



**First South East European  
Regional CIGRÉ Conference**

**SEERC**

Portoroz, Slovenia, 7—8 June 2016

***THE INTERCONNECTION OF THE CYCLADIC  
ISLANDS: A MAJOR INNOVATIVE  
TRANSMISSION PROJECT FOR THE GREEK EPS***

**2-07**

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**IPTO - GREECE**

# *Autonomous Island systems in Greece*



- Large amount of islands in the Greek territory
- All islands close to the coast connected (from the 60s) either through 150kV (Ionian islands) or via MV connections
- 28 autonomous island systems representing ~10% of National load
- Peak load from some hundreds of KW to ~700 MW (Crete)
- Blocks of islands with local interconnections

## ***Main characteristics***

- Local power plants fed by oil (light or heavy oil) ⇒ high generation cost
- Low reliability of supply
- **Severe limitations in existing power plants from 2020 on (EC Dir. 2010/75/EE & 2015/2193/EE)**

## ***Potential Solution: Interconnection ??***



# An ambitious plan to interconnect the Aegean islands



- 1 Cycladic islands
- 2 NE Aegean
- 3 Crete
- 4 Dodecanese complex

# ***Main drivers for the Transmission System Development (TYNDP)***

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- **Strengthening the backbone (400kV) (Peloponnese, NE Greece)**
- **New Interconnectors with neighbouring TSOs**
- **Accommodation of RES plants (very ambitious National targets related to avoiding climate change)**
- **Connection of isolated islands**
  - Related to the exploitation of high RES potential in the Aegean sea

# The Islands to be Connected

Northern Cycladic complex: 4 isolated electricity systems (oil fed) serving 12 islands - 5 of them quite big (Andros, Syros, Mykonos, Paros & Naxos).

## Current situation

- Andros connected to Mainland (Sub cable & OHL 150kV)
- Sub cable Andros - Tinos (150kV), Syros - Tinos and Mykonos - Tinos (66kV)
- Critical situation during peaks (summer), use of hired portable units



# *Main characteristics*

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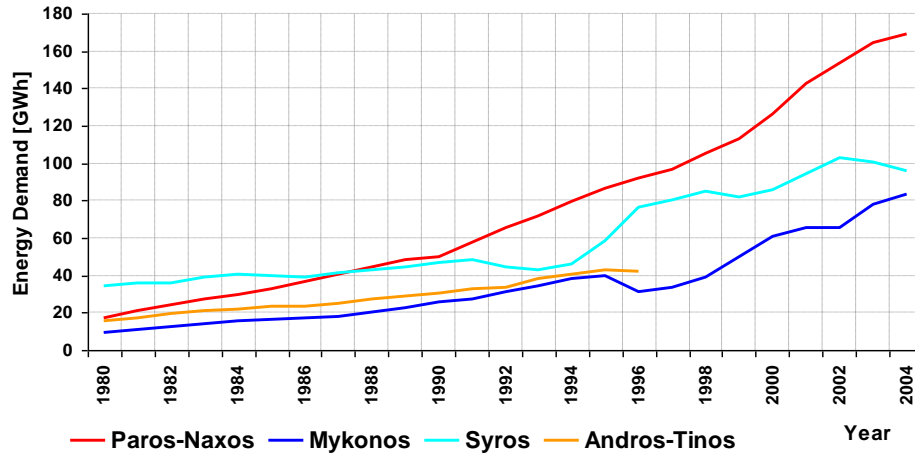
- Fed by small internal combustion units (light or heavy oil) ⇒ high generation cost – some very old
- Large load variations ⇒ very low load factor (low local population, increased significantly during summer due to tourism)
- High rates of load increase (7% - 10% annually)
- Main activities related to tourism ⇒ high environmental concern
- High wind and solar potential not exploited (technical restrictions due to autonomous operation of electrical systems)
- Existing generation capacity no longer adequate to cover increasing electricity needs (due to the rapid economic growth)
- Expansion of existing power stations (located next to main towns) is no longer possible, but also economically insufficient
- **Severe limitations in the existing power plants**

# *Potential Benefits*

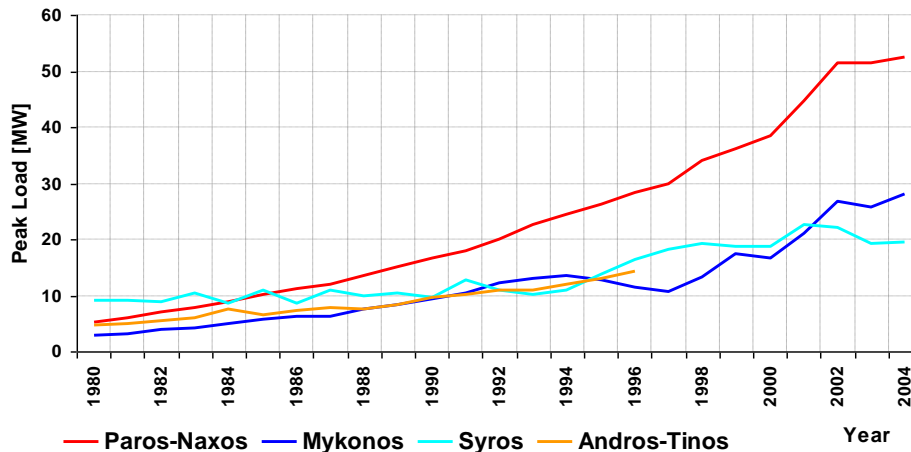
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- **Significant savings of fuel costs (the generation cost in the island varies from 80 up to 180 €/MWh compared to 50-60 €/MWh in the mainland). Uplift costs are distributed to all consumers in the country ("Public Service" Obligation)**
- **Significant savings of avoided high investment costs for the development and conversion of local power plants.**
- **Increased security and reliability of supply**
- **Interconnection allows the exploitation of the high RES potential of the islands (currently very limited due to the small size of the autonomous island systems)**
- **Contribution to the reduction (and in long term the elimination) of CO<sub>2</sub> pollutants and associated costs.**
- **Drastic reduction the environmental impact caused by the continuous operation of the local stations, many of which are located in residential areas.**
- **Expansion of the "Energy Market" to the interconnected islands.**

# EVOLUTION OF DEMAND

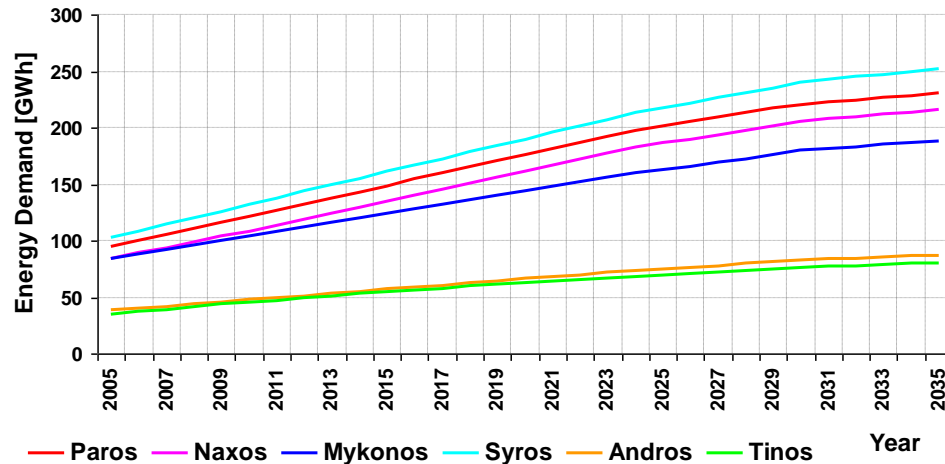


Evolution of energy demand

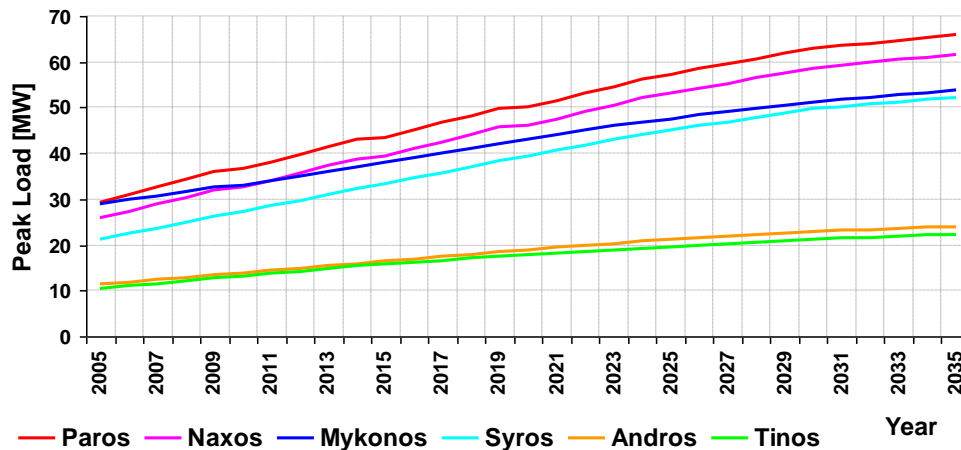


Evolution of peak load

# LOAD FORECAST

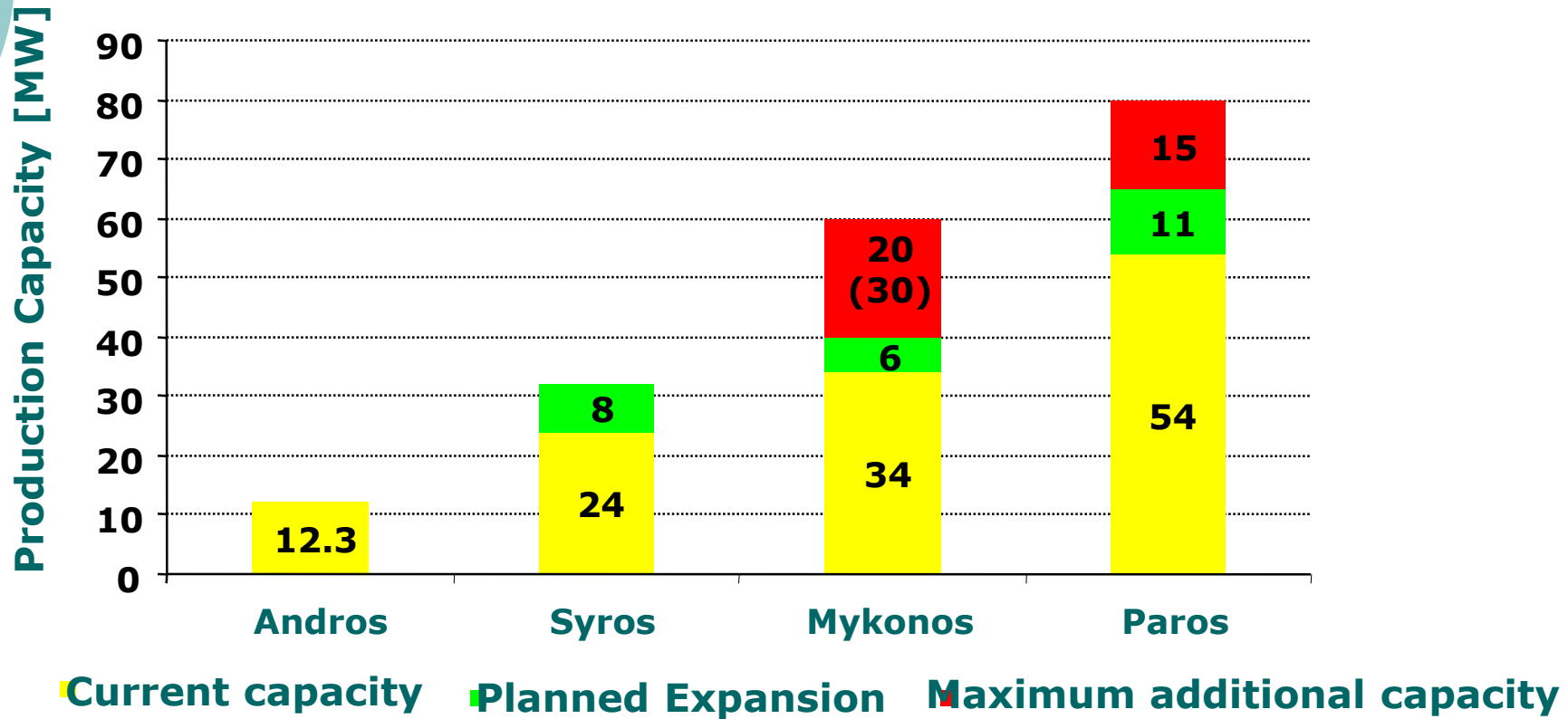


Forecasted energy demand (up to 2035)



Forecasted peaks (2035)

# LOCAL GENERATION CAPACITY



# KEY FIGURES

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YEAR	2005	2035
<b>Total load (GWh)</b>	<b>439</b>	<b>1054</b>
<b>Peak demand (MW)</b>	<b>127</b>	<b>280</b>
<b>Local Generation capacity (MW)</b>	<b>124</b>	<b>174</b>
<b>Load factor (%)</b>	<b>34% - 51%</b>	

# Some history



## First attempt on 90s

- Connection of Andros, Syros, Tinos, Mykonos at 66kV and 150kV using undersea cables and OHL
- Connection through Evia island

## Partial materialization – laying of undersea cables (large fail)

- Strong opposition to the OHLs by local communities – Forbidden by the Courts
- Andros is now connected (supplying also Tinos)

# ***New Project Design***

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- **By a Common WG: Regulator, IPTO and PPC**
  - Objective: Provide a long-term solution for the electrification of the islands (May 2006)
  - No OHLs on the islands
  - Decommission of the local plants on the islands
  - Final design and tuning by IPTO
  - First Tender released on 2011 – Final tender on 2013
  - Construction started on 2015
    - On site Investigations (cable landing, s/s location etc.)
    - Agreements with local authorities
    - Difficulties in permitting process
  - Project is materialized in 3 phases

# Studies Performed

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- Feasibility studies (**multi-criteria process** (technical, economical, environmental, etc.))
- Static Security assessment (N and N-1)
  - Focus on reactive power compensation and voltage regulation
  - High voltage fluctuations between day/night and severe seasonal fluctuations
  - Use of both switched capacitors and reactors and an SVC centrally located (Syros) +/- 100 MVAR
- Dynamic security assessment in all credible contingencies
- Specific issues on cables (Transient Over-voltages, cables energization, subsynchronous resonance, ferro resonance, ....)
- **Maximum transfer capacity from the mainland: ~170MW**
  - **Enough transfer capacity to fully supply the islands up to 2040-2050**
  - Local generators initially in cold reserve mode and then decommissioned

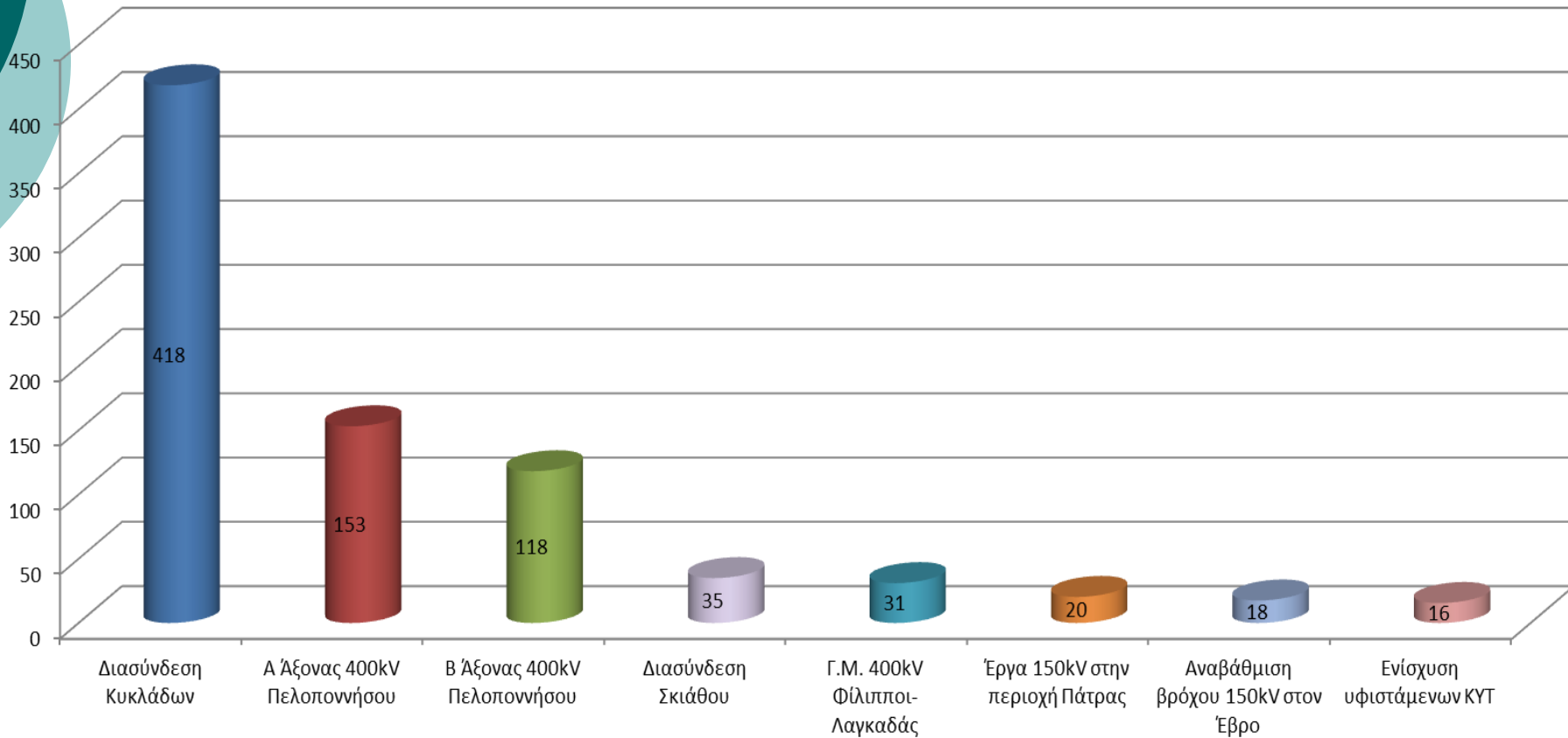
# PROJECT OVERVIEW

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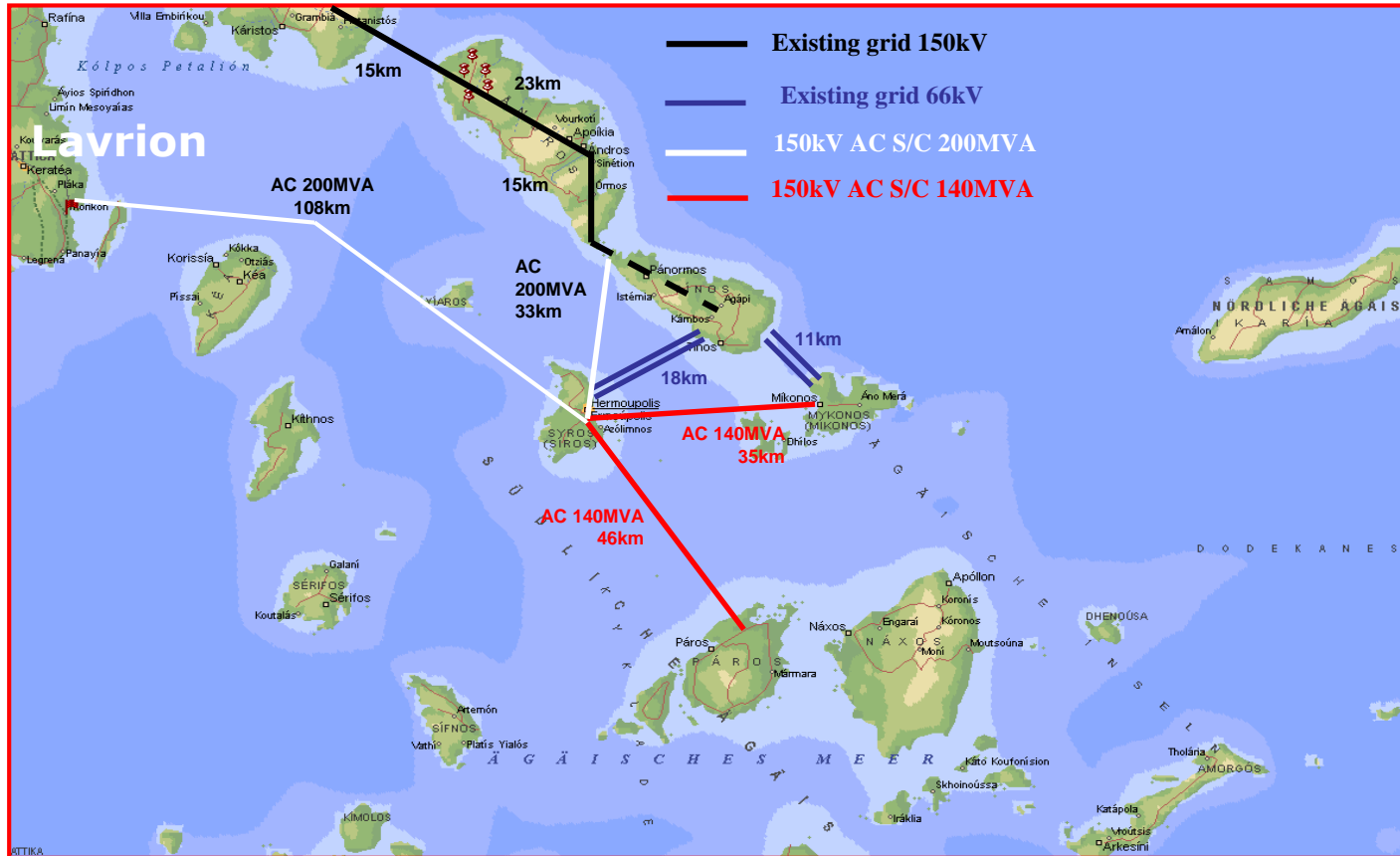
- **Interconnection to the mainland to achieve** long-term solution
  - high degree of reliability
  - gradual decommission of the existing local power stations
  - further exploitation of the considerable wind potential of the islands
  - capable to accommodate future interconnection of a geothermal plant on Milos island
- **Connection-point:** the strong EHV substation of Lavrion – Upgrading of Lavrion s/s and new autotransformer
- **Both AC and DC interconnection technologies were investigated and proved technically feasible – both options acceptable in the tender**
  - **The AC option has been selected (the cheaper option in the tender)**
- **365 km of 3-core undersea cables of nominal capacity 200MVA and 140MVA- XLPE cables have been chosen**
- **4 New 150/20 substations of GIS type** (to minimize space requirement and visual impact, to protect installations from sea environment).
- **Scheduled projects on the islands should precede the laying of cables** (to avoid further delay and stranded investments due to reactions)
- **Financing by EIB and own capital**
- **Total budget: 420 M€**

# The largest project in TYDP of Greece

Συνολικό κόστος έργων σε προχωρημένο στάδιο ωρίμανσης (εκατ. €)



# Phase I

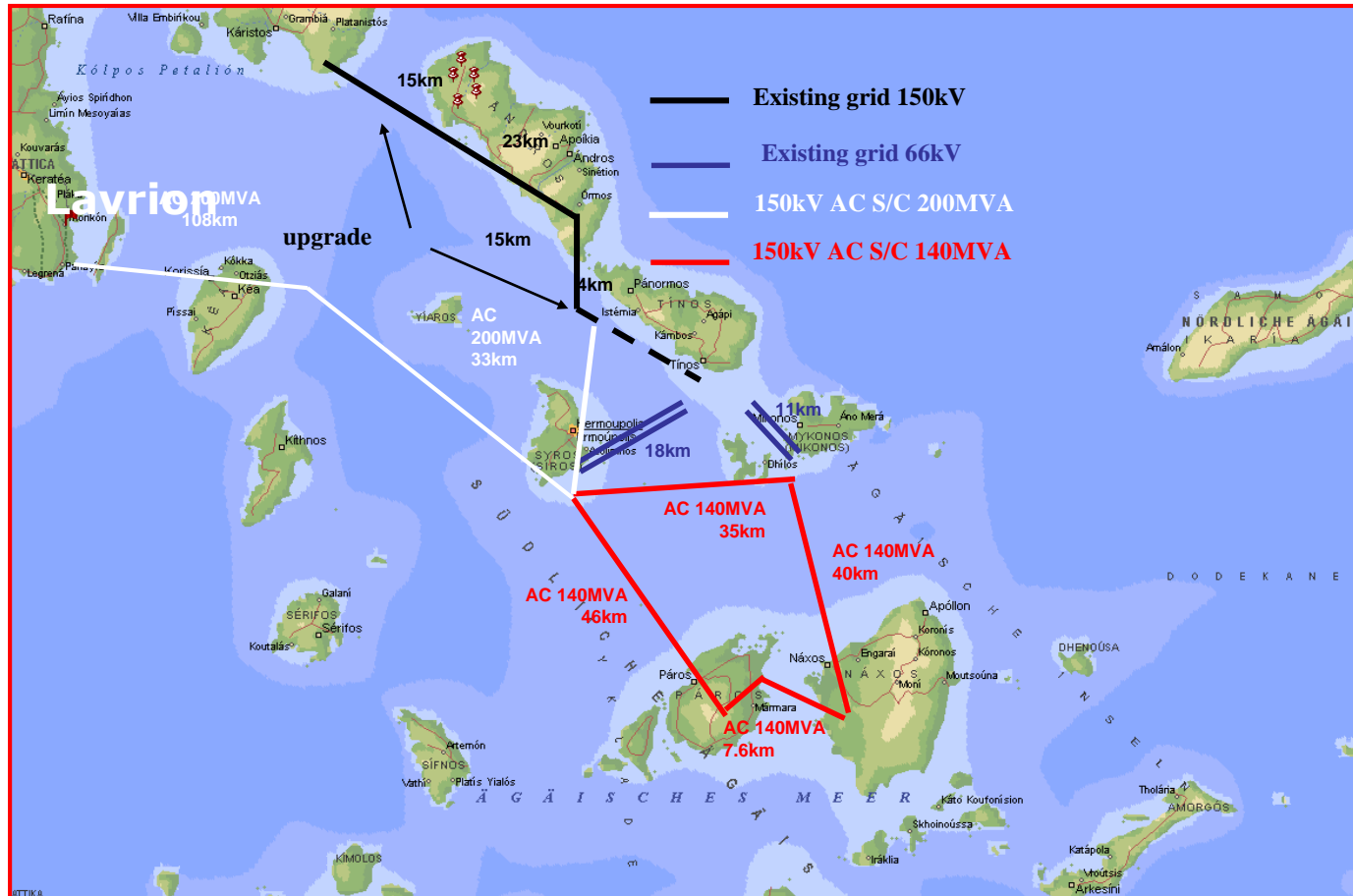


- **Total budget: ~252 M€**
- **Total cable length: 220km**
- **Commissioning: 2016**

**Cable Lavrion-Syros already commissioned**

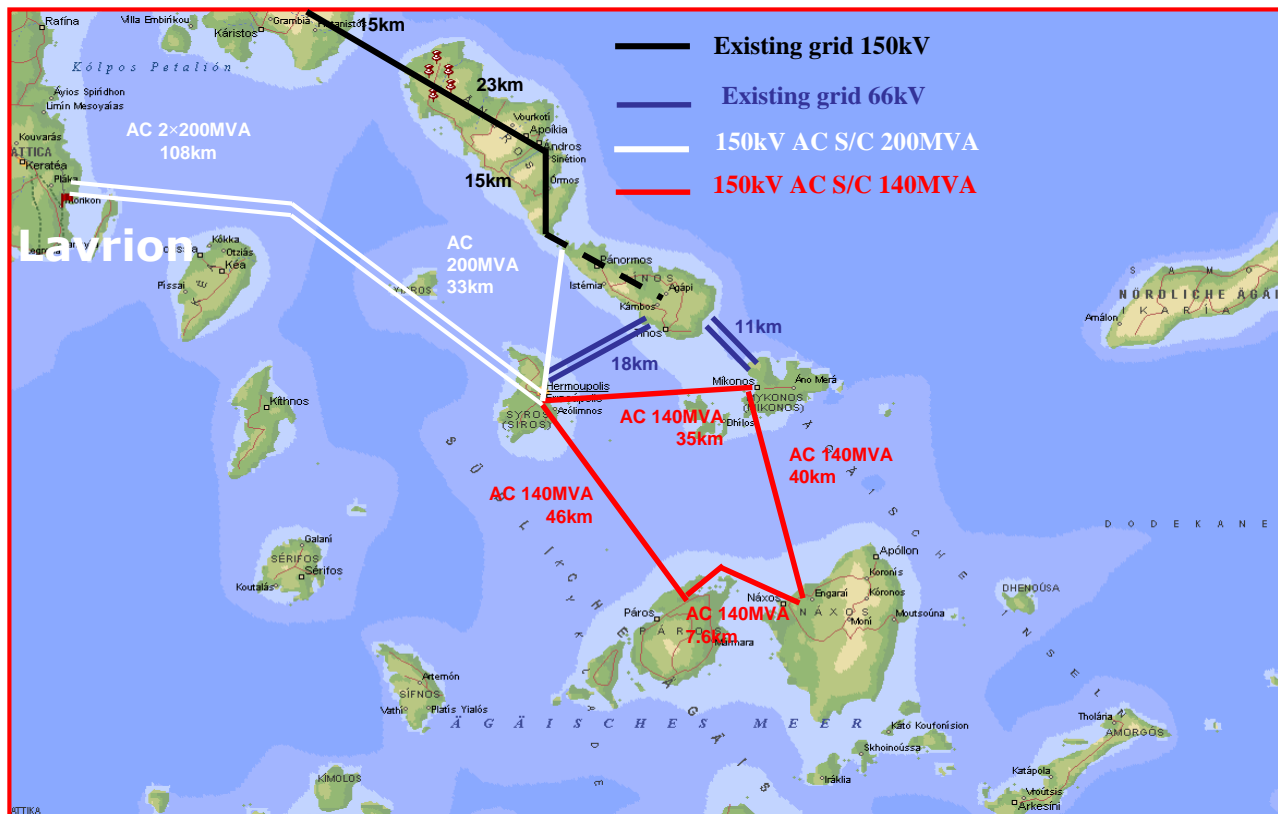
**Delays in s/s construction**

# Phase II



- Total budget: ~62 M€
- Total length: 65km
- Commissioning 2018

# Phase III



- **Total budget: ~100 M€**
- **Total cables' length: 108km**
- **Commissioning: after 2020 (according to load evolution)**
- **Integration of additional ~200MW of RES**

# ***Concluding Remarks***

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- **The Cycladic interconnection project is the most expensive and challenging transmission project for Greece – The first of its kind Europe wide**
- **It incorporates 365km of subsea cables and 4 new 150/20kV substations**
- **Significant potential benefits for the islands (environmental, security of supply, RES exploitation) and for the country (reduction of costs)**
- **Total budget: 420 M€**
- **Huge initial problems in permitting, finding locations and agreements with local authorities caused severe delays**
- **Under construction from 2015**
- **First important step towards possible expansion of interconnections to other Aegean islands**

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# ***Thank you***

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# ***General characteristics and ... general design***

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following individual sub-projects:

Initial interconnection of Syros island to Lavrio via one 3phase AC XLPE 150kV submarine cable, with nominal capacity of 200MVA and 108km in length.

Interconnection of Syros to the northern end of Tinos island via one 3phase AC XLPE 150kV submarine cable, with nominal capacity of 200MVA and 33km in length.

Radial connection of Paros Island to Syros via one 3phase AC XLPE 150kV submarine cable with nominal capacity of 140MVA and 46km in length.

Radial connection of Mykonos Island to Syros via one 3phase AC XLPE 150kV submarine cable with nominal capacity of 140MVA and 35km in length.

Construction of GIS Substations on the islands of Syros, Paros, Mykonos (installation of reactive compensation devices included), construction of one connection point at Tinos Island and additional construction works at Lavrio Substation.

# ***PROJECT OBJECTIVES***

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**To establish an interconnection scheme that guarantees:**

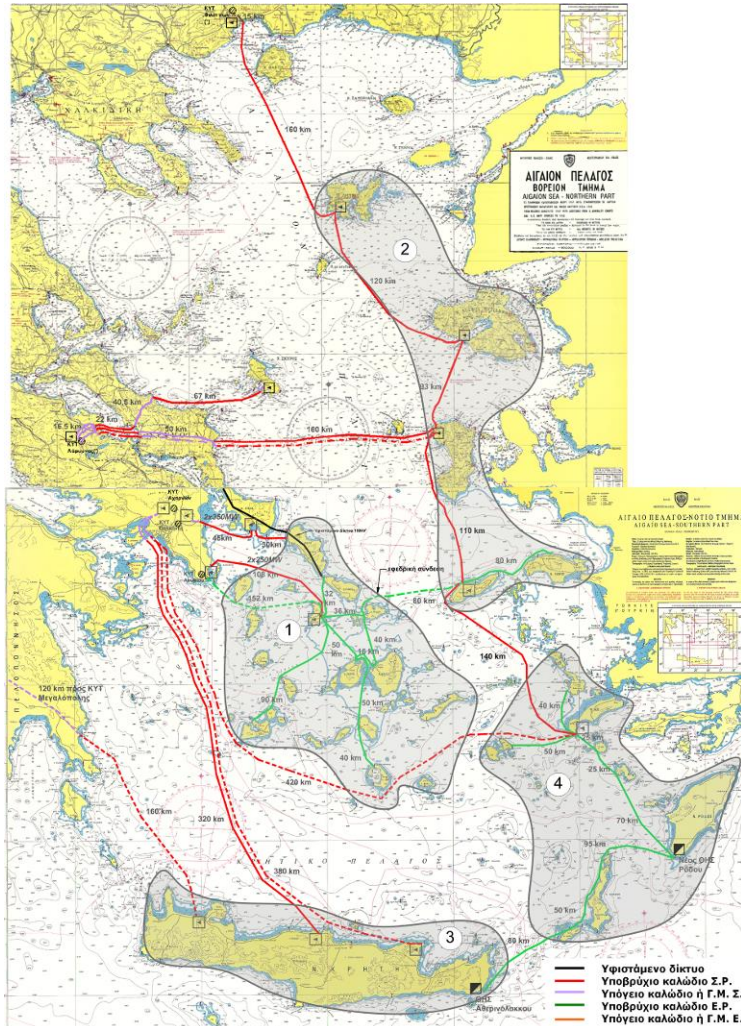
- **high reliability of supply**
- **long-term solution**
- **reduction of production costs**
- **future exploitation of wind potential**
- **gradual decommission of existing power stations**

**taking into consideration:**

- **environmental constraints (court order following reactions of locals against erection of OHL on the islands)**
- **new innovative commercially available technologies**
- **possibility to accommodate future interconnection of a geothermal plant on Milos island**

**Initial interconnection plan (put into effect in the early '90s) inhibited recently by court order (strong protest by locals to the erection of HV OHL**

# Part of an ambitious plan to interconnect the Aegean islands



- 1 Cycladic islands
- 2 NE Aegean
- 3 Crete
- 4 Dodecanese complex

# ***CYCLADIC ISLANDS***

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## ***MAIN CHARACTERISTICS***

- **Northern Cycladic complex: 5 Greek islands (Andros, Syros, Mykonos, Paros & Naxos) supplied by isolated electricity systems (oil fed).**
- **Fed by small internal combustion units (light or heavy oil) ⇒ high generation cost**
- **Large load variations ⇒ very low load factor (low local population, increase during summer due to tourism)**
- **High rates of load increase (7% - 10% annually)**
- **Main activities related to tourism ⇒ high environmental concern**
- **High wind potential not exploited (technical restrictions due to autonomous operation of electrical systems)**

# ***CYCLADIC ISLANDS***

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- **Andros connected to Mainland (Sub cable & OHL 150kV)**
- **Sub cable Andros - Tinos (150kV), Syros - Tinos and Mykonos - Tinos (66kV)**
- **Critical situation during peaks (summer), use of hired portable units**
- **Existing generation capacity no longer adequate to cover increasing electricity needs (due to the rapid economic growth)**
- **Expansion of existing power stations (located next to main towns) is no longer possible, but also economically insufficient**

- Study of Transient Over-voltages and other Special Issues in the Interconnection cable between Cyclades and Main Inland Greece

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- Insulation coordination Study **Scope** : The selection of insulation strength consistent with expected overvoltage to obtain an acceptable risk of failure. EMTP simulations to estimate overvoltages in the events of
  - Load rejection,
  - Transformer energization,
  - Uneven breaker poles,
  - Line fault,
  - Fault clearing,
  - Line energisation,
  - Line dropping and
  - Switching of inductive and capacitive current
- Evaluation of results - **Conclusions**
  - The insulation level 325/750 kV ensures the safe operation area of all the equipment installed in the Cycladic islands interconnection system.
  - The single core cables could be of a lower insulation level (275/650 kV)
  - The energization of Syros-Andros cable should be done from Andros and not from Syros as the resulted switching overvoltages are lower.

- Calculation of transient and steady state Overvoltages during the energization of Lavrio – Syros interconnection
  - **Conclusions:** Max calculated transient overvoltages in the energisation of LAVrio – Syros interconnection are within acceptable limits

# other Special Issues in the Interconnection cable between Cyclades and Main Inland Greece »

**Insulation co-ordination procedure** as in IEC 60071-1 in **four main steps:**

1. Determination of the representative overvoltages ( $U_{rp}$ ) - EMTP simulations to estimate overvoltages in the events of load rejection, transformer energization, uneven breaker poles, line fault, fault clearing, line energisation, line dropping and switching of inductive and capacitive current

Summary of representative overvoltages

## Temporary overvoltage:

Phase-to-earth:  $U_{rp} = 147 \text{ kV}$

Phase-to-phase:  $U_{rp} = 255 \text{ kV}$

## Slow-front overvoltages:

For the equipment not protected by surge arresters

Phase-to-earth:  $U_{rp} = 382 \text{ kV}$

Phase-to-phase:  $U_{rp} = 553 \text{ kV}$

For the equipment protected by surge arresters:

Phase-to-earth:  $U_{rp} = 297 \text{ kV}$

Phase-to-phase:  $U_{rp} = 553 \text{ kV}$

# Insulation co-ordination procedure as in IEC 60071-1 in four main steps:

2. determination of the co-ordination withstand voltages ( $U_{cw}$ ) as in IEC 60071-1

<b>Temporary overvoltage:</b>	
Phase-to-earth:	$U_{cw} = 147 \text{ kV}$
Phase-to-phase:	$U_{cw} = 255 \text{ kV}$
<b>Slow-front overvoltages:</b>	
For the equipment not protected by surge arresters	
Phase-to-earth:	$U_{cw} = 382 \text{ kV}$
Phase-to-phase:	$U_{cw} = 553 \text{ kV}$
For the equipment protected by surge arresters:	
Phase-to-earth:	$U_{cw} = 327 \text{ kV}$
Phase-to-phase:	$U_{cw} = 553 \text{ kV}$

3. determination of the required withstand voltages ( $U_{rw}$ )

		Equipment not protected by surge arresters (cables)	Equipment protected by surge arresters	
			Internal insulation	External insulation
TOVs	Phase-to-earth	170 kV	170 kV	162 kV
	Phase-to-phase	293 kV	293 kV	281 kV
SFOs	Phase-to-earth	439 kV	377 kV	361 kV
	Phase-to-phase	635 kV	635 kV	610 kV

4. determination of the standard withstand voltages ( $U_{lw}$ )

	Standard rated short duration power-frequency withstand voltage kV (r.m.s. value)	Standard rated lightning impulse withstand voltage or BIL kV (peak value)
Single phase underground and submarine cables	275	650
Three phase underground and submarine cables	325	750
Three phase equipment internal insulation protected by surge arresters	325	750

# ***Conclusions - Insulation Co-ordination study***

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- The insulation level 325/750 kV ensures the safe operation area of all the equipment installed in the Cycladic islands interconnection system.
- The single core cables could be of a lower insulation level (275/650 kV)
- The energization of Syros-Andros cable should be done from Andros and not from Syros as the resulted switching overvoltages are lower.

# Calculation of transient and steady state Overvoltages during the energization of Lavrio – Syros interconnection

- Max calculated transient overvoltages in the energisation of Lavrio – Syros interconnection (within acceptable limits)

	Lavrio	Syros
Max. Load Conditions	1,915 p.u.	2,422 p.u.
Min. Load Conditions	2,011 p.u.	2,346 p.u.