THE INTERCONNECTION OF THE CRETE POWER SYSTEM TO THE MAINLAND GRID

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INTERCONNECTION VERSUS AUTONOMOUS POWER SYSTEMS IN ISLANDS

**Advantages of the interconnections**

- Economic interest, due to the higher production cost of local power stations using oil products compared to the mainland production cost.

- Unconstrained local RES development, instead of limited RES penetration - up to 15% (in energy) in case of autonomous local power stations.

- Avoidance of local pollution

**Disadvantages**

- Eventual long loss of supply, if the proper security of supply measures are not taken
Since 1960, more than 70 interconnections of Greek islands to the mainland grid or to adjacent islands, are in operation

Especially all the Ionian islands are connected to the mainland grid since ‘70s

Nevertheless, actually there are 56 autonomous power stations in Aegean islands, including the largest ones

The considerable progress on the submarine interconnection technologies during the last years, offers the possibility of the connection of all the Aegean islands to the mainland grid, including Crete.

In the following, the main results of previous studies, as well as some new considerations on the subject, are presented and discussed.
RECENT DEVELOPMENT OF THE SUBMARINE INTERCONNECTION TECHNOLOGIES

Pros and Cons of AC and DC Systems

- Extended use of plastic insulation for HV AC and DC cables
- Development of new type AC/DC or DC/AC converters “Voltage Source” instead of “Line commutated”
- Higher lengths can be obtained by DC transmission
  Overhead HV lines on islands can be avoided
- Higher control capabilities may be obtained by DC transmission due to the flexibility of the converters
  This is very important in case of intermittent power generation
- AC systems remain usually more economic solution for distances up to about 70km
SUBMARINE CABLES (SC)

Self-Contained Fluid Filled Cables

Extruded Insulation Cables
INTERCONNECTION STUDIES
IN THE PLANNING STAGE

1. CRETE, 1988, by PPC – conventional technology

2. CYCLADES ISLANDS,
   1989 by PPC, partially constructed
   2004 by NTUA/RAE, preliminary study
   2006 by, PPC, DESMIE, NTUA/RAE: Final planning,
   2010, in the final tender stage

3. ALL AEGEAN ISLANDS, 2006-8, feasibility study by NTUA/RAE, including:
   - Extension of the interconnection of Cyclades, to include all the islands
   - Interconnection of the North-East Aegean islands
   - Interconnection of Crete
   - Interconnection of the Dodecanese islands

4. ALL AEGEAN ISLANDS, 2010, re-examination of the subject by H-TSO
INTERCONNECTION OF ALL AEGEAN ISLANDS
Study of NTUA (for RAE) 2006-08
Three possible solutions are considered for each one of the interconnected groups of islands:

- **Autonomous local power stations, using oil products**
  - Local RES up to 25% of maximum demand (15% per year in energy)

- **Interconnection to the mainland grid, so that the security of supply (N-1 criterion) is satisfied – local stations may be eliminated**
  - Different network schemes, by AC or DC, are examined
  - Local RES was taken equal to 100% of the maximum demand, that is more than 60% of the year consumption is obtained by RES

- **Interconnection to the mainland grid plus local power stations, for peak shaving or/and security of supply**
  - This is an alternative of the above solution, in the case of large islands for large islands (like Crete)
The 25-year (2010-35) total electrification cost of all the islands for each one of the above solutions where calculated and compared.

In cases of Crete and Dodecanese, local power stations remain in operation, mainly for peak shaving and reliability purposes. In all other islands the existing local diesel power stations are eliminated.

It was found that in all cases, the interconnections are more economic or practically equivalent to the autonomous development of the power system of the islands.

The loads of the islands were taken increasing by 5% up to 2020, reduced gradually the next years
Two alternatives were studied:

(a) - Interconnection of Crete only, by two DC circuits
  2x350=700MW total capacity
  - Autonomous development of Dodecanese (Rodos)
(b) Interconnection of Crete firstly and in a second stage
    and Dodecanese:
    - Two DC circuits  2x550=1.100MW capacity
      and extension to Dodecanese by AC 150kV

In all cases:

Local power stations are provided:
- In Crete (Korakia and Atherinolakos, with oil products or
  Natural Gas) and
- In Rodos (with oil products),
INTERCONNECTION OF CRETE AND DODECANESE TO THE MAINLAND GRID
Conventional power stations on Crete and Rodos
INTERCONNECTION SCHEME OF CRETE TO THE MAINLAND GRID

Mainland grid

MEGALOPOLI

Overhead DC lines ~120 km

Submarine Cables
2x350MW or 2x550MW
~250 km

Korakia (Crete)
# TOTAL ELECTRICITY COSTS

## Initial - 2006

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>Total electricity cost 2010-35 referred to 2010 (M€)</th>
<th>Unitary cost referred to 2010 (€/MWh)</th>
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<tbody>
<tr>
<td><strong>Autonomous power stations</strong></td>
<td></td>
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<tr>
<td>Crete Oil Products</td>
<td>11.729</td>
<td>168</td>
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<tr>
<td>Crete NG</td>
<td>10.200</td>
<td>146</td>
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<td>Dodecanese islands</td>
<td>4.301</td>
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<td><strong>Separate Interconnections (Crete cable capacity 2x350MW)</strong></td>
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<tr>
<td>Crete Oil Products</td>
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<tr>
<td>Crete NG</td>
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<td>Dodecanese islands</td>
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<td><strong>Interconnection of Crete and Dodecanese (Cable capacity 2x550MW)</strong></td>
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<tr>
<td>Crete Oil Products</td>
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<tr>
<td>Crete NG</td>
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</table>
• If the development of the interconnection is effectuated gradually (e.g. in two stages, 2010: 1x550MW of Crete plus 1x550MW at 2020, or 1000 plus 1000MW), the total cost can be considerably reduced, without reduction of the reliability.

• The consideration of different RES penetration level does not change considerably the total cost, given that their tariff is fixed and near the occidental System’s cost.

• Sensibility analysis related to different scenarios and different values of the main parameters was effectuate for the following scenarios:
  A: Autonomous development,
  B: Interconnection 2x550MW
  C: Interconnection 2x1000MW, in final stage
Per Unit (PU) total energy cost change with the Variable cost of CCPU with NG

![Graph showing the relationship between per unit 25-year total energy cost and variable cost of CCPU with NG. The graph has a linear trend line for each scenario (A, B, C), withScenario A having the highest cost and Scenario C the lowest. The x-axis represents the variable cost of CCPU with NG in €/MWh, ranging from 37 to 97, and the y-axis shows the per unit 25-year total energy cost in €/MWh, ranging from 120 to 180. The three scenarios are differentiated by color: Scenario A (blue), Scenario B (red), and Scenario C (green).]
Per Unit (PU) total energy cost change with the Rate of change of the fuel cost in next years
Per Unit (PU) total energy cost change with the Rate of change of the CO₂ cost in next years

![Graph showing the relationship between CO₂ cost (€/tn CO₂) and per unit 25-year total energy cost (€/MWh) for three different scenarios: Scenario A, Scenario B, and Scenario C. The graph indicates an upward trend as the CO₂ cost increases.]
Per Unit (PU) total energy cost change with the Interconnection cost
Per Unit (PU) total energy cost change with the rate of money

Per unit 25-year total energy cost (€/MWh)

Discount Rate (%)
• Scenario B, that is the interconnection by 2x550MW, seems to be in all cases the most economic.

• The interconnection of Crete and next of Dodecanese appears as the best solution. In any case the “timing” of the interconnection works, as well as the rate of the RES development are of primary importance.

• The installation and use of NG in Crete seems to be marginally more economic than the use of Oil Products. Nevertheless this conclusion can be reversed if the rate of load increase is lower than the considered one (5% per year up to 2020, gradually reduced in the next years) or the RES penetration is higher.

For these reasons a more detailed analysis is necessary.
The target remains:
- Minimization of the use of Oil Products
- Exploitation of the local RES capabilities

Differences to the NTUA Study:
- Detailed examination of the capability of the Greek Transmission Power System to integrate RES was effectuated.
- The exact maximum RES capacity of each island remains unknown. So the wind power that can be installed on the islands, on- or offshore, was roughly estimated.
- The RES power seems to be usually much higher than the maximum electric power demand of the island, so that the design of the interconnection must be based on this capacity.
- The proposals of private investors for RES development should be taken into account.
STAGES OF THE WORK

PHASE A’ : General Planning

• The target is the development of a HV network, extending to all the Aegean islands and will be realized gradually in a consistent way, in different time periods.
• Any proposal of private investor will be incorporated in a consistent way to this general planning.

PHASE B’ : Engineering Design

• The detailed design will be realized in time separately for each interconnection (usually including more than one islands), following the environmental licenses.

PHASE C’ : Realization of project

• Decisions related to the financing and the construction of the work
THE INTERCONNECTION OF CRETE
The main characteristics

- In 2008: Maximum load demand - 640MW and electric energy production, 3.040GWh (by RES 14%)

- It is estimated that up to 100% of the electricity consumption of Crete can be produced by RES (mainly by wind).

- This requires the installation of RES power about three times the maximum demand of the year, as well as the proper interconnection of Crete with the mainland grid.

- A special study is actually effectuated (by HTSO, PPC and RAE) for the long term development of the Crete Power System, taking into account the planning of PPC for the development of conventional power stations and the extended gradual development of the RES. (It is a part of PHASE B’).
All Aegean islands Interconnection Planning – STAGE 1
INTERCONNECTION OF CRETE AND EXTENSION TO DODECANESE

- **In Crete:** The power stations of Korakia and Atherinolakos are developed as scheduled, but in such a way that, in long term, they will be used mainly for security of supply and peak shaving.

- **In Rodos:** The new power station is developed as scheduled, but will be used mainly for security of supply and peak shaving. The diesel power stations of all other islands are eliminated.

- The power Systems of **Crete** and **Dodecanese** will be interconnected (through Kassos and Karpathos) by 150kV AC cables.

- New DC interconnections from **mainland** to **Crete** or/and **Dodecanese** (directly to Kos) may be necessary, in the future, mainly following the development of RES, (mainly onshore or/and offshore wind parks).
All Aegean islands Interconnection Planning – STAGE 2