Interconnessioni elettriche: nuovi scenari e tecnologie

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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

<table>
<thead>
<tr>
<th>Year</th>
<th>ELECTRICITY CONSUMPTION [TWh]</th>
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<tbody>
<tr>
<td>2010</td>
<td>3 360</td>
</tr>
<tr>
<td>2011</td>
<td>3 339</td>
</tr>
<tr>
<td>2012</td>
<td>3 336</td>
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ENTSO-E

Electricity demand projection 2013-2023 in Italy [TWh]

Pre-crisis levels attained in 2023

Source: Terna and CESI elaborations

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**

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

(*)& more challenging system controllability

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Source: Terna and CESI elaborations
Power system security: the increasing concerns

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

![Graph showing RES generation trends](image)

Source: ENTSO-E

**EU targets**

- **2020**
  - 20% CO₂ reduct.
  - 20% RES

- **2030**
  - 40% / 35% CO₂ reduct.
  - 27% / 24% RES

- **2050**
  - 80% / 95% CO₂ 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.
Economic, environmental, regulatory and market issues have to be addressed in addition to the “classical” reliability and security criteria.
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

**South & East Med Countries**
- Demand: 241 TWh
- Installed capacity: 59 GW

**Turkey**
- Demand: 198 TWh
- Installed capacity: 42 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 21\textsuperscript{st} November 2005

**RED ELECTRICA DE ESPAÑA**

**November 21\textsuperscript{st} system stats**

**Generation (MW):** 35973  
**Load (MW):** 33520  
E→F: 507  
E→P: 1120

**Generation (MW):** 2572  
**Load (MW):** 2600  
MA→DZ: -13  
MA→E: 15

**Generation (MW):** 3780  
**Load (MW):** 3784

**Generation (MW):** 1430  
**Load (MW):** 1415

**Generation (MW):** 2526 (E) 648  
Load (MW): 1918 (E) 643

**Generation (MW):** 4553  
**Load (MW):** 1366

**Generation (MW):** 10900  
**Load (MW):**
Synchronisation test on 21st November 2005

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

Defence plans (old):

(DZ-TN)
Wattmeter relay
(instantaneous & time delayed)
200MW 0.2s
150MW 3s
180MW 0.2s
140 MW 3s

(MA-DZ)
Wattmeter relay
(instantaneous & time delayed)
300MW 0.2s (l1+l2)
250MW 15s (l1+l2)
380 MW 1s (l1+l2)
320 MW 15s (l1+l2)
200MW 15s (l1+l2)

(ES-MA)
• Voltage collapse
• Out of step

(LY-EG)
Wattmeter relay 120 MW, 3s
Time delayed minimum voltage 0.82 pu 0.6s
Time delayed over voltage 1.2 pu 5s
Time delayed minimum frequency 49.5Hz 0.15s

(TN-LY)
Wattmeter relay Lib → Tun
130 MW, 5s (ABK-MED) (150 MW, 5 sec STEG)
80 MW 5s (Rowies-Tataouine) (170 MW 5 sec STEG)

Wattmeter relay Tun → Lib
240 MW 5s (MED-ADK)
170 MW 3s (Tataouine-Rowies)
Time delayed minimum frequency 49.5Hz 0.2s

Tunisia-Libya Interconnection: MEDELEC meeting 24
Measures after failed synchronisation test

Updating the coordinated defence plan

Defence plans (new):

- (ES-MA)
  - Voltage-collapse
  - Out of step

- (MA-DZ)
  - Wattmeter relay
  - Instantaneous & time delayed
  300 MW 0.2 s (I+I+2) →
  250 MW 15 s (I+I+2) →
  330 MW 0.2 s (I+I+2) →
  300 MW 10 s (I+I+2)

- (DZ-TN)
  - Wattmeter relay
  - Instantaneous & time delayed
  250 MW 0.2 s →
  225 MW 10 s →
  360 MW 0.2 s →
  330 MW 3 s

- (TN-LY)
  - Wattmeter relay
  - Time delayed minimum frequency 49.5 Hz 0.2 s

- (LY-EG)
  - Wattmeter relay
  - Time delayed minimum voltage 0.62 pu 0.5 s
  - Time delayed over voltage 1.2 pu 5 s
  - Time delayed minimum frequency 49.5 Hz 0.15 s
Measures after failed synchronisation test

Solving the network weaknesses

New 400 kV network developments:
New synchronisation test on 27th-28th April 2010
New synchronisation test on 27th-28th April 2010

Test organisation: implementation of defence plans.
New synchronisation test on 27\textsuperscript{th}-28\textsuperscript{th} April 2010
New synchronisation test on 27th-28th April 2010
New synchronisation test on 27\textsuperscript{th}-28\textsuperscript{th} 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

System not stable!
New synchronisation test on 27\textsuperscript{th}-28\textsuperscript{th} April 2010

**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 ($\approx 0.1$ 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 be 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):

**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.
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

TC = Terminal costs

Break-even distance

TC

TC

Distance [km]

Costs

AC

DC

600

800

600
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.
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
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
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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