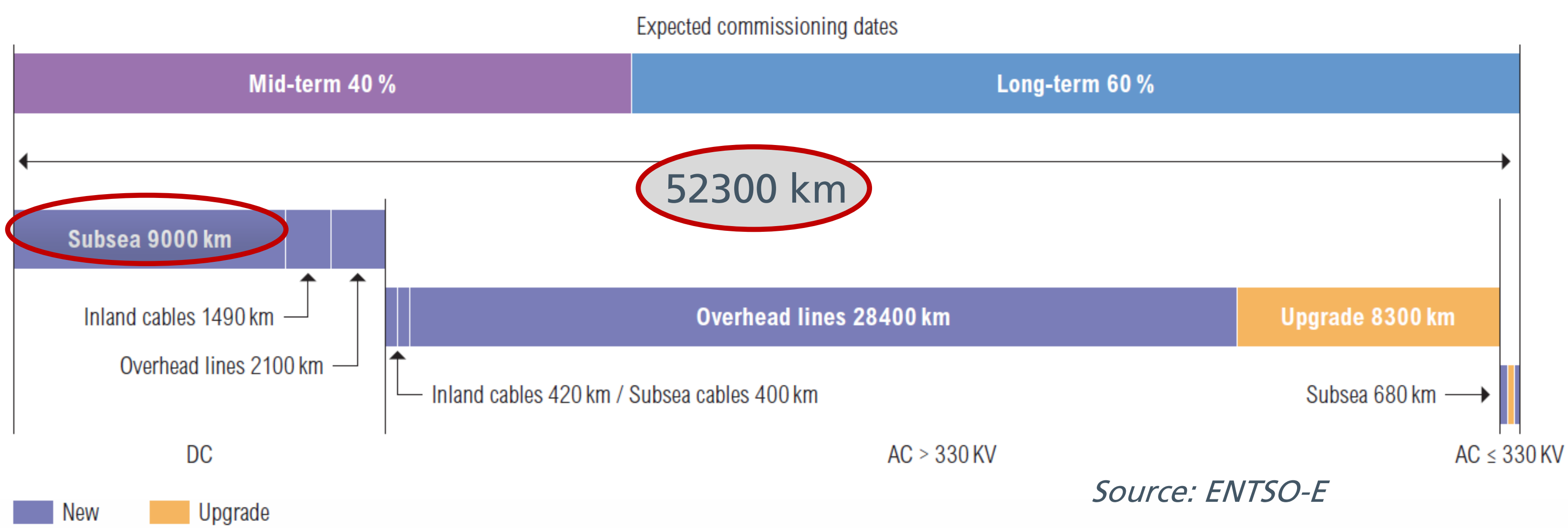
2020	2030	2050
20% CO_2 reduct. 20% RES	40% / 35% CO_2 reduct. 27% / 24% RES	80% / 95% CO_2 reduct.

Power system security: the increasing concerns

The deployment of RES generation is the main driver for the **reinforcement** and the **redesign** of the European transmission grid

REINFORCEMENTS

ENTSO-E TYNDP 2012: investments on projects of pan-European significance **>104 b€** to solve the **100 bottlenecks** across Europe, out of which **80** are caused by new RES generation



Source: ENTSO-E

Power system security: the increasing concerns

RESEDIGN

Redesign of the European transmission grid building a new transmission layer overlapped to the existing AC EHV grid: concept of e-highways.

Several initiatives ongoing:

If the networks reinforcements and the European Supergrid do not keep up with the RES generation deployment, the power system stability can be at risk

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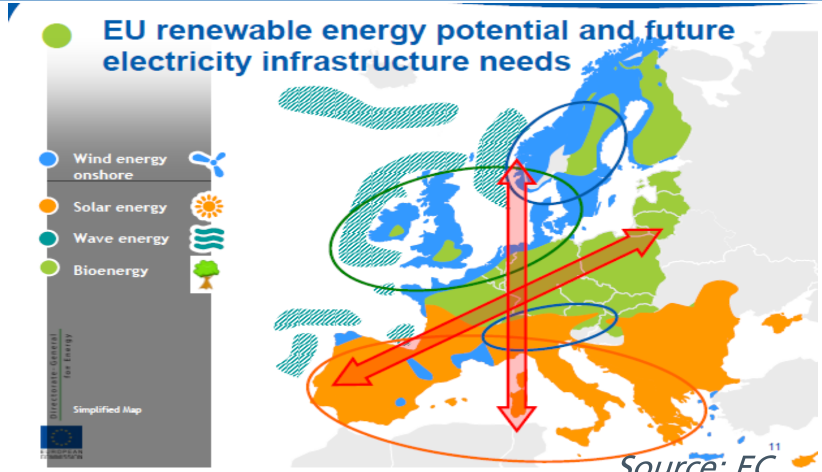
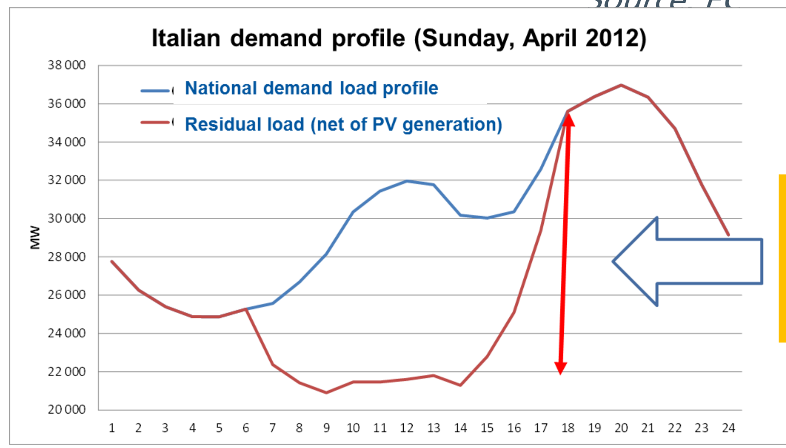
Measures ensuring power system security margins

- A sufficiently **strong pan-European grid** is needed to attain the 2020 and beyond EU targets…

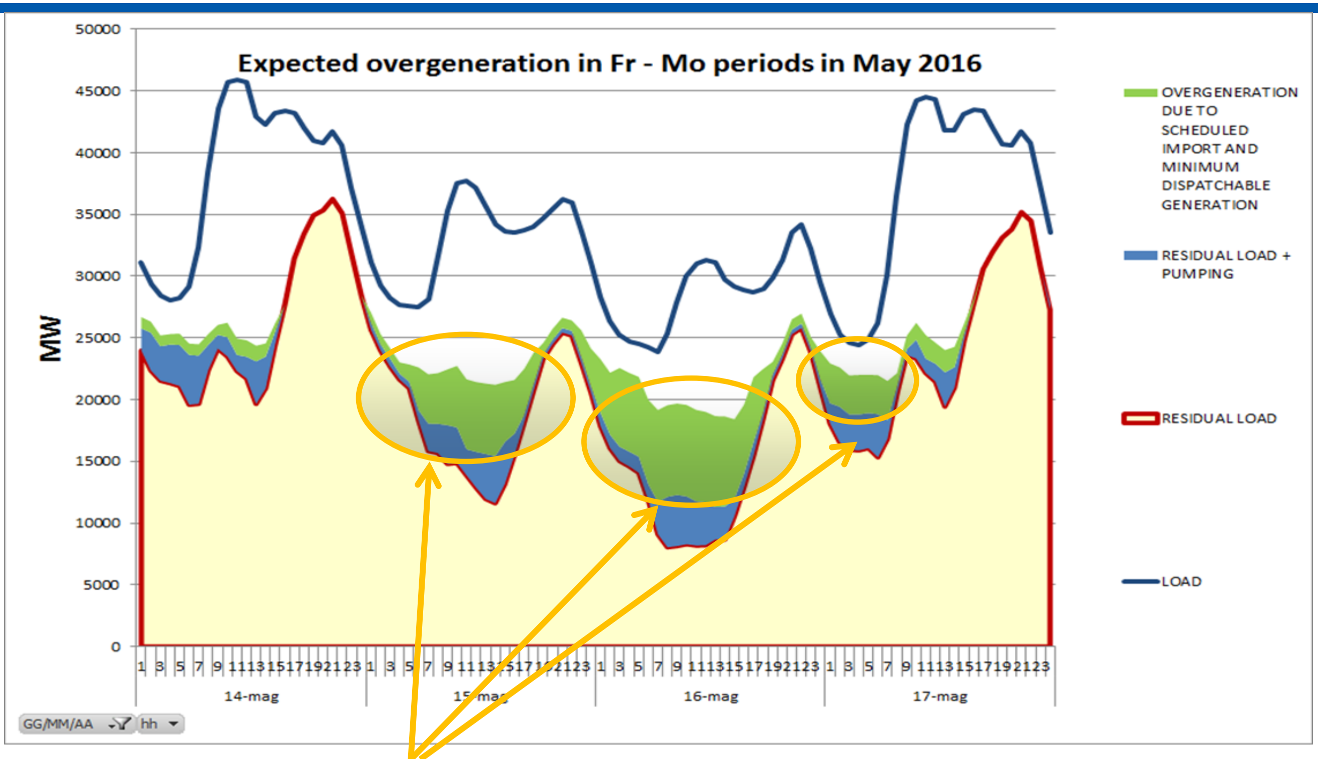




- …together with **highly flexible controllable generation….**

- …but it is not enough unless an **appropriate market design** is realized together with a regulatory framework harmonised at the EU level.

Example: cross-border balancing to mitigate the risk of "overgeneration"



Situations of "overgeneration" can be solved, if the following conditions are fulfilled:

a) Availability of a **sufficient Transfer Capacity across the borders/market zones**

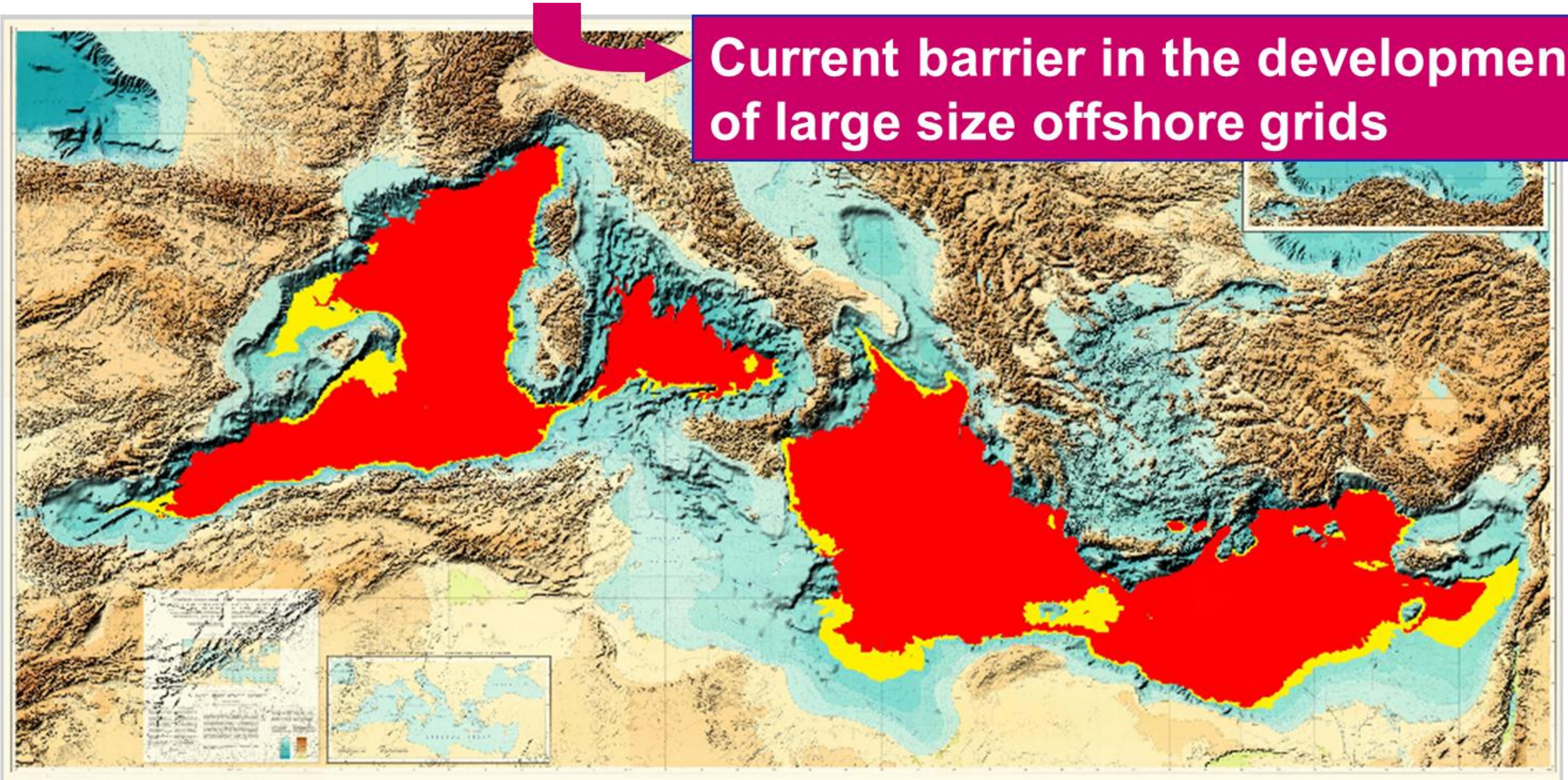
b) Possibility of **cross-border balancing** through a European balancing market (not existing now)

Technology challenges

Crossing the Mediterranean basin

technology limits related to the sea depth for laying down cables (about 2000 m) and their rating (about 1000 MW per circuit)

Current barrier in the development of large size offshore grids



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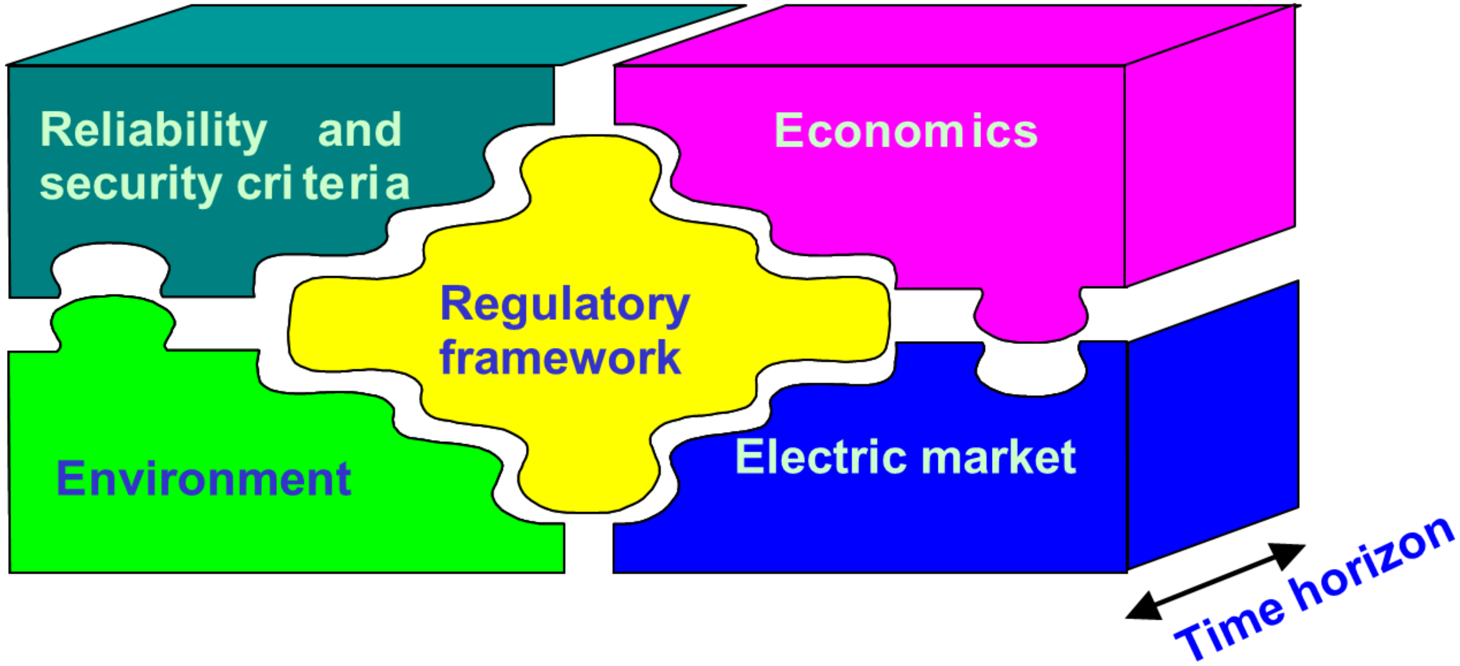
Planning of Electric Transmission Systems

The planning process has progressively changed as a consequence of a series of factors such as:

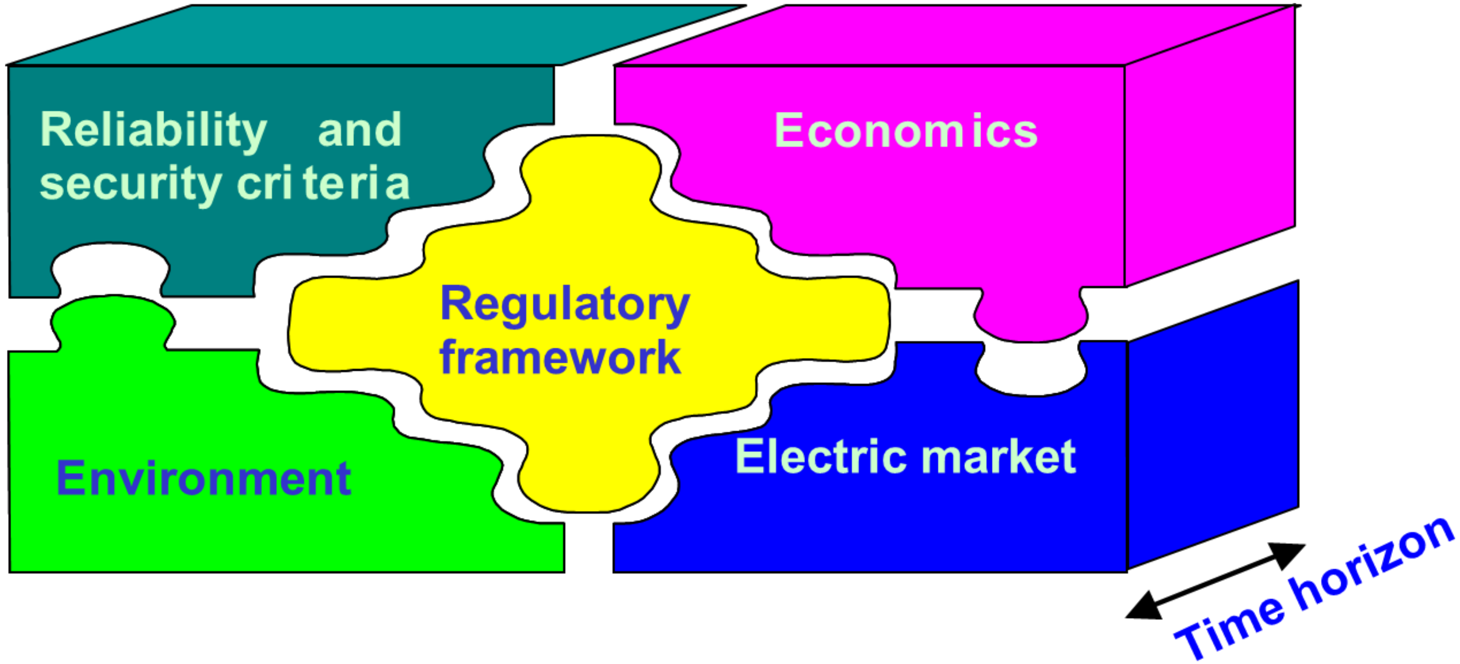
- **greater sensitivity of the local communities to the environmental impact of new transmission infrastructures;**
- **detailed cost-benefit analyses to justify the proposed investments towards the authority** (energy ministry, regulatory body), **who is empowered to deliberate for the recovery of the investments through transmission fees;**
- **increased efficiency in the G & T sector to smooth GHG emissions;**
- **constraints related to market mechanisms.**

Planning of Electric Transmission Systems - Foreword



Economic, **environmental**, **regulatory** and **market** issues have to be addressed in addition to the "classical" **reliability and security criteria**

Planning of Electric Transmission Systems - Foreword



Different expertise and skills required

Need for joint-team work

Interconnections between countries or regions within a country: different roles

Stage 1	➢ **Role of reserve and mutual help facing large perturbations**
Stage 2	➢ **Pre-established contracts for energy exchange (usually on a multi-year basis)**
Stage 3	➢ **Cross-border trading based on medium and short term contracts. Driving forces:** ➢ **different primary resources and generation prices** ➢ **different patterns in the load absorption** ➢ **market rules in the involved countries facilitating international transactions**
Stage 4	➢ **Mean to foster penetration of RES generation**

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The Mediterranean Electrical Ring: an example of a tri-continental interconnection

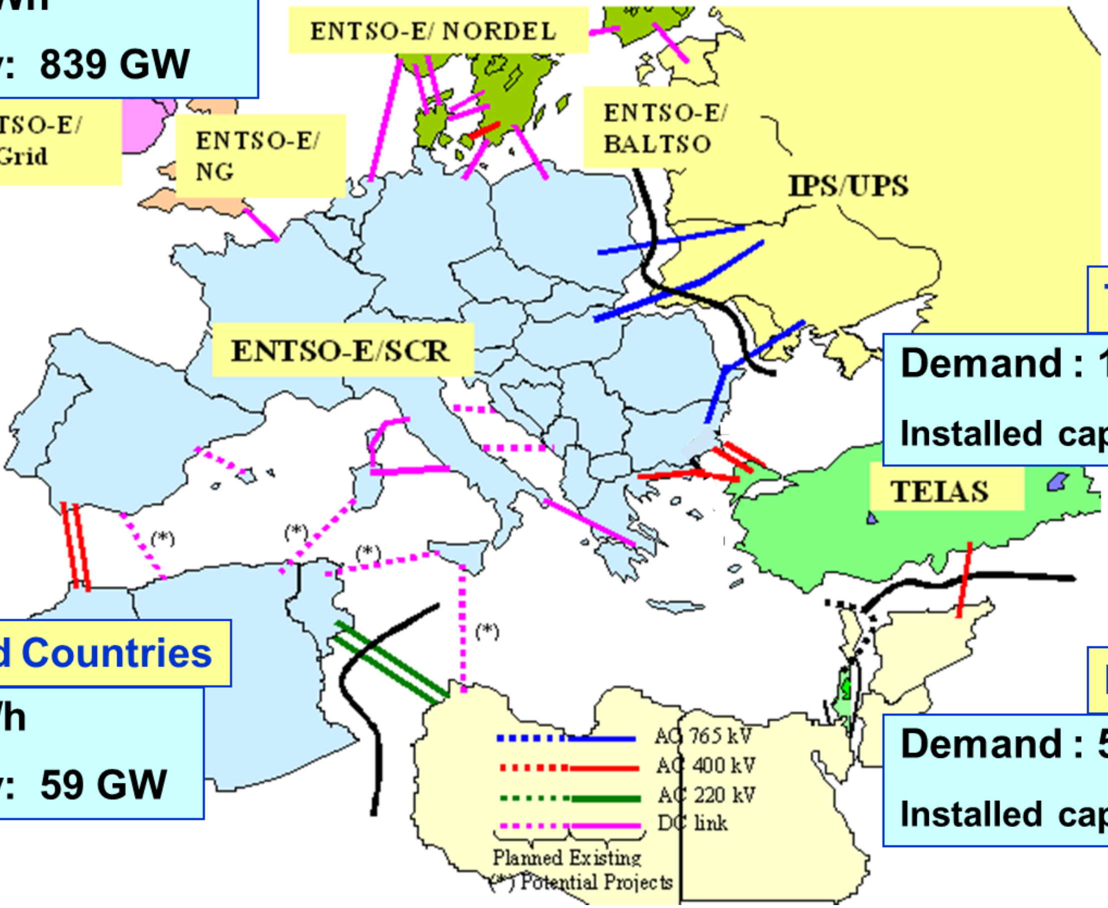
- **Current status of the interconnections in the Euro-Mediterranean region**
- **Tunisia – Libya interconnection**
- **Europe – Turkey interconnection**

Current status of the interconnections in the Euro-Mediterranean region

ENTSO-E

Demand : 3336 TWh

Installed capacity: 839 GW



Turkey

Demand : 198 TWh

Installed capacity: 42 GW

South & East Med Countries

Demand : 241 TWh

Installed capacity: 59 GW

Israel

Demand : 50 TWh

Installed capacity: 12 GW

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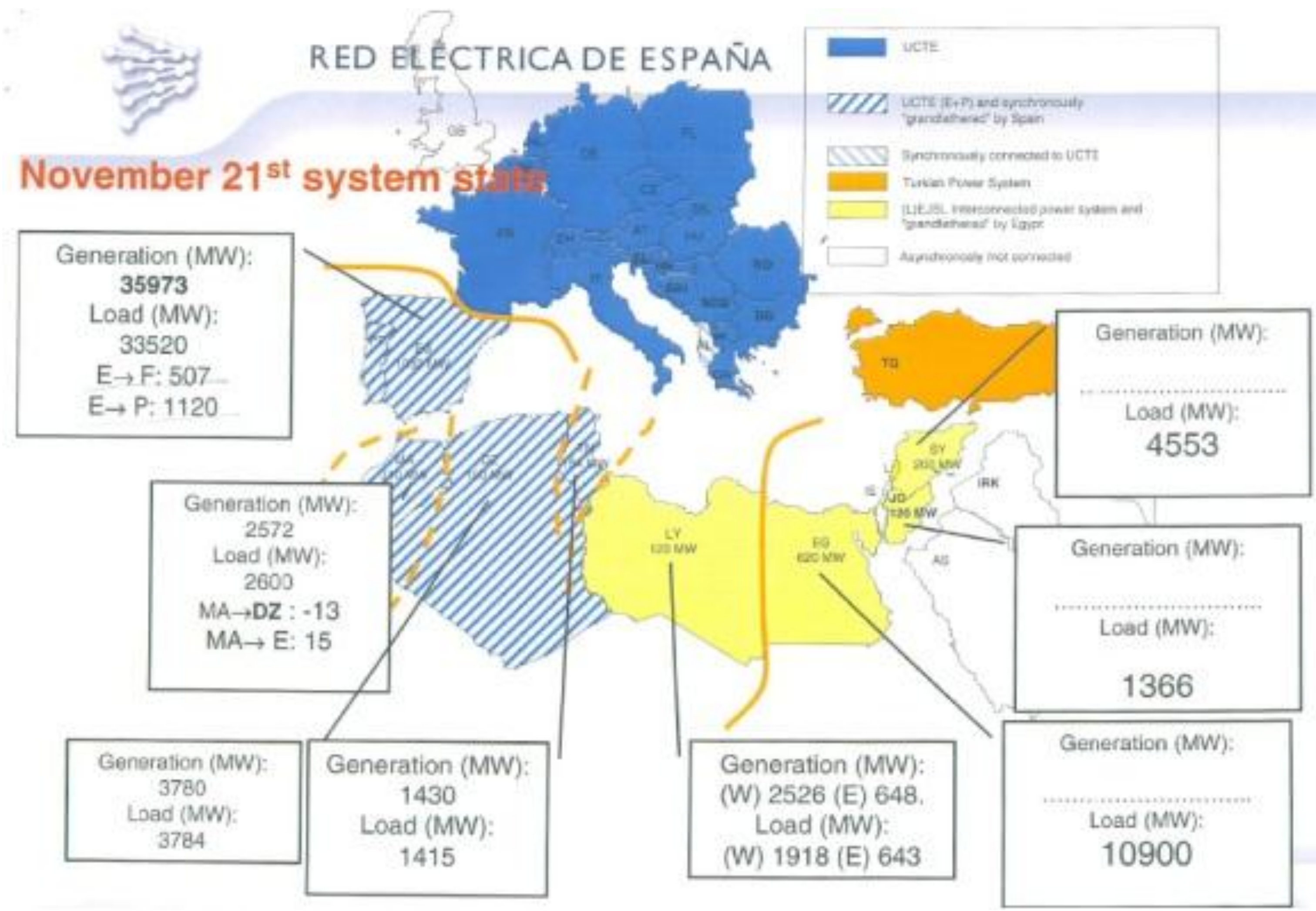
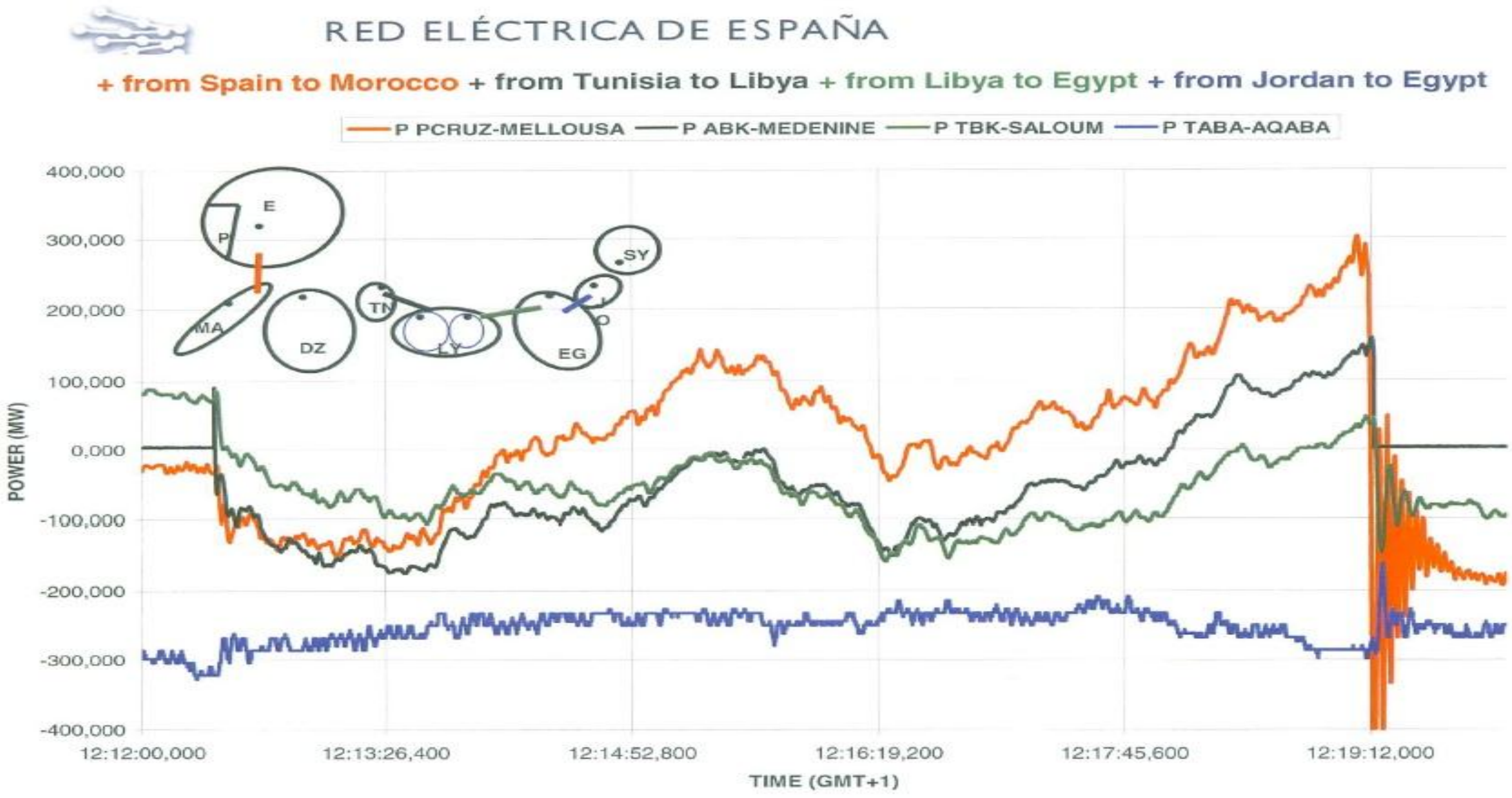
Tunisia-Libya interconnection lines

Lines built in 2002 following a bilateral agreement between Tunisia and Libya

Synchronisation test on 21st November 2005



Synchronisation test on 21st November 2005



Recording of power flows on cross-border cut-sets during the Tunisia-Libya synchronisation trial (source: REE)

Synchronisation test on 21st November 2005

Failed synchronisation attempt due to:

- **Excessive load deviations with respect to scheduling and poor AGC (Automatic Gain Control)**
- **Too binding defence plans**
- **Weak network structure**

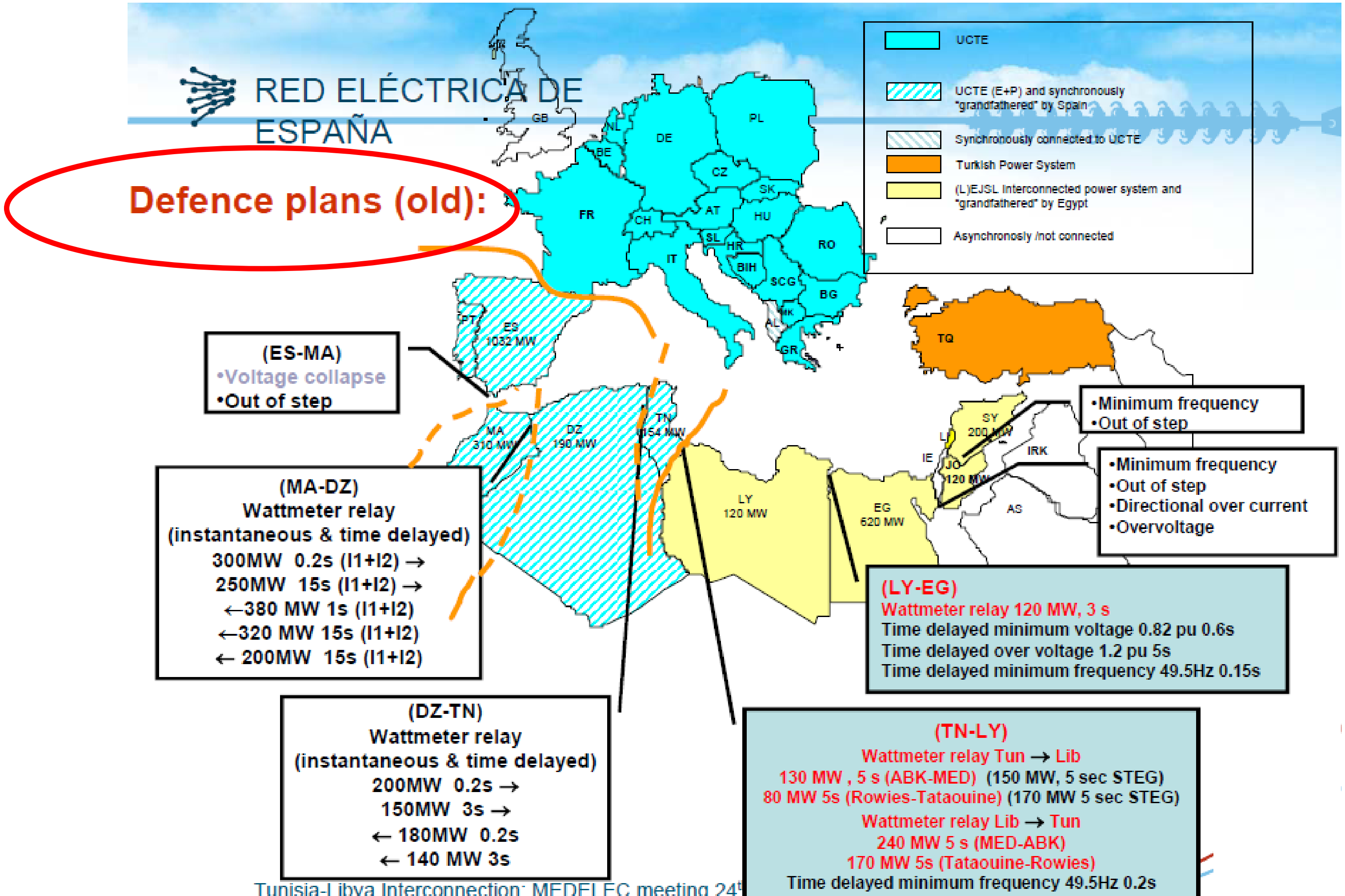
Measures after failed synchronisation test

Smoothing load deviations:

- Improvement of power-frequency control
- Automatic Gain Control (AGC) time constant reduction
- Increase of the number of generating units under regulation
- AGC configuration
- Egypt AGC testing

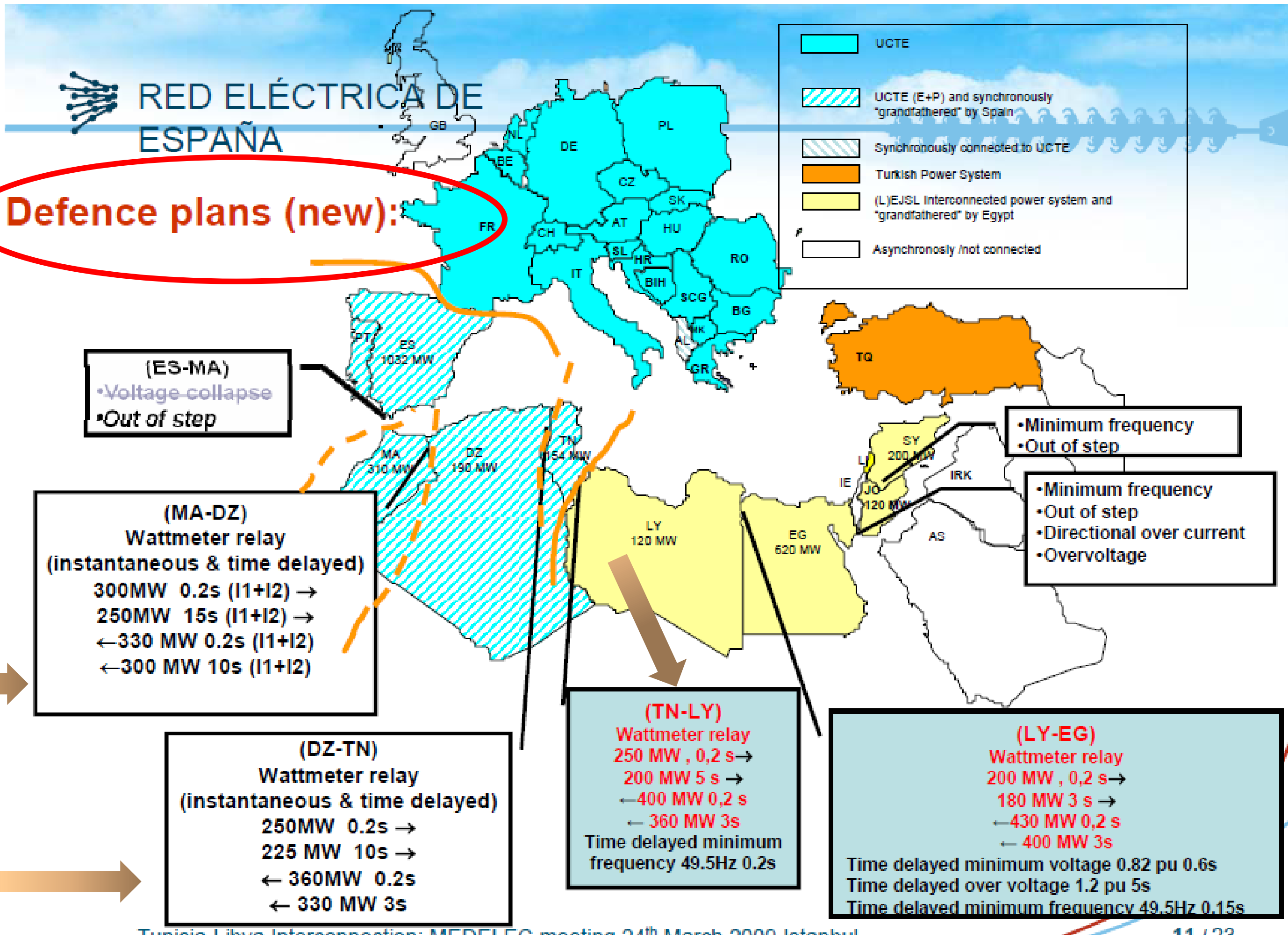
Measures after failed synchronisation test

Updating the coordinated defence plan



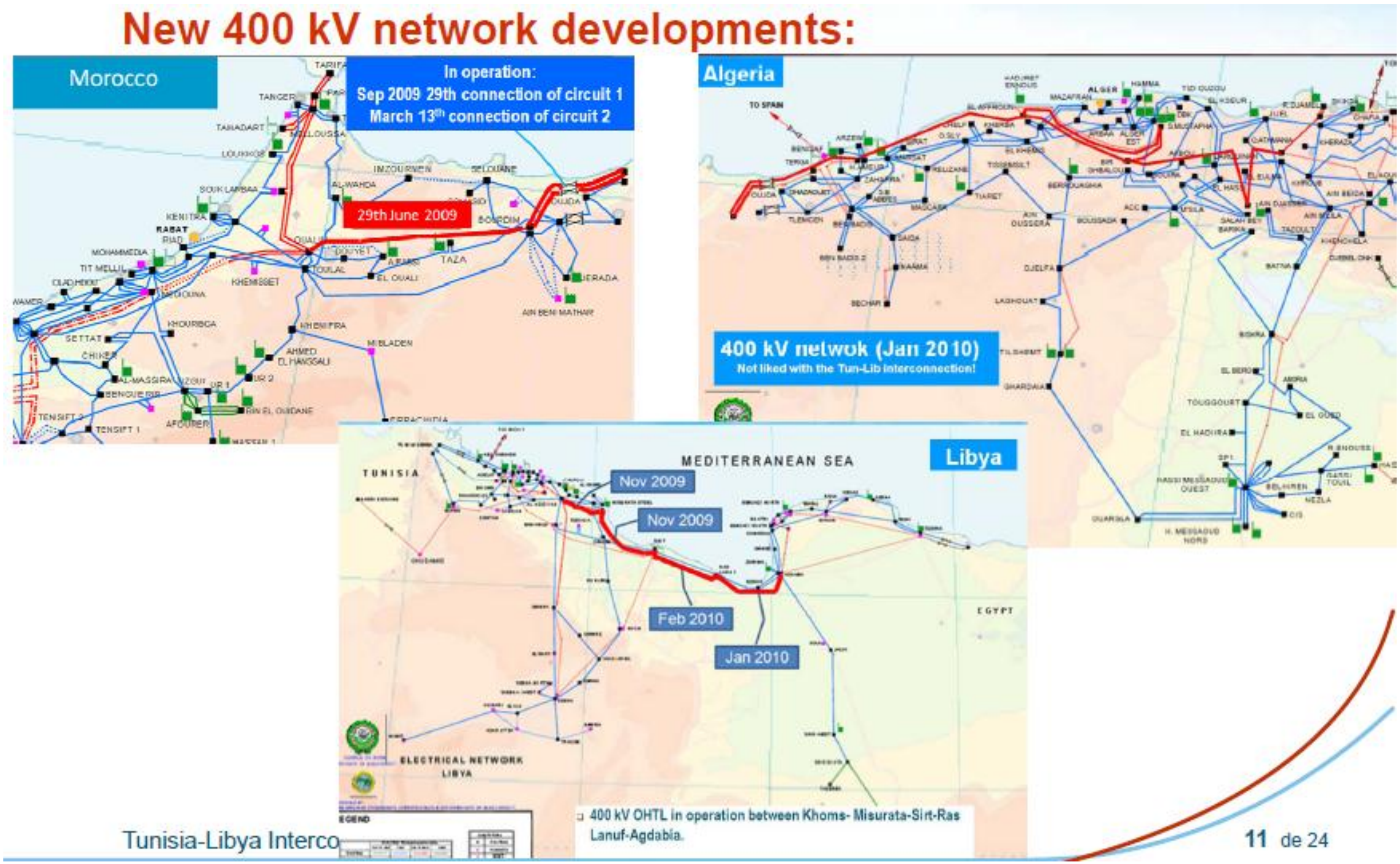
Measures after failed synchronisation test

Updating the coordinated defence plan



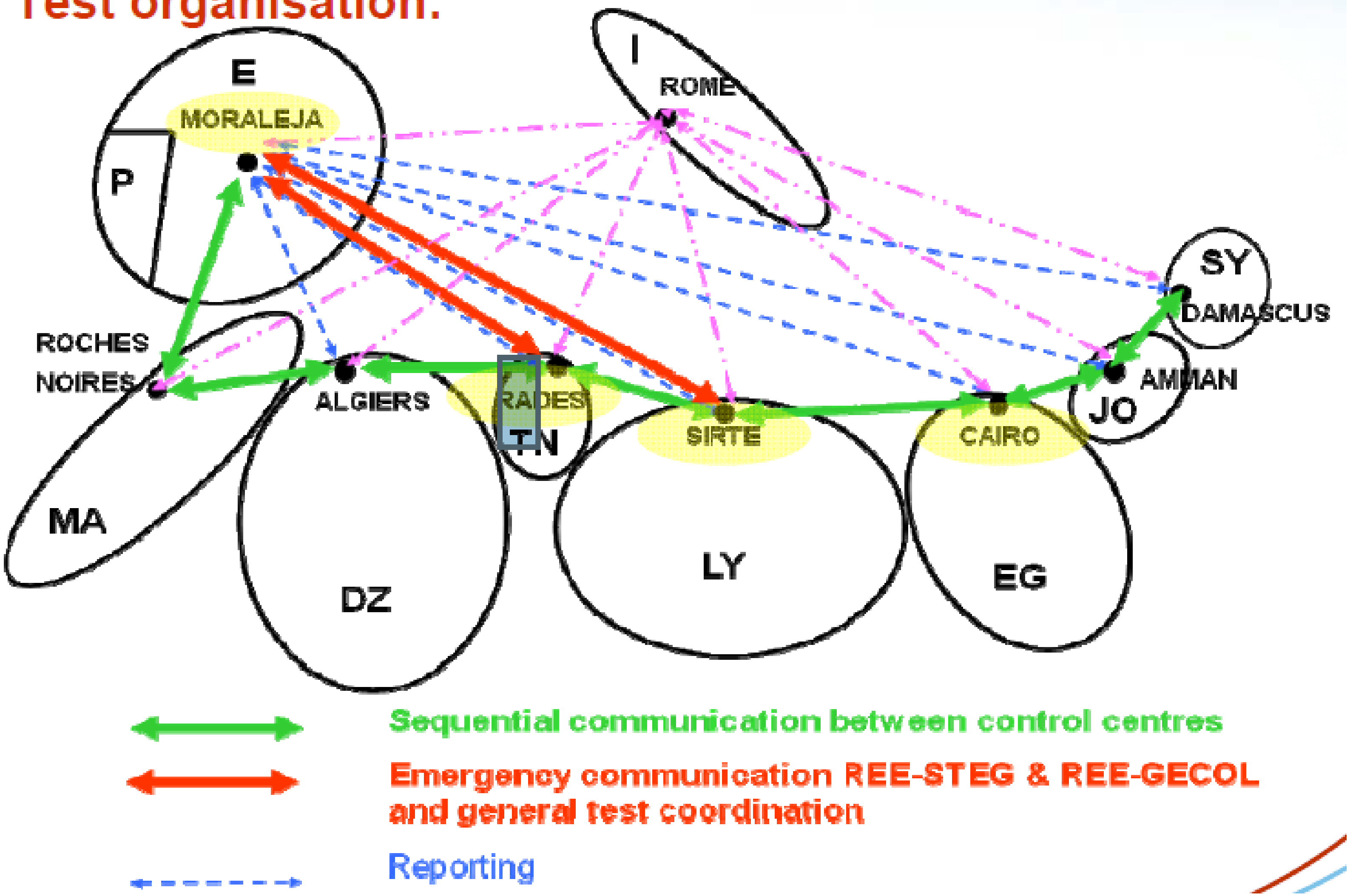
Measures after failed synchronisation test

Solving the network weaknesses



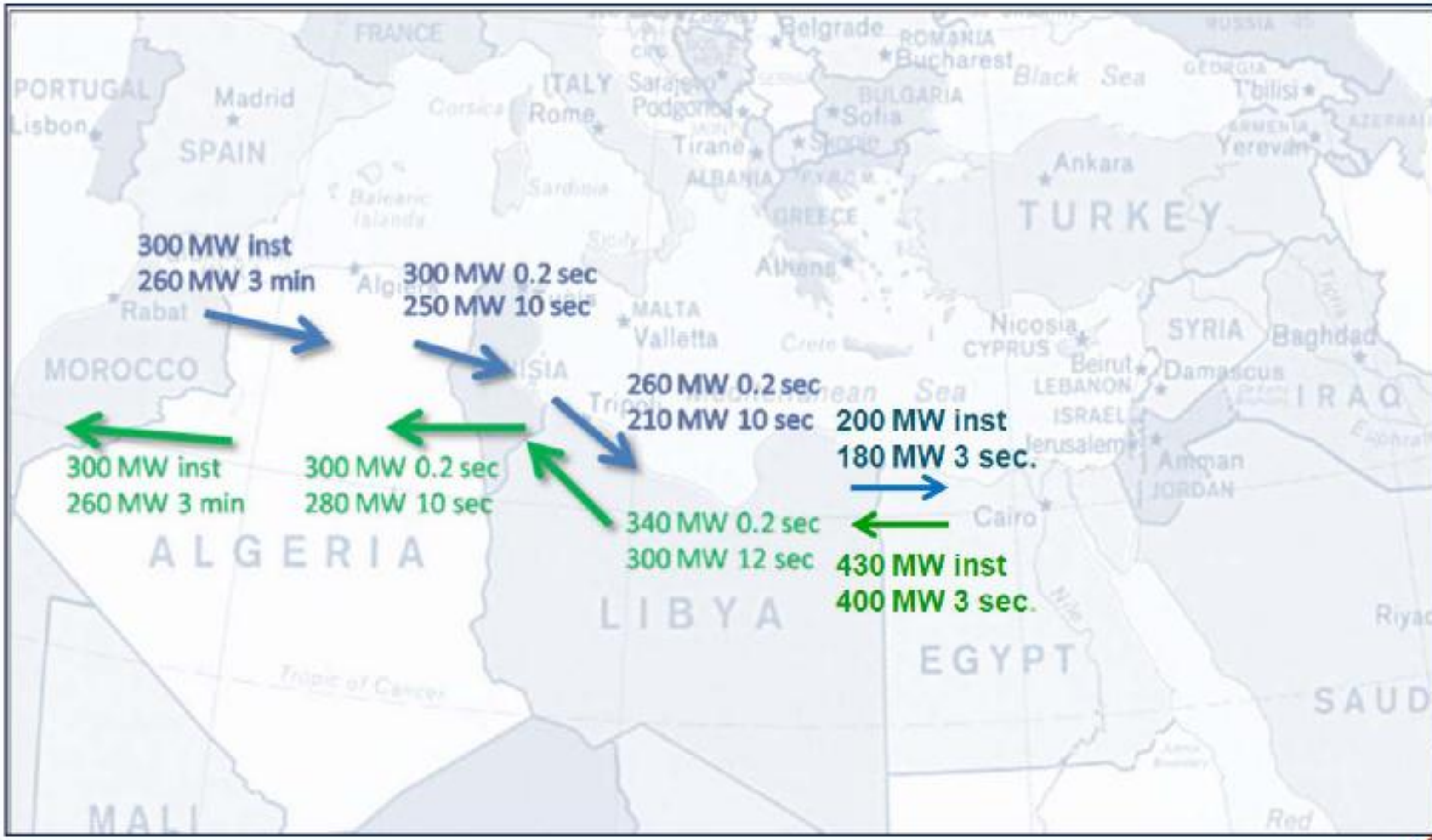
New synchronisation test on 27th-28th April 2010

Test organisation:



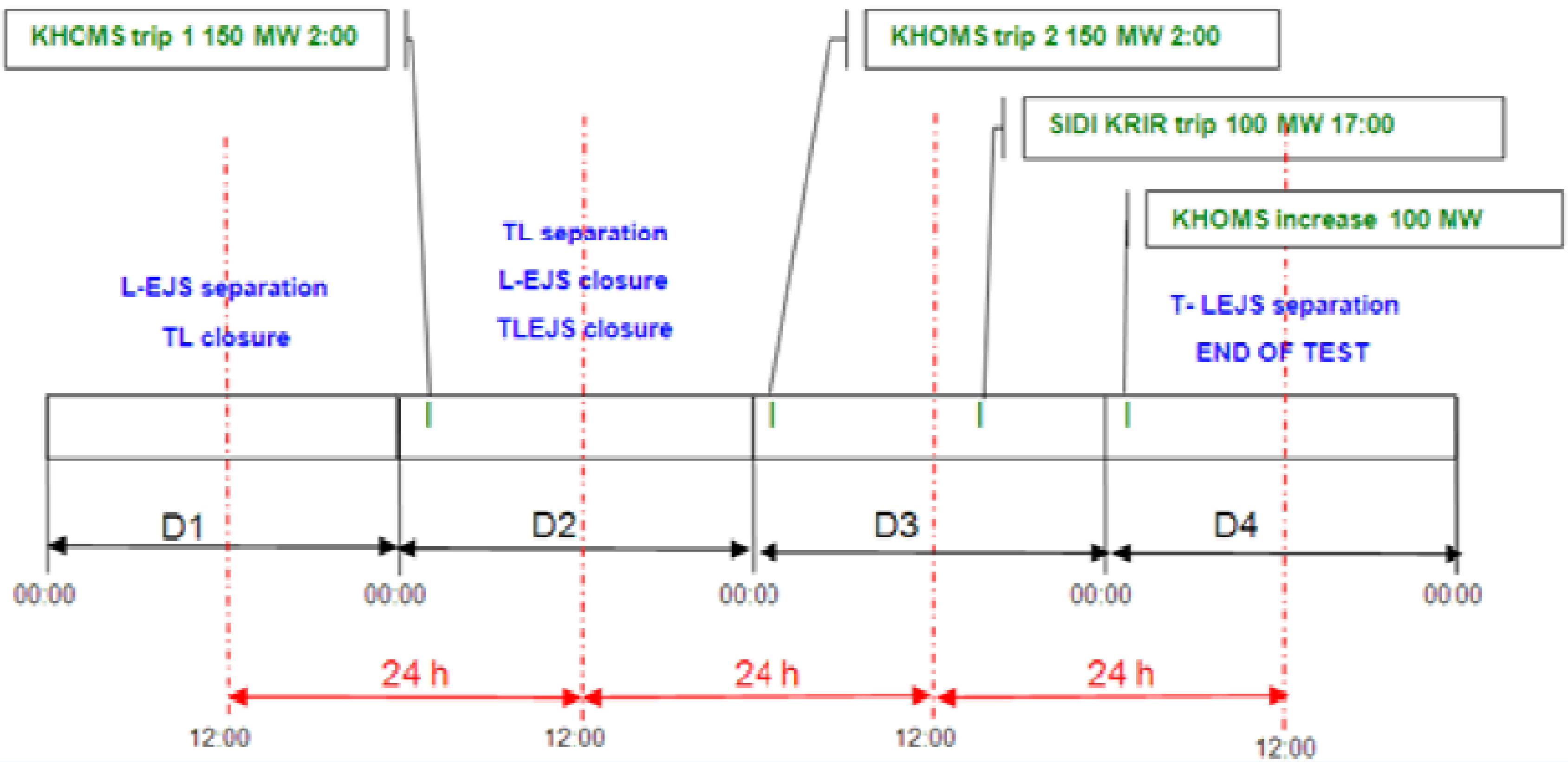
New synchronisation test on 27th-28th April 2010

Test organisation: implementation of defence plans.



New synchronisation test on 27th-28th April 2010

Test organisation: scheduled disturbances.



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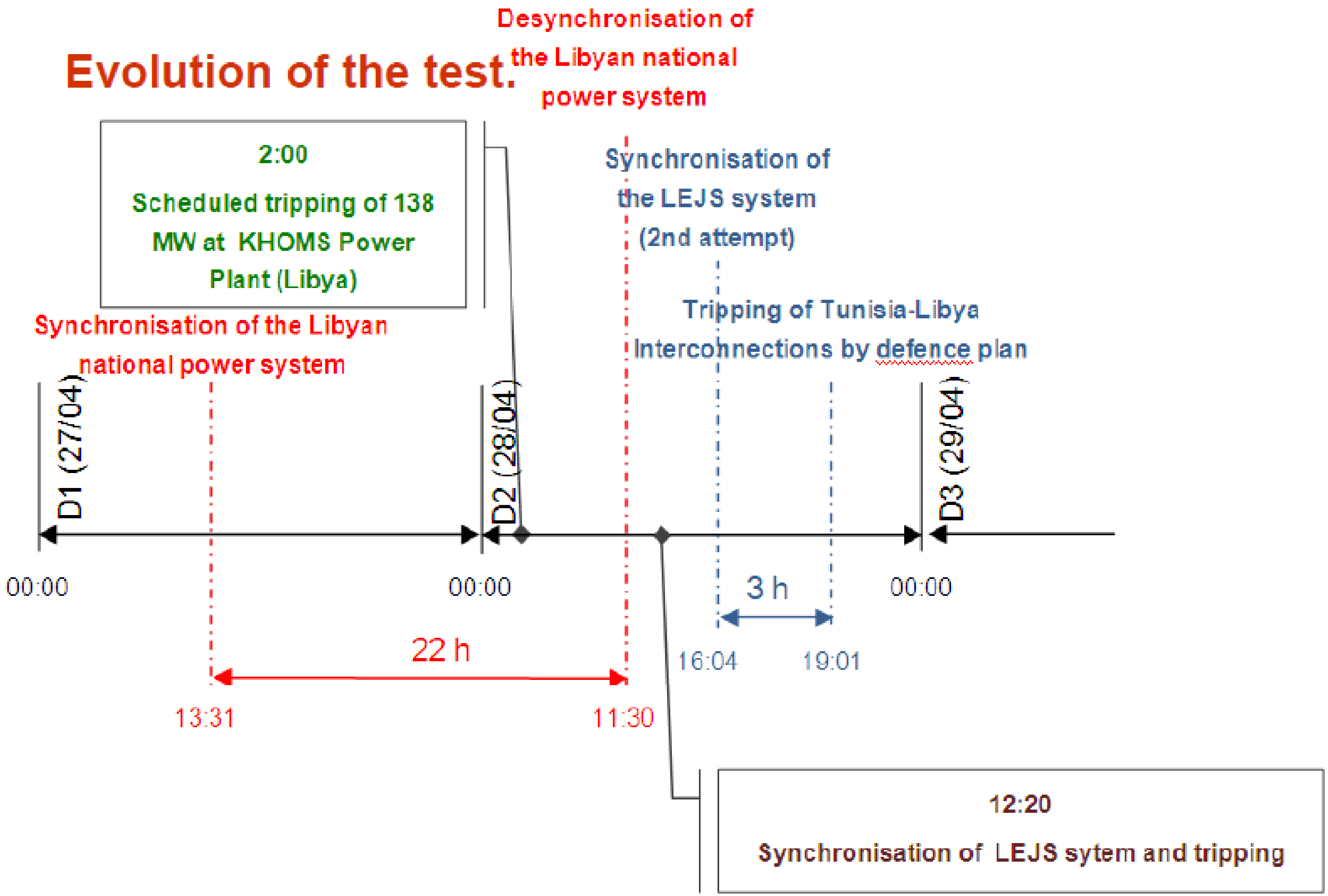
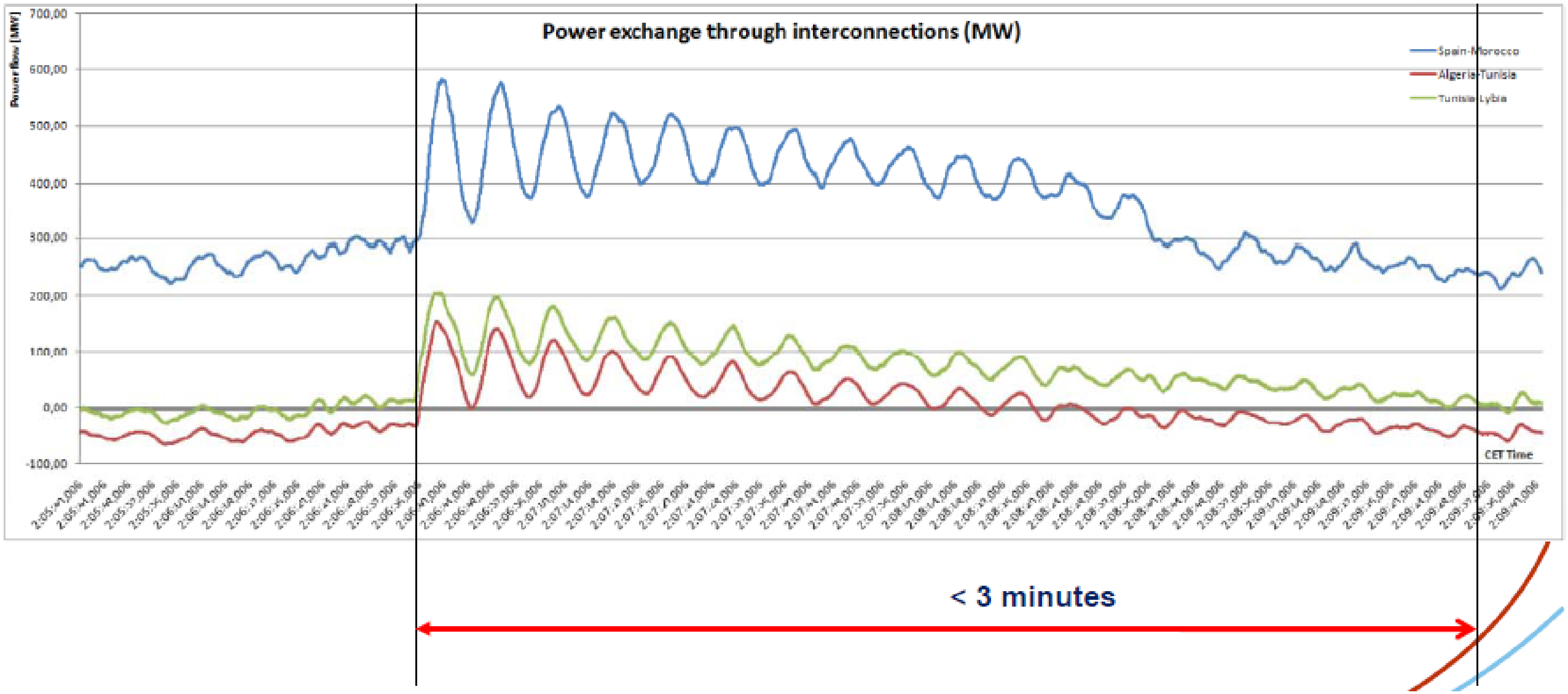


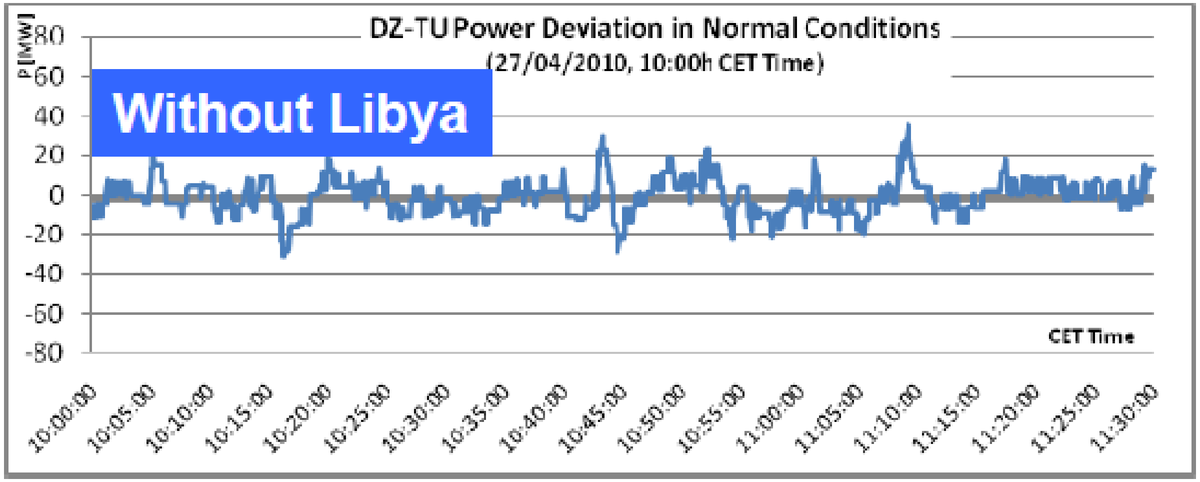
New synchronisation test on 27th-28th April 2010

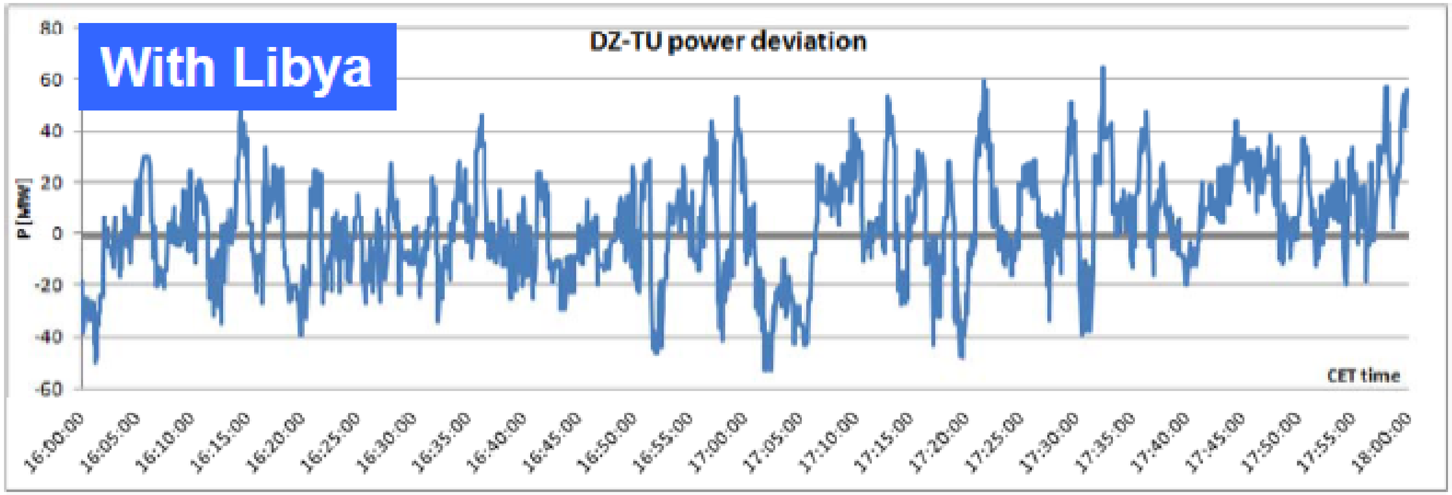
Only Libya connected: scheduled disturbance (138 MW trip in Libya).



New synchronisation test on 27th-28th April 2010

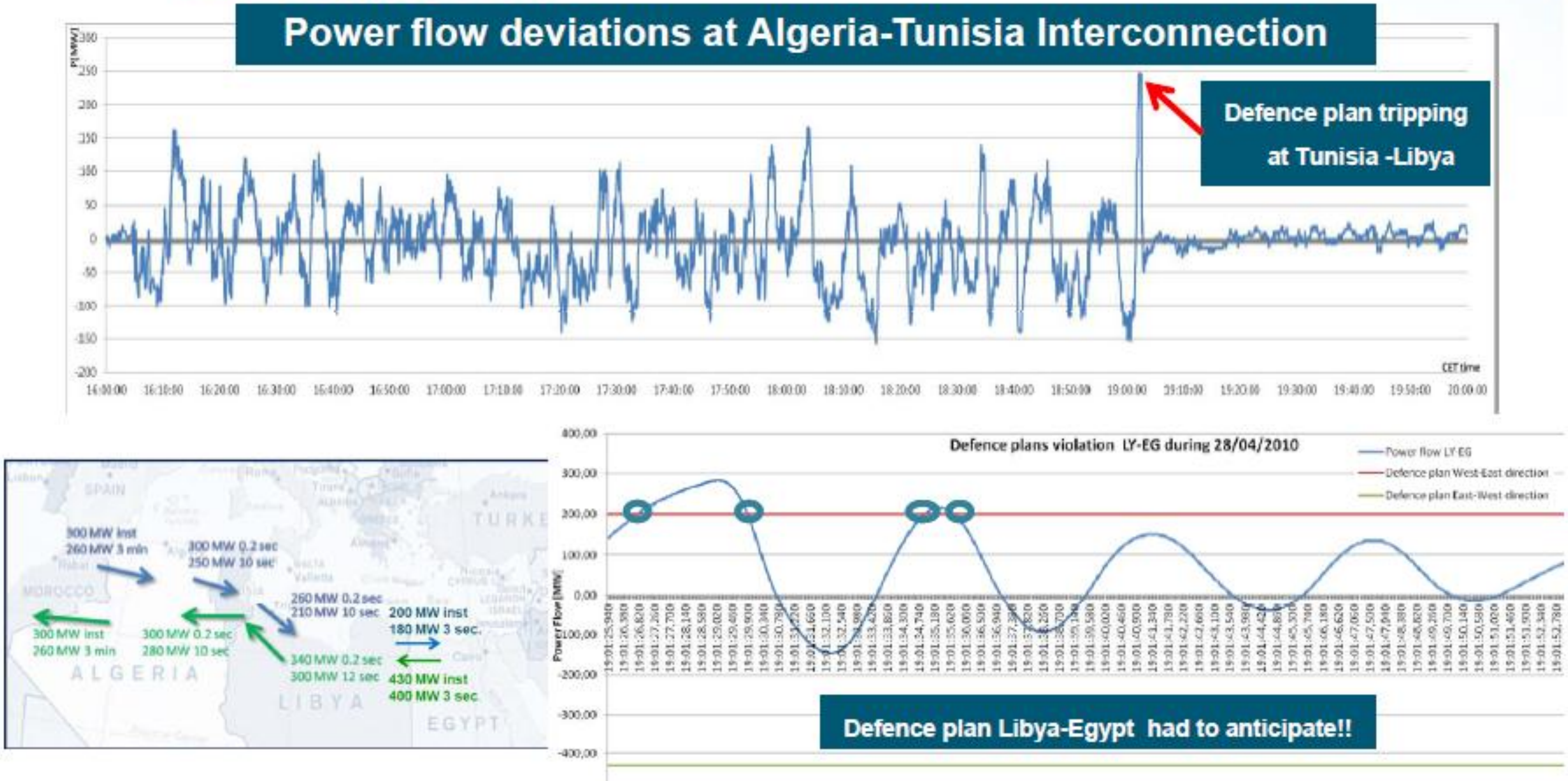
Only Libya connected: Power flow at Algeria-Tunisia interconnection.





New synchronisation test on 27th-28th April 2010

LEJS connected:



System not stable!

Test results:

- Coordination achieved during the test.
- WAMS performance.
- First 22 hours (only Libya connected):
  - Implementation of power exchanges.
  - Scheduled disturbance (tripping of 138 MW generating unit).
  - low damped oscillatory mode (≈ 0.1 Hz).
  - deviations detected at international lines.
- LEJS connection:
  - Power flow deviations in the international interconnections
  - ~~Control of power exchanges~~.
  - Defence plan.

Tunisia-Libya interconnection: lessons learned

- When deciding the interconnection between isolated systems, one shall consider the implications on the whole interconnected system

- A thorough analysis on the overall interconnected system may lead to different technological solutions (e.g.: HVDC or BtB+AC instead of full AC)

- Stabilising the behaviour of the interconnected system may entail interventions on other countries not directly involved in the new cross-border lines. These interventions may be “soft” (e.g.: retuning of the defence plans) or “hard” (e.g.: construction of new lines to solve network weaknesses)

- Lack of accurate technical investigations may lead to the loss of investments: lines are built, but cannot ne operated

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Europe-Turkey interconnection: a long way

- 1990's: first idea of interconnecting Turkey with South-east Europe
- March 2000: the Greek system operator PPC on behalf of TEIAS, when PPC filed an application to the UCTE (now ENTSO-E) asking for the synchronous interconnection of Turkey to the UCTE system and for Turkey's UCTE membership.
- March 2002: Turkey and Greece signed a Memorandum of Understanding for the construction of a 400 kV line between Babaeski in Turkey and Nea Santa in Greece
- June 2002: MoU signed in Bratislava between Turkey and UCTE on starting investigations for the synchronisation of Turkey with Europe

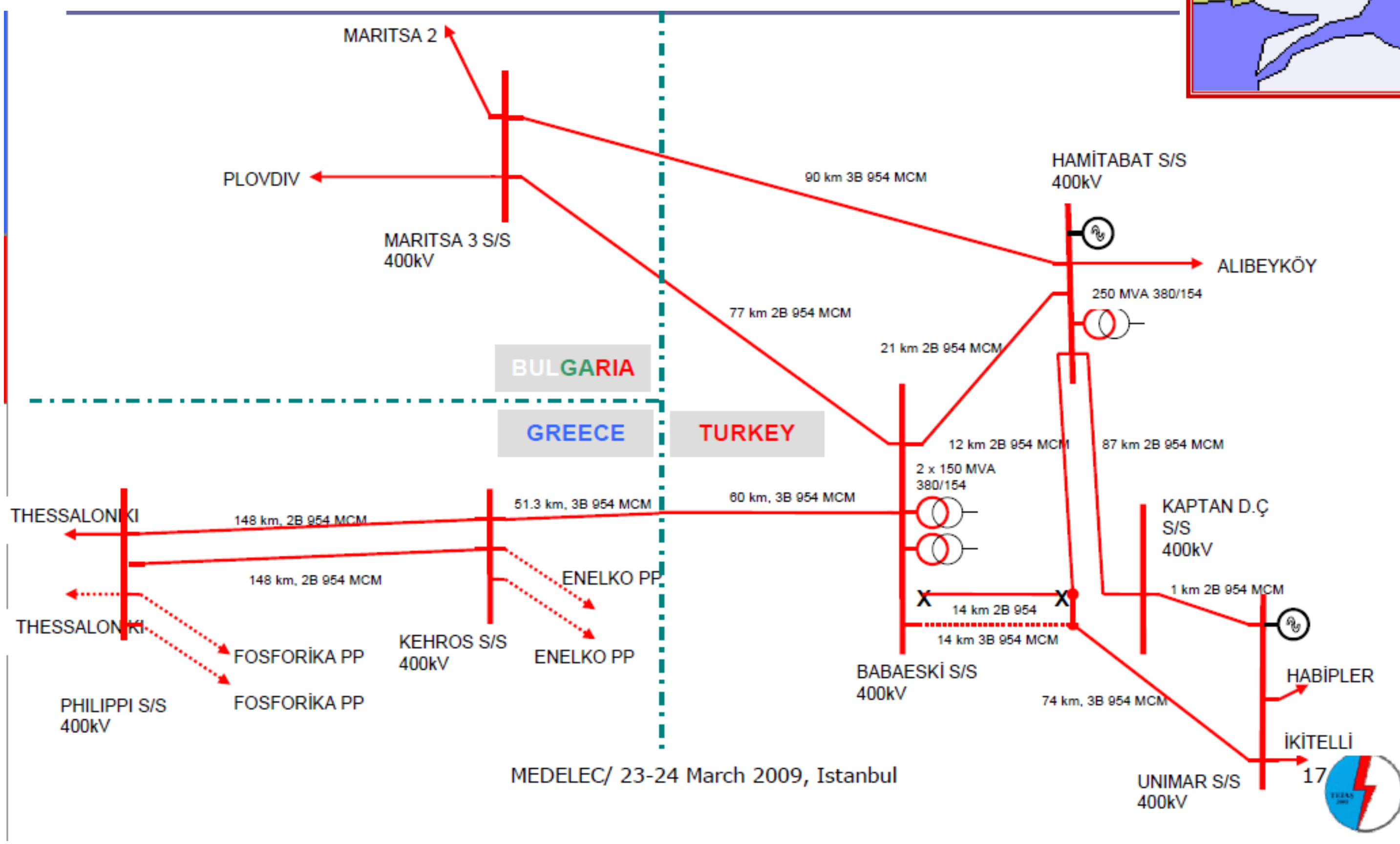
Europe-Turkey interconnection: a long way

- Nov. 2002: Turkey signed a MoU, which envisioned the establishment of South-East Europe Regional Electricity Market and its integration to the EU's internal electricity market.

- Sept. 2005: Service contract with UCTE for technical studies and investigations on rehabilitation requirements of Turkish transmission system and generating units

- Apr. 2007: study project finalised and report submitted

Final EU-Turkey interconnection scheme



Europe-Turkey interconnection: a long way

Main outcomes of the technical studies achieved in Apr. 2007:

- New critical UCTE-Turkey inter-area mode at 0,15Hz with insufficient damping
- Insufficient damping mainly caused by dynamic characteristics of:
  - Existing AVR
  - Governors of hydraulic turbines
- Deterioration of the existing UCTE inter-area oscillation mode (0,2Hz)
- Damping performance highly dependent on power exchange Turkey - UCTE
- Power export from Turkey to UCTE has to be limited by 500MW for the trial operation phase

Europe-Turkey interconnection: a long way

Further phase of investigations and technical performance improvement (2007-2009):

UCTE

Organization of the Project Group Activities

Phase A: Preparatory Phase

- Technical Studies
- Reports on the Turkish Power System
- Monitoring of the Turkish Power System operation
- Measurements and Units Tests
- Drafting of Contractual Agreement

Phase B: Monitoring of the upgrading measures implementation

Phase C: Tests in island mode and trial parallel operation

Europe-Turkey interconnection: … finally the day has come

1st synchronisation tests: "Isolated mode" tests with peak load (11-24 January 2010) and off-peak load (22 March-5 April 2010)

Note: the term "isolated mode" tests refers to performance tests of the Turkish power system while it is disconnected from all the neighbouring countries

Europe-Turkey interconnection: … finally the day has come

2nd synchronisation tests: Trial parallel operation (started 18 September 2010)

In this step, the Turkish power system was synchronised with the interconnected power systems of Continental Europe; during this phase, the power exchanges between Turkey and the ENTSO-E were fixed according to the following steps:

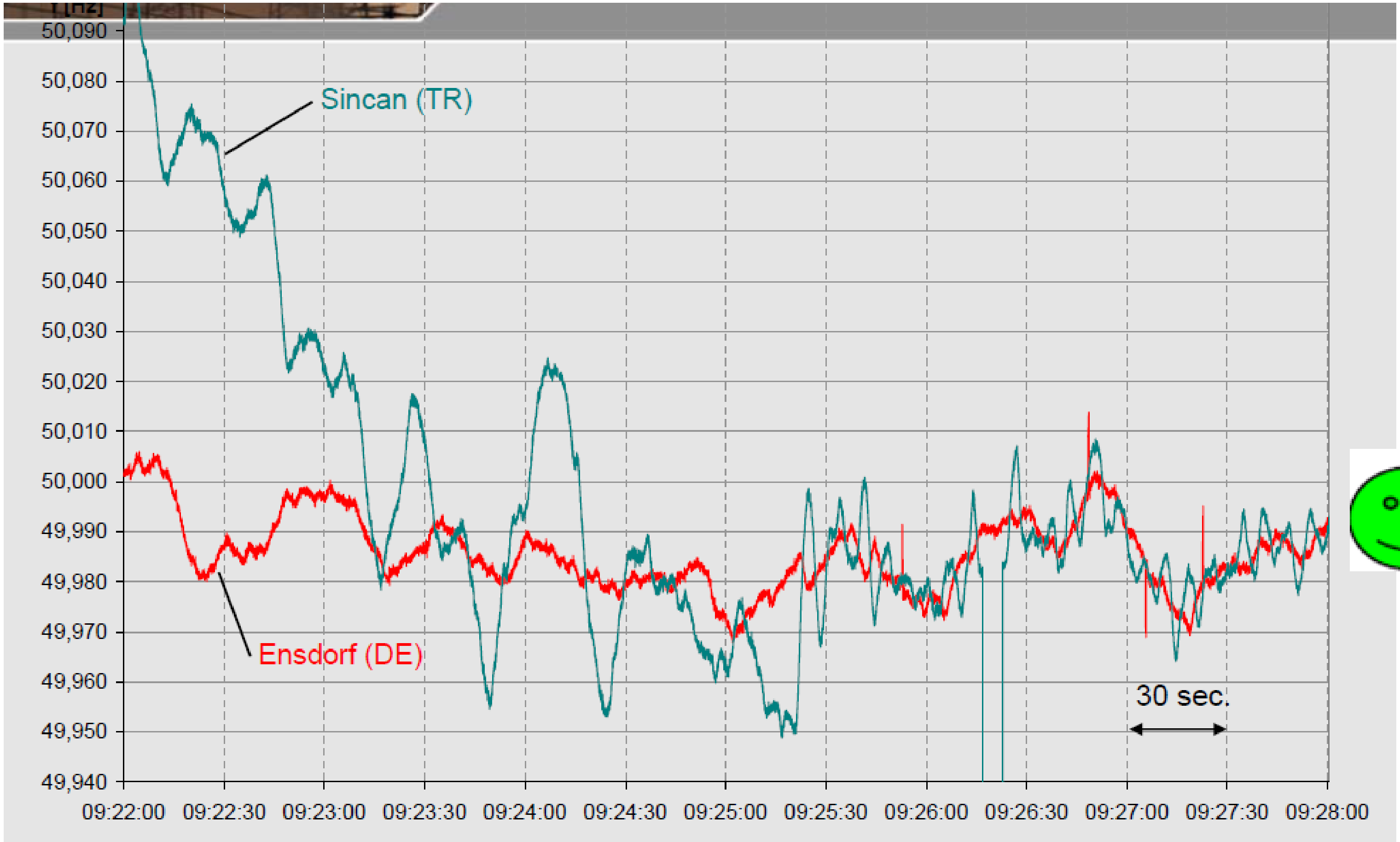
- in the first phase no exchanges were scheduled;
- the second phase (21 February-7 March 2011), non-commercial energy exchanges between the Turkish system operator and respectively the Bulgarian and the Greek transmission system operators in both directions and at both borders were scheduled by TSO's;
- in the third phase (1 June 2011, on-going), limited capacity allocation for commercial electricity exchange between Turkey and ENTSO-E's Continental Europe Synchronous Area is available.

Europe-Turkey interconnection: contractual agreement

To enable the synchronous operation and energy exchanges with ENTSO-E, a Contractual Agreement has been signed. The Contractual Agreement is a legally binding document, which includes all technical, organisational and legal issues to be fulfilled for the interconnection of the Turkish power system to the ENTSO-E network. The topics addressed are:

- *operational feasibility;*
- *delimitation of conditions for joint synchronous operation;*
- *congestion management;*
- *legal/regulatory conditions;*
- *liabilities of TEIAS in case of non-compliance with the agreement;*
- *liabilities of ENTSO-E in case that TEIAS fully complies with the requirements, but ENTSO-E would not allow the synchronous interconnection;*
- *liability of TEIAS in case of problems during the synchronous trial operation.*

Europe-Turkey interconnection: a long way…
…but everything was successful



Outcome of the first synchronisation test on 18.09.2010 at 09:25:21 – six minutes recording

Europe-Turkey interconnection: lesson learned

- Multilateral agreement and involvement of all partners of the two systems (ENTSO-E and TEIAS)

- Execution of detailed technical studies and simulations with checks on the real system and definition of the necessary upgrading measures in the Turkish power system

- Synchronisation test carried out in stages (Turkey isolated, non-power exchanges, increasing power exchanges and finally starting with commercial-based power exchanges)

- Multilateral agreement on common rules for the Cross-border trading of electricity.

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Typologies of interconnection lines

- The transport capacity required for interconnection can be realised with technologies very different each other, namely:
  - HVAC
  - HVDC

- The planner shall select:
  - voltage level
  - number of lines
  - number of circuits per line (e.g.: single / double circuit)
  - type of wires
  - design of electric tower
  - right-of-ways
  - etc.

Typologies of interconnection lines

- Analyses for the design of an interconnector are very similar to the process followed for the planning of transmission lines, but with less degrees of freedom dictated by the pre-existing situation in the two systems (e.g.: in case of a new power plant in antenna, the voltage at the power plant side is not predetermined).

- The planner proceeds generally to techno-economical evaluations targeted to the interconnection area only (see following example) considering the technical constraints set by the two systems and, in a later stage, detailed technical verifications are carried out to check the compatibility of the new interconnector with the system performances.

Alternate Current or Direct Current?

- HVDC solutions can become economically profitable for OHL covering long distances (e.g.: >600 km) and high utilisation hours

- It is necessary to accurately assess reliability and costs of alternatives, keeping in mind that HVAC on long distances can require intermediate s/s for compensation of reactive power and voltage control

- For power transmission through submarine cables, AC is not suited when distances exceed a 40-60 km

- In general economic profitability of DC submarine cables is directly related to their rating

Alternate Current or Direct Current?

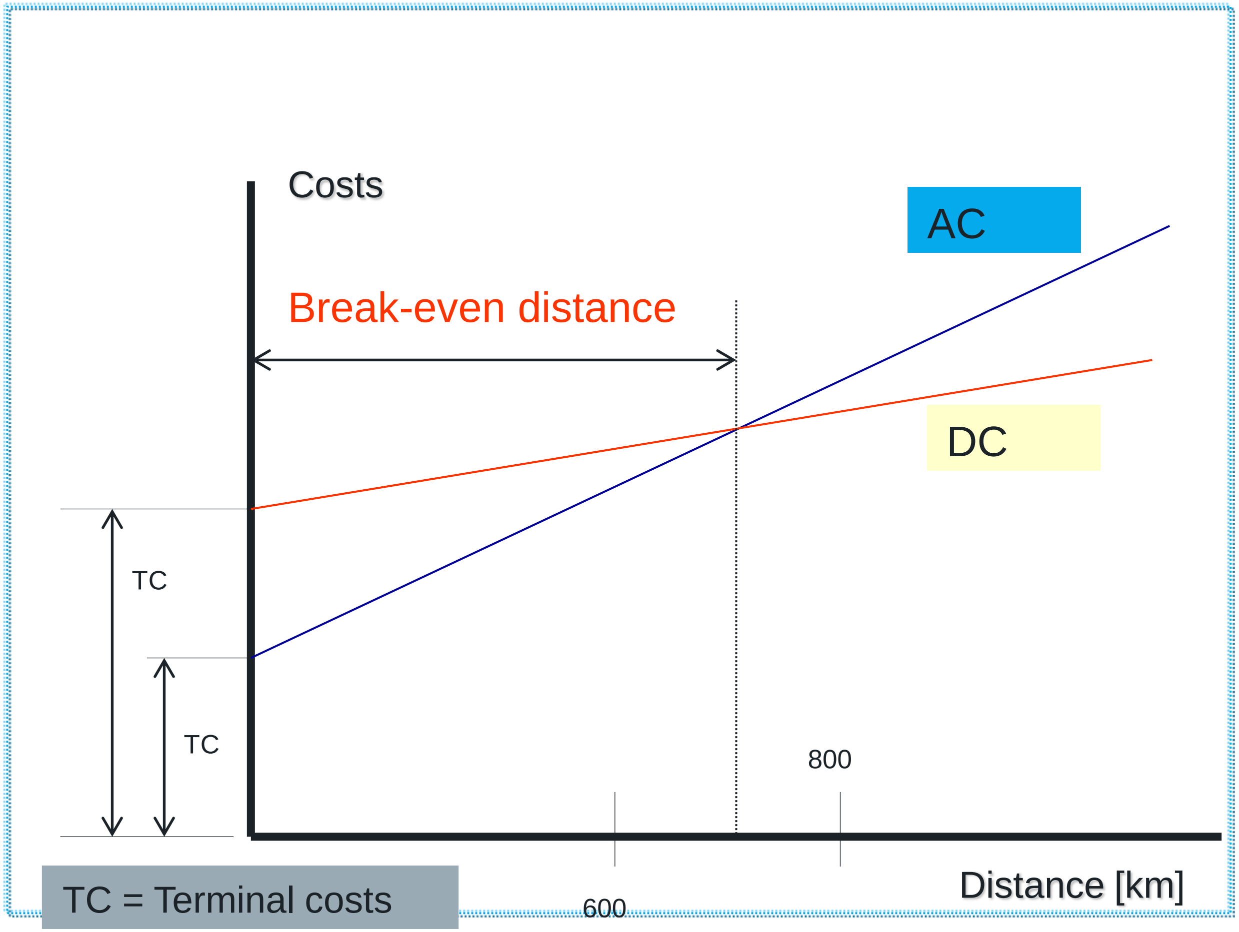
- Larger distances can be reached with AC cables laid on land, on condition of installing intermediate s/s for Var compensation

- DC links (even with very short distances or null distances Back-to-back-) are designed to interconnect systems with different frequencies or different dynamic performances (e.g.: different regulating characteristics)

Break-even distance between DC and AC transmission in case of overhead lines

High voltage direct current links

Cost comparison between AC - DC



AC solution vs. DC solution

The comparison between two transmission schemes shall account for their reliability, in terms of hours of out-of-service and number of occurred faults

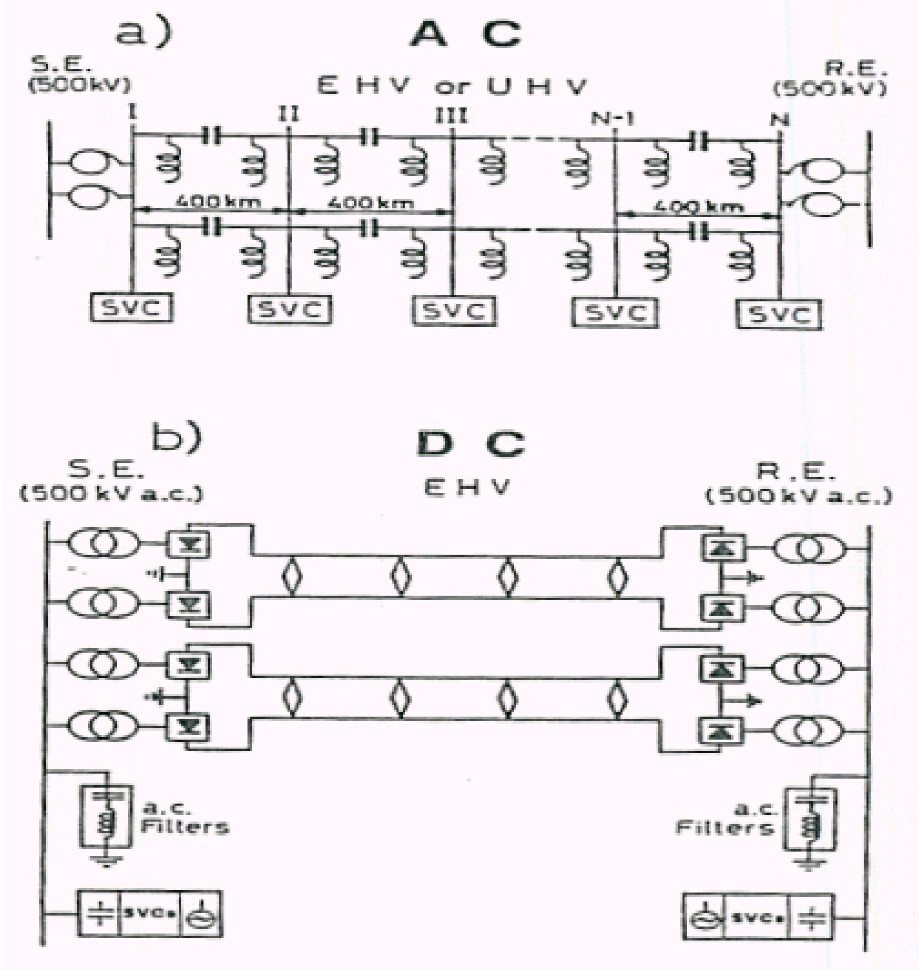


Fig. 1 - Typical schemes of AC and DC point-to-point transmission

AC solution vs. DC solution

The comparison between two transmission schemes shall account for their reliability, in terms of hours of out-of-service and number of occurred faults

Reliability analysis

Adequacy of the transmission schemes examined
(only forced outages considered)

AVAILABLE CAPACITY (MW)	EXPECTED ANNUAL AVAILABILITY (%)					
	AC3	AC2	AC1	DC1	DC2	DC3
0	1.1	0.01	0.01	0.66	0.66	0.66
0.25 W	–	~0.	~0.	–	~0.	–
0.50 W	–	0.02	0.	1.06	0.52	–
0.66 W	~0.	0.07	0.01	–	–	0.52
0.75 W	–	1.87	0.07	–	1.00	–
W	98.89	98.03	99.91	98.28	98.74	98.82
Equivalent available %	98.89	99.50	99.97	98.81	98.81	99.17

Annual Expected frequency of sudden loss of transmission capacity

LOSS OF	AC3	AC2	AC1	DC1	DC2	DC3
W	18.	1.8	0.15	1.7	1.7	1.7
0.75 W	–	0.15	~0.	–	~0.	–
0.5 W	–	~ 0.	–	22.9	13.7	–
0.33 W	–	–	–	–	–	13.7
0.75 W	–	–		–	18.4	–

Synchronous interconnection
AC1: two 500 kV lines with "high" VAR compensation
AC2: two 500 kV lines with "low" VAR compensation
AC3: one 800 kV line

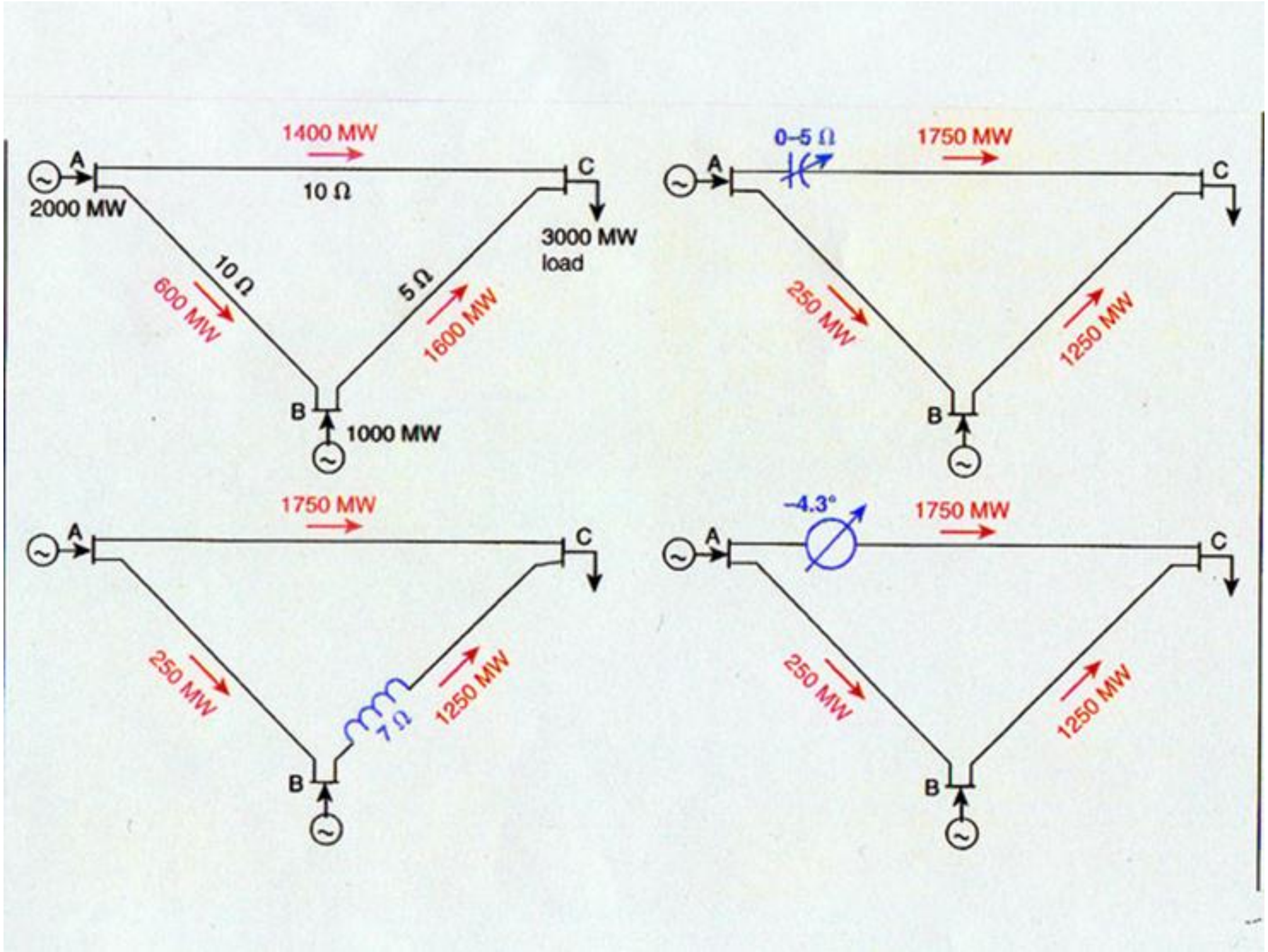
Asynchronous interconnection
DC1: one HVDC bipolar line, one valve-group/pole
DC2: as DC1, two valve-groups/pole, automatic by-pass
DC3: as DC2, with 33% pole overloading

Alternative technologies for network development and interconnection

- **CSC** controlled series compensation
- **GTO-CSC** controlled series compensation with GTO converter
- **SVC** static VAR compensator
- **STATCOM** adv. static compensator
- **PST** phase angle regulator and quadrature boosting transformer
- **UPFC** unified power flow controller

FACTS: Flexible AC Transmission Systems

Effect of FACTS devices on grid flows



Use of FACTS devices: network computing issues

- Best location and sizing of FACTS devices (e.g.: the LIMPS computing procedure developed by CESI to optimally locate and size phase-shifter transformers)

- Analysis of FACTS devices impact on power flows and voltage profile

- Structure and performance of associated control system: system dynamics with FACTS devices

Summary

- Power system security: the increasing concerns
- Measures ensuring power system security margins
- New paradigms and complexity of the planning process
- Examples of interconnection studies among large systems
  - Tunisia-Libya interconnection
  - Europe-Turkey interconnection
- Technologies of links and development of complex grids
- Conclusions and key messages

INTERCONNECTIONS

- ✓ The establishment of new interconnections or the reinforcement of the existing ones is a complex process that shall be examined not only through bilateral studies, but considering the implications on the whole interconnected system
  - ✓ see the example of the Tunisia-Libya synchronisation

- ✓ Accurate Feasibility Studies covering all the issues of the interconnection projects are a key factor to pave the way for the acceptance and financing of the projects' implementation
  - ✓ Technical investigations (AC or DC?)
  - ✓ Environmental impact
  - ✓ Harmonisation of the rules for the Cross-Border Trading of electricity
  - ✓ Be open to innovative solutions
  - ✓ Direct and honest involvement of the affected population

Conclusions and key messages

GRID

- ✓ Urgent need to continue with the reinforcements of the European transmission grids at regional/national levels and start the progressive implementation of the European Supergrid including the offshore sections

- ✓ Adoption of a clear and simple CBA, by avoiding excessive efforts /requests of too detailed estimations on cost/benefit components

- ✓ A robust CBA is indeed essential to get:
  - the approval of the investments by the Regulatory Bodies and Energy Ministries (case of regulated assets),
  - to attract investments from the private sector (e.g.: merchant offshore cables).

- ✓ Furthermore, a clear and simple benefits assessment of the new network infrastructures will enhance the population and local authorities acceptance

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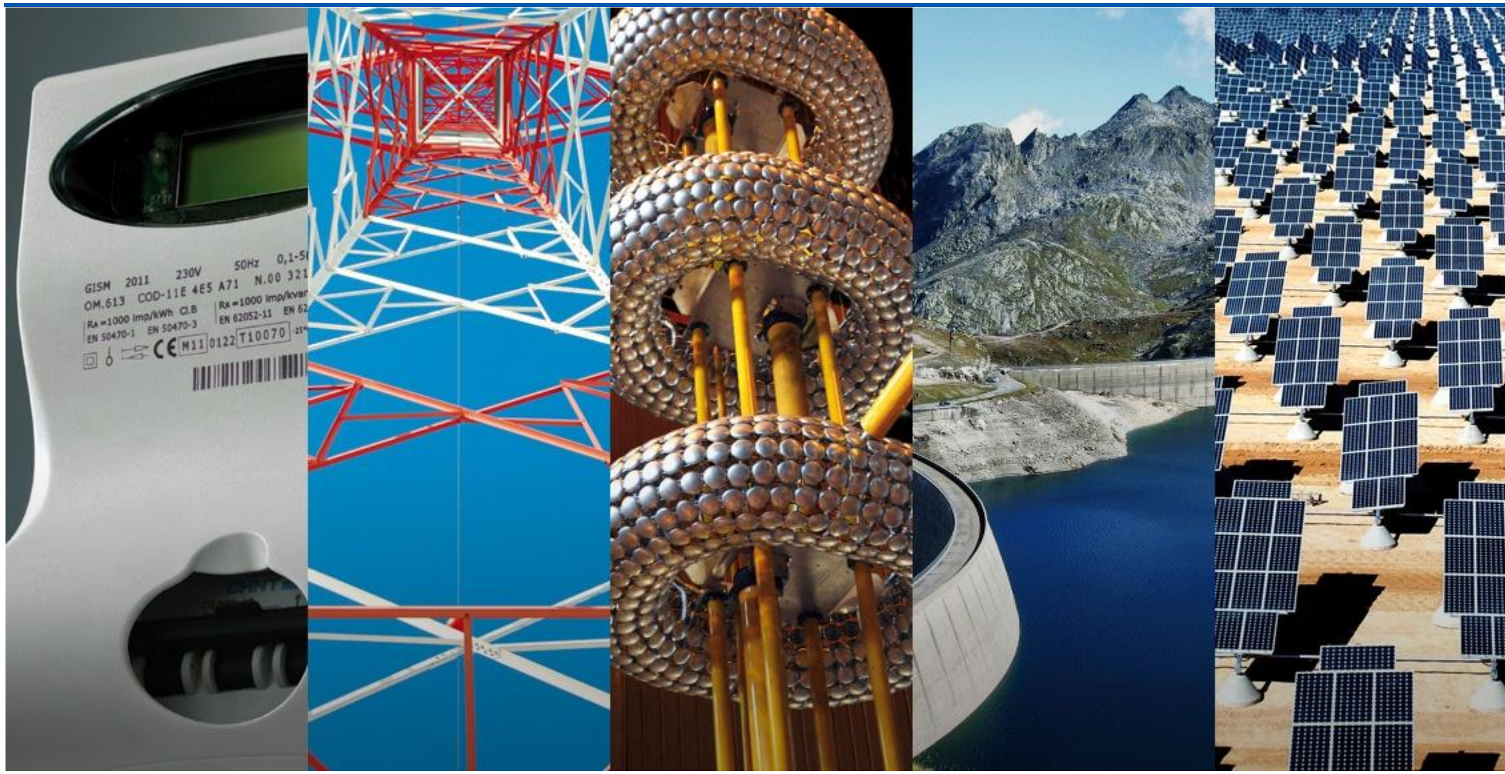

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