Impact of the Euro-Asia Interconnector project on the economic operation of Crete and Cyprus power systems

Antonis Antoniou, Nikolas Theodorou, Antonis Tsikalakis, Kostas Kalaitzakis, George Stavrakakis

Technical University of Crete.
School of Electronic and Computer Engineering

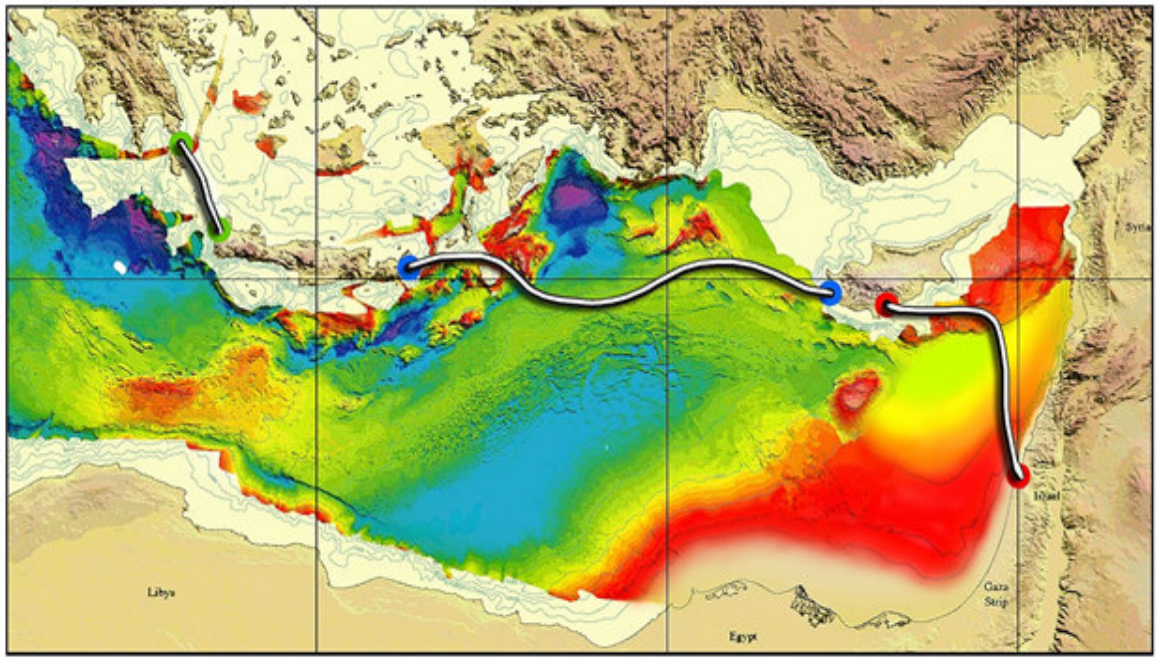
2nd International Energy Conference on Power Option for the Eastern Mediterranean Region

INTRODUCTION

- EuroAsia Interconnector is a very ambitious project for interconnecting three countries, Israel, Cyprus and Greece via submarine High Voltage Direct Current (HVDC) cables.
- The total length will be 540 n.m. at depth 2000m and capacity of 2000MW making the interconnection one of the largest in the world.
- EuroAsia Interconnector's partners are the Public Power Corp. (PPC) of Greece, Institutional authorities in Israel and DEH Quantum Energy of Cyprus.
- Interconnection with mainland Greece via Peloponnese is foreseen as a follow up of this project

2

Euro-Asia Interconnector



Κύπρος - Ισραήλ
155* ναυτικά μίλια

Κύπρος - Κρήτη
320* ναυτικά μίλια

Κρήτη - Πελοπόννησος
65* ναυτικά μίλια

3

Scope of the study

The paper focuses on the potential impact (economic and operational) and potential required upgrades due to interconnection of Cyprus and Crete.

- Actual data from both island power systems for year 2010 have been used to analyze
  - The expected flow between the island power systems
  - The change in committed units and thus operational costs
  - A preliminary assessment of upgrades required for the Transmission Network and voltage analysis

4

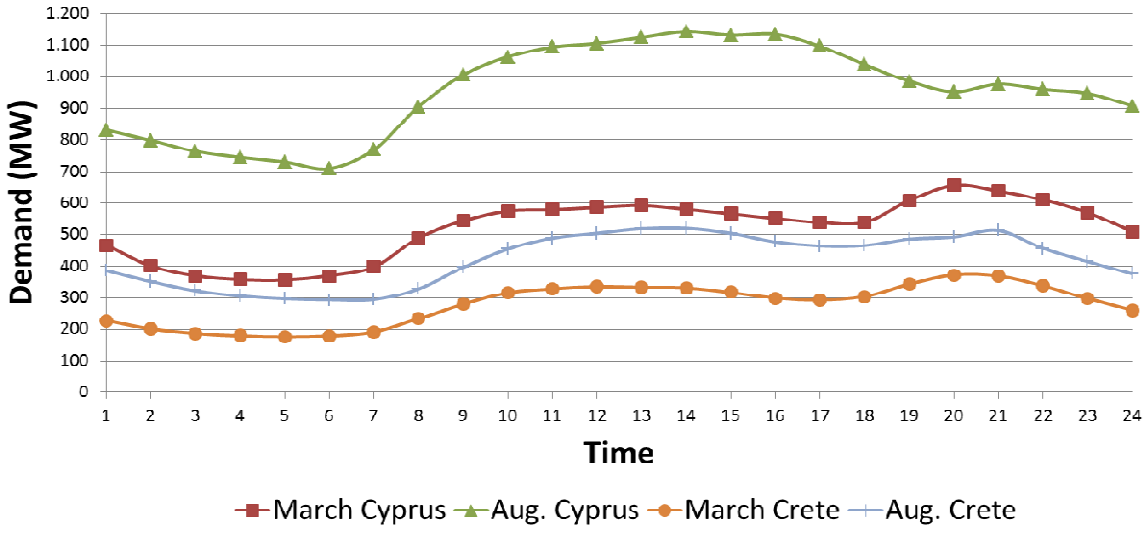
Demand Characteristics

Power System	Demand (GWh)	Peak Demand (MW)	Min Demand (MW)
Cyprus	5189,18	1143.2	308.50
Crete	2732,64	577.9	126
Unified	7921,82	1662.9	467.25

- Unified system 34.5% of the demand comes from Crete and the rest from Cyprus

5

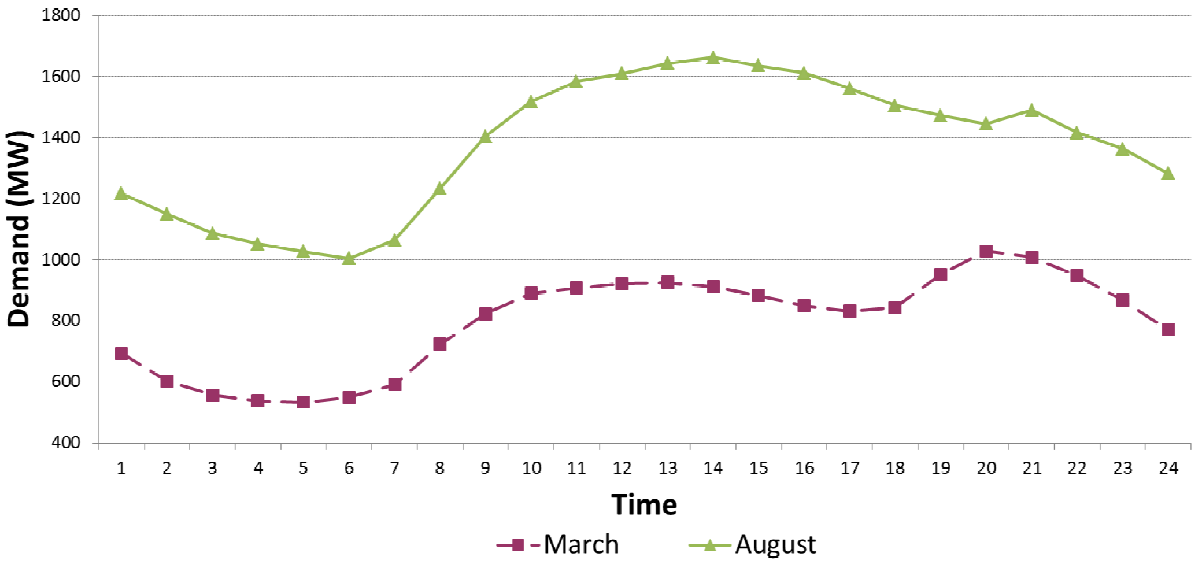
Demand Characteristics



6

Demand Characteristics

Typical demand curves for the unified power system for low and high demand periods



7

Demand Pattern analysis

- Rather correlated power systems - The correlation factor (ε) is **1.035** and during summer months this may be as low as 1.013.
- The load factor (lf) is expected to be **54.38%** compared to **51.8%** for Cyprus alone.
- The minimum to maximum ratio, which even though it is increased, is as low as 28.1% on annual base but can be as high as 45% for the summer period.
  - This is much higher compared to 21% of the Cretan power system alone.

8

Thermal Power Stations Characteristics

Installed Capacity (MW) Per Unit Type & Power Station

Power Station	ST	ICE	GT	CC	Installed Capacity (MW)
Vasilikos	390	-	37.5	220	647.5
Dekelia	360	104.8	-	-	464.8
Moni	180	-	150	-	330
Linoperamata	106	44	115	-	265
Chania	-	-	216	132	348
Atherinolakos	102	88	-	-	190
Total Capacity(MW)	1138	236.8	518.5	352	2245.3

Interconnection will create a power system with 66.4% of the installed capacity coming from must run units ST and CC.

9

Renewable Energy Sources (RES)

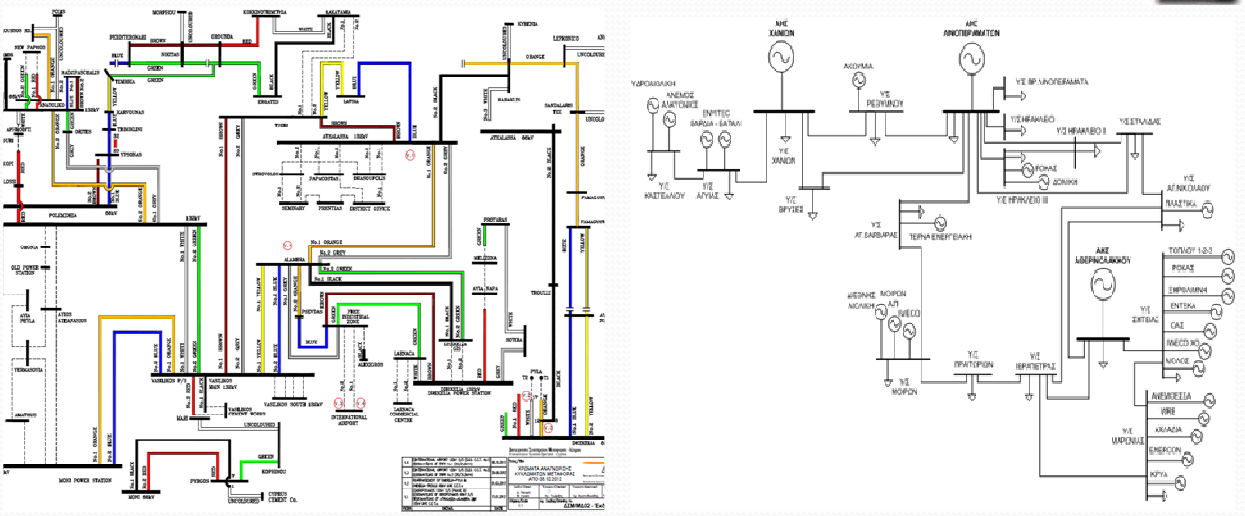
Currently Installed RES Capacity (MW) Per Type and Island.

Power System	Wind (MW)	PV (MW)	Other RES (MW)
Cyprus	146.7	16.4	8.7
Crete	183.54	91.41	1
Unified	330.24	107.81	9.7

- The installed capacity in both islands is currently slightly below 450MW.
- In the simulations, RES hourly output of wind and PVs were used.
- The authorized RES including also Solar Thermal power Stations were not considered.

10

One-line diagram of Cyprus and Crete



- The interconnector is performed via two submarine High Voltage Direct Current (HVDC) cables with 400kV voltage.
- Each section 2000mm^2 cable with a capacity 500MW. (N-1 criterion)
- The nominal voltage of transmission lines HV of Cyprus is 132 kV while Crete is 150 kV.

11

Upgrades required for Cyprus and Crete HV transmission Systems

- The interconnector is performed via two submarine (HVDC) cables with 400kV voltage between Paphos and Atherinolakos
- Each section 2000 mm^2 cable with a capacity 500MW. (N-1 criterion)
- The nominal voltage of transmission lines HV of Cyprus is 132 kV while Crete is 150 kV and thus the terminal inverter stations
- There is the need of building double circuit lines between VASILIKOS and PAPHOS for maintaining voltage on the eastern part of Cyprus preferably on 400kV.
- The voltage on the island of Cyprus should be at least on 132kV
- New 132kV transmission line between Polemidia and Anatoliko.
- Line between Moni and Paphos would improve significantly voltage profile on Western Cyprus.
- Additional line between Atherinolakos and Iraklio would have been helpful as well.

12

Simulation Approach

Unit Commitment process

The Unit commitment process is based on priority list formulated by average fuel cost of each unit at full load. If required, priority is given to must run units.

- The thermal units meet the rest demand after substracting expected RES production on both islands. *Pl(t)=Pd(t)-RES_prod(t)*
- The commitment process takes into account the following uncertainties
  - Combined load, wind and PV forecasting error utilizing probabilistic methodology of known forecasting tools behaviour. Geographic dispersion may lead to narrower prediction errors thus to be on the "safe" side.
  - The potential of losing the largest operating unit so spinning reserve equal to its operating point

14

Economic Dispatch

- If there is problem with the technical minima of the committed units and potential simultaneous decrease of load and increase of RES, the RES production should be reduced -RES Curtailment- to accommodate the technical minima of the units. The must run character of the operating units deteriorates this issue
- The demand (taking into account the RES curtailment, if any) is allocated to the committed units based on their cost function and optimization toolbox of MATLAB based on Kuhn-Tacker Conditions.

15

Simulations-Results

To export the results we simulated the power systems of Cyprus and Crete operating autonomously and then the unified power system created by interconnection.

Consumption and Fuel costs

Fuel Prices

Fuel	Price (€/Tn)
HFO -Crete	415
Diesel-Crete	698
HFO -Cyprus	359
Diesel- Cyprus	539

Considered Remuneration For RES.

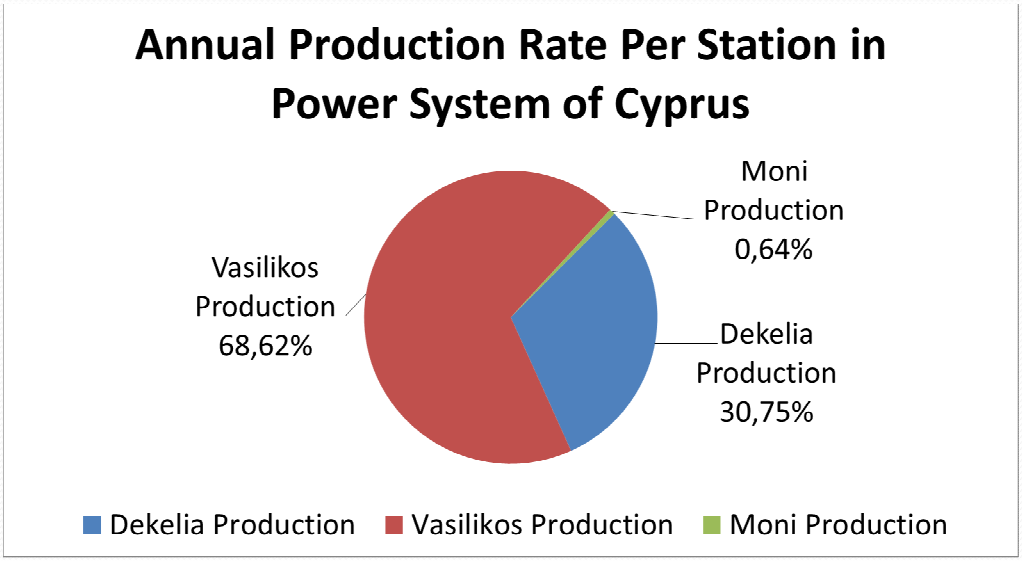
RES	Remuneration (€/MWh)
Wind Power on Crete	99.45
PV on Crete	305.6
Wind Power on Cyprus	129
PV on Cyprus	340

17

Thermal Production

Independent Power System of Cyprus

- Total production **5.3 TWh**.
- Thermal production **5.1 TWh**.
- RES production **206 GWh**.
- The maximum thermal production was estimated at 1140.48 MW and occurred in August, the month with the peak system demand (1143.20 MW).

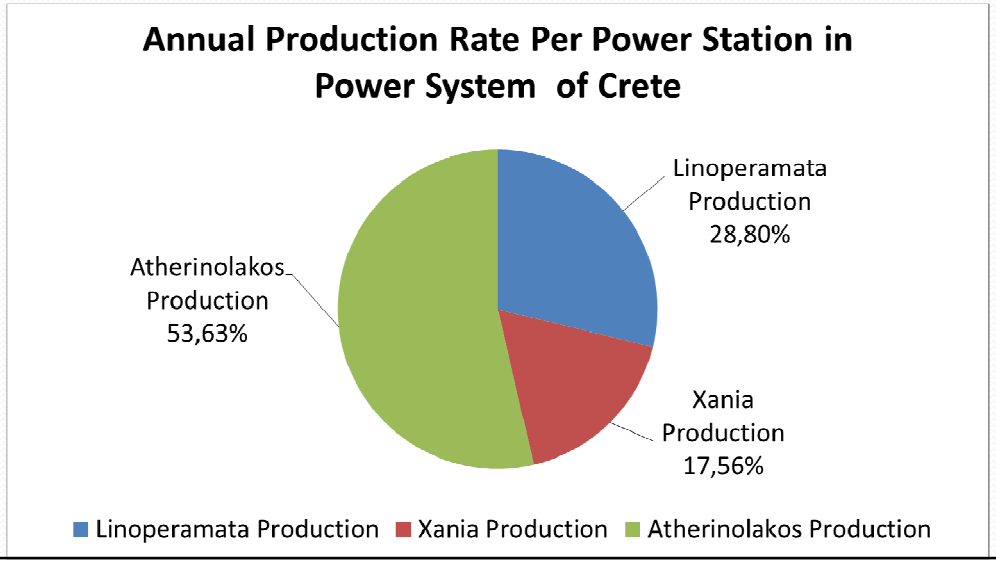


18

Thermal Production

Independent Power System of Crete

- Total production **2.9 TWh**.
  - Thermal production **2.3 TWh**.
  - RES production **584 GWh**.
- The maximum thermal production was estimated at **560.86 MW** and occurred in August, the month with the peak system demand **(577.9 MW)**.

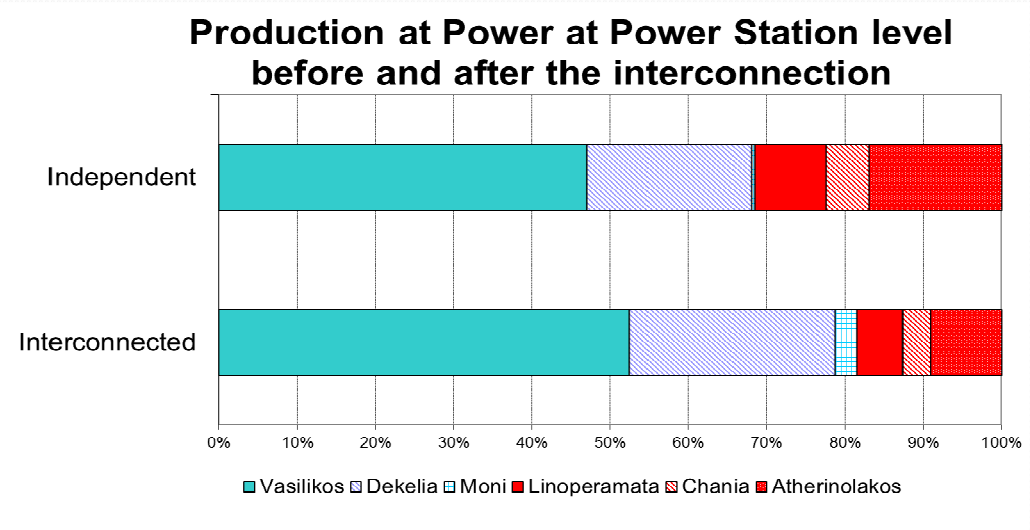


19

Thermal Production

Interconnected Power System

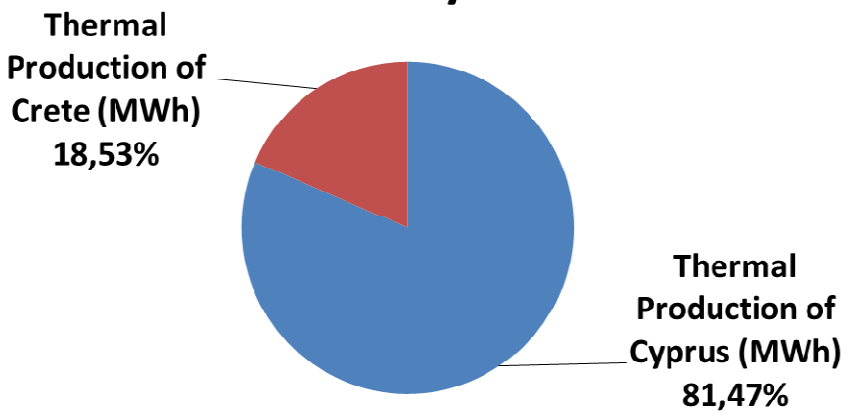
- Total production **8.3 TWh**.
- Thermal production **7.5 TWh**.
- RES production **790 GWh**.
- The maximum thermal production was estimated at **1598.94 MW** and occurred in August, the month with the peak system demand (**1662 MW**).



20

Thermal Production

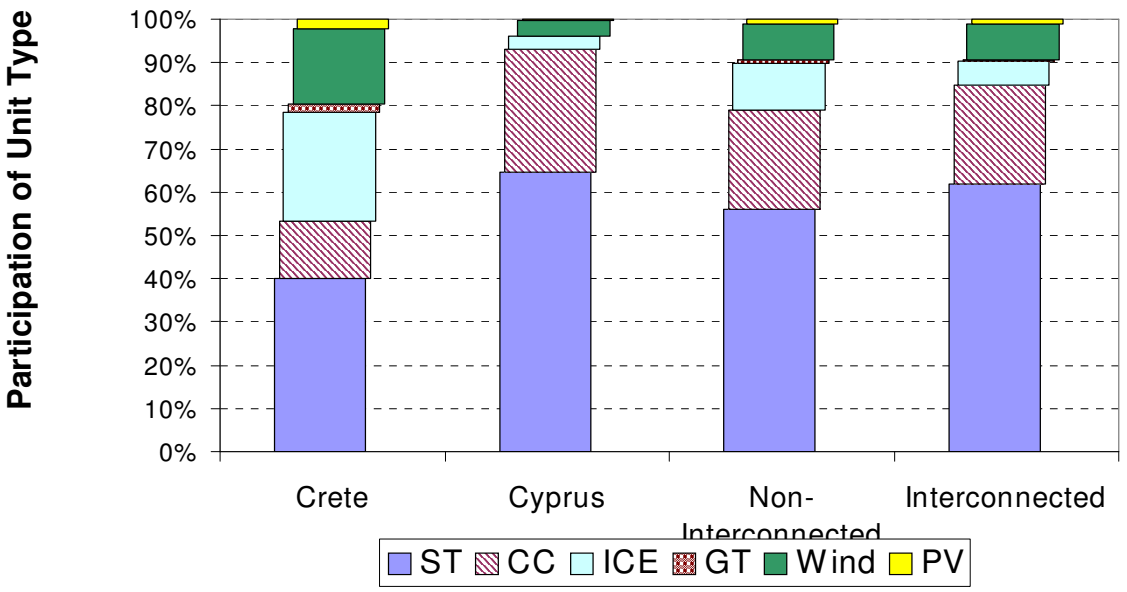
Annual Quota of Thermal Production in Unified System



21

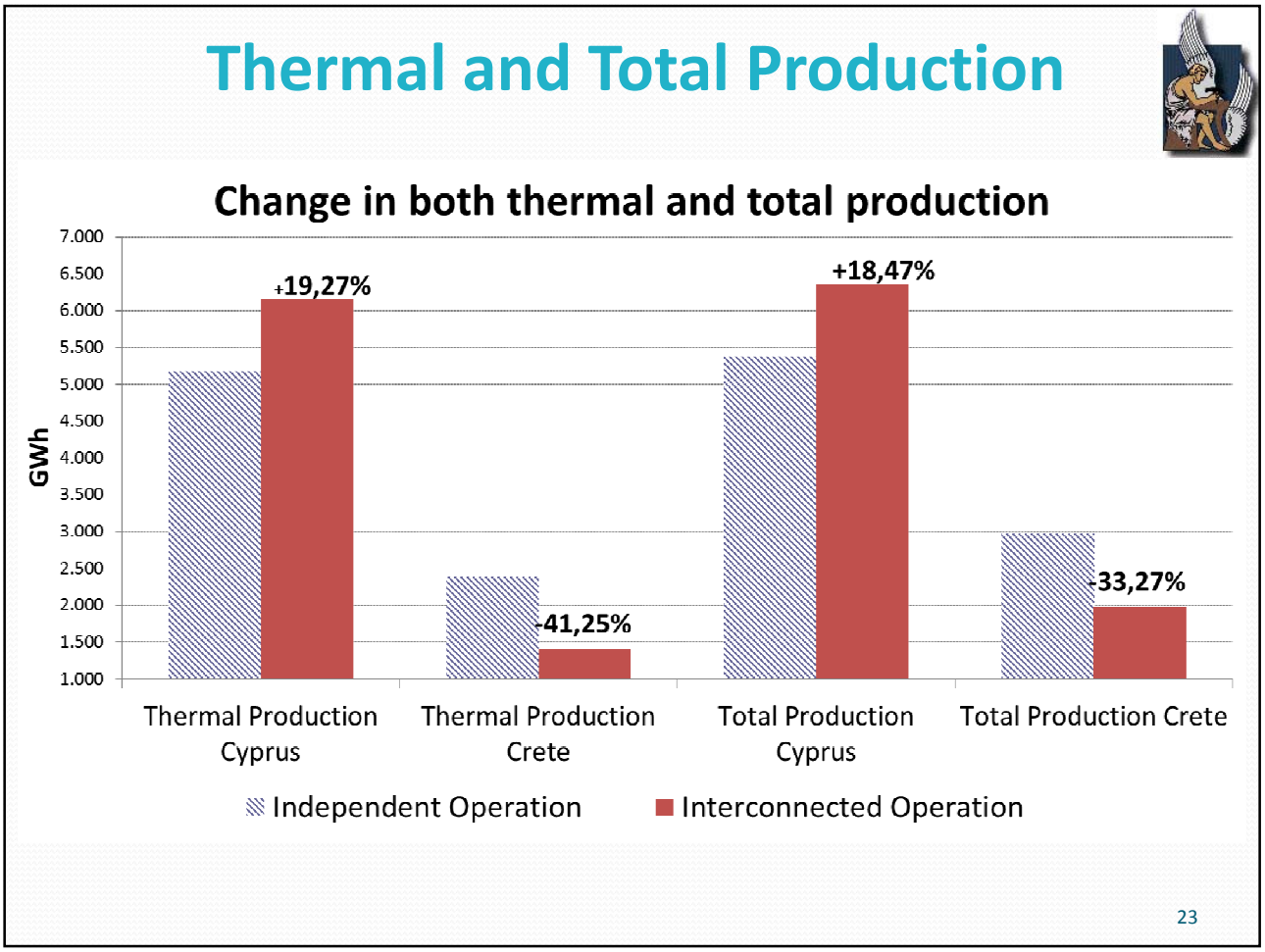
Thermal Production

Production at Power Station level before and after the interconnection

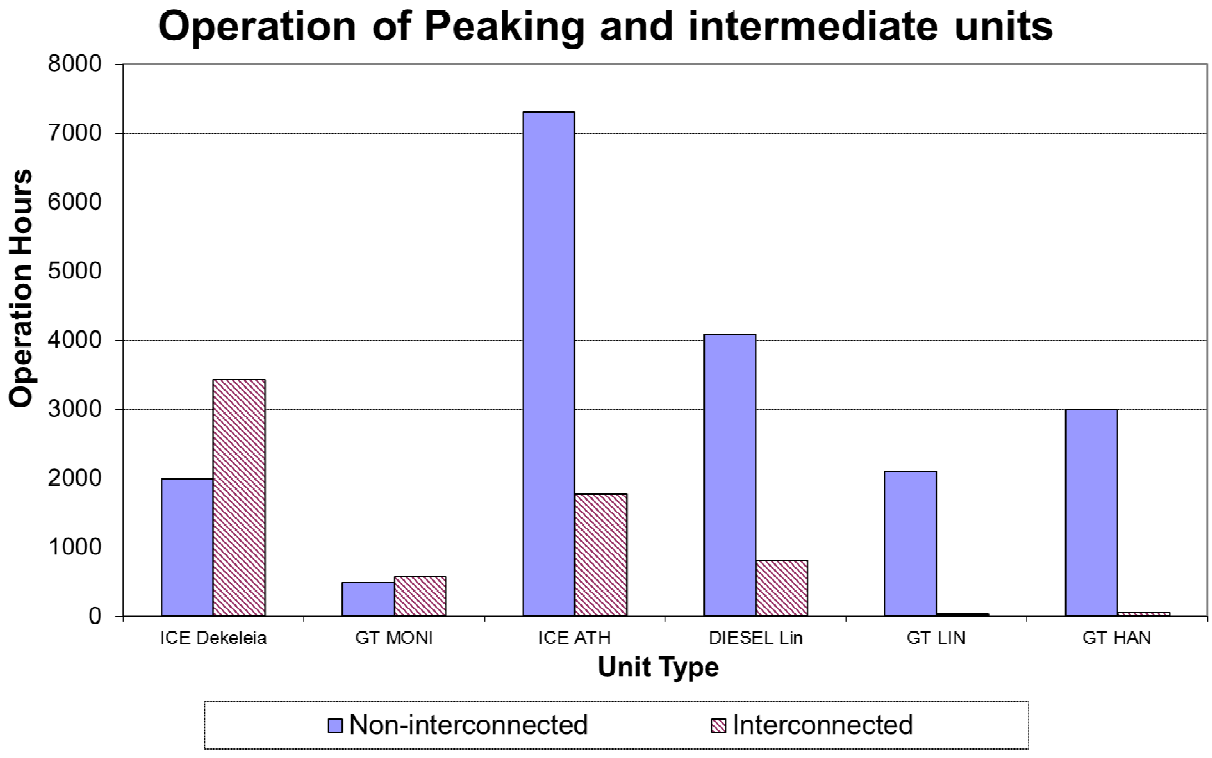


22

Thermal and Total Production



Thermal Production



24

RES Integration

Power System of Cyprus- Independent Operation

- 3.69% of RES production is expected to be curtailed-almost inclusively from wind power (4.13% of the expected wind power production).
- 12% of the expected wind power production may be curtailed in November.
- RES penetration reaches 3.6% and monthly penetration in February exceeds 6%.

Power System of Crete- Independent Operation

- RES curtailment is 0.55% with highest curtailment during January at 4%.
- RES penetration reaches 19.6% with July penetration at 26%.
- The estimated curtailed RES production from both power systems is 11.3 GWh or 1.5% of the estimated production.

25

RES Integration

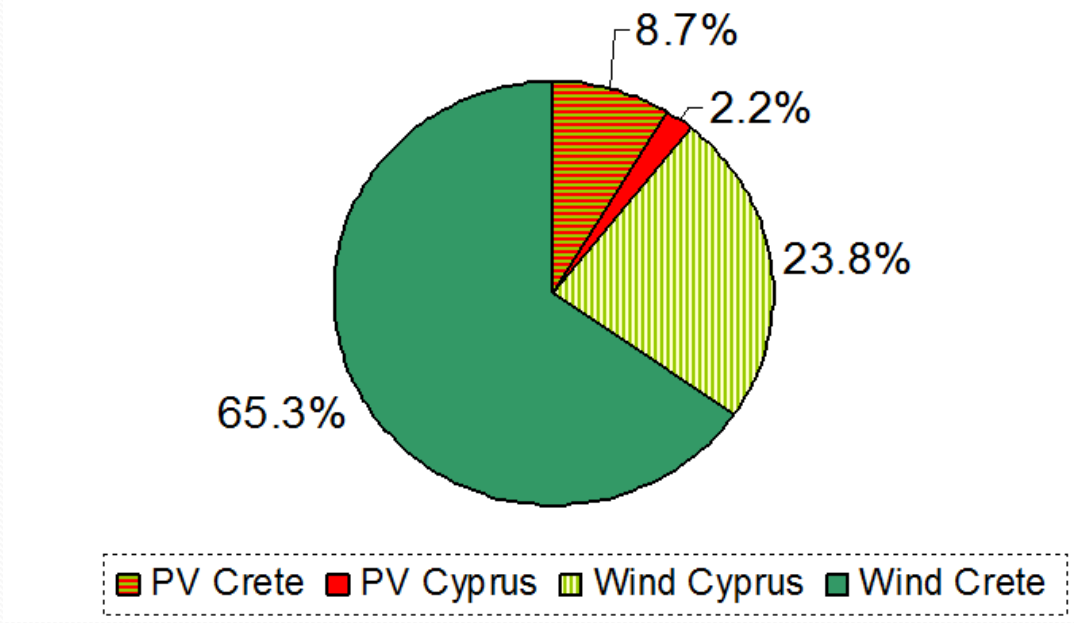
Interconnected Power System

- For wind power owners in Cyprus, the curtailment is reduced by 53% , but for wind power owners on Crete the curtailment increases by 175%.
- The curtailed RES production is increased by 6.2% reaching 12.1 GWh annually.
- The percentage of RES production curtailed is still limited accounting for 1.51% of RES production.
- The curtailment is expected during early morning hours, i.e. about 5.00am and is significantly increased during Spring, when demand is low. This could be exploited for providing power to Desalination loads -already existing on Cyprus- acting as flexible loads.

RES Integration

Interconnected Power System

Allocation of RES production per type and island



27

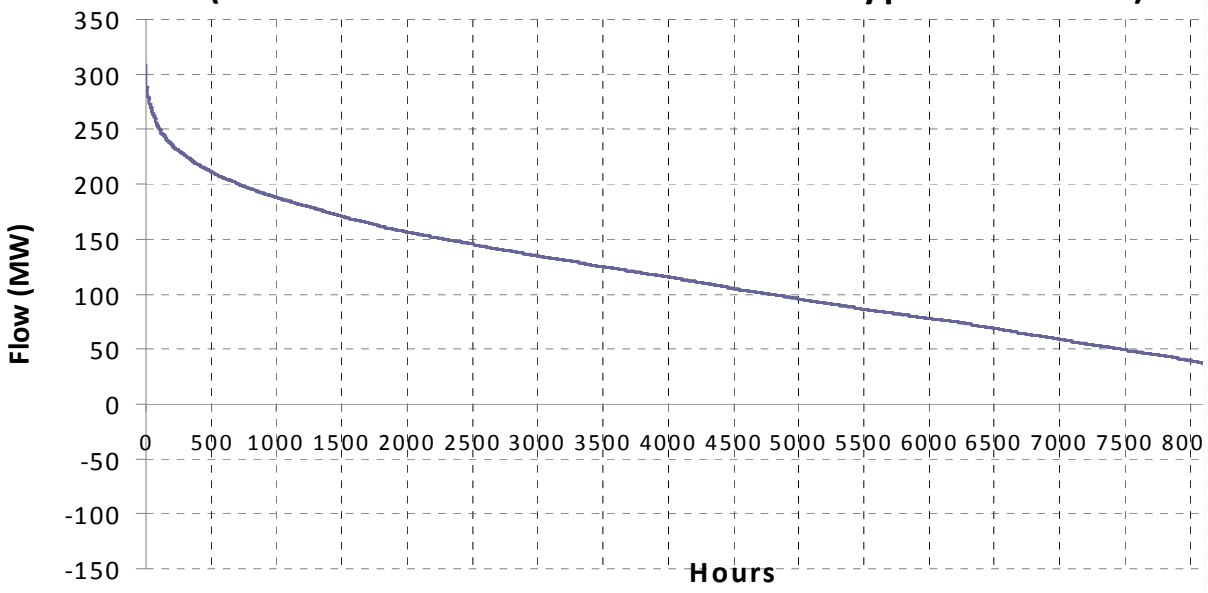
Power Exchange

- The maximum flow on the cable is 308.77 MW from Cyprus to Crete (June).
- The maximum flow from Crete to Cyprus is below 100MW.
- For the whole year 987.8 GWh are imported to Crete (33% of the demand) and 0.8 GWh to Cyprus.
- June presents the highest monthly flow with 118.74GWh.
- Crete meets 33% of the energy needs with imports from Cyprus.
- During November, about 52% of demand on Crete is imported from Cyprus.

28

Power Exchange

Duration curve of the Power Flow in the interconnecting HVDC cables (Positive values mean flow from Cyprus to Crete)



29

Consumption and Fuel costs

Summary of the Fuel Consumption And Cost.

Power System	HFO (tn)	Diesel (klt)	Fuel Cost (mil. €)	Operational Cost (mil. €)
Cyprus	936628	249092	470.6	499.7
Crete	488629	143191	281.04	352.85
Total Independent Operation	1385294	392284	751.6	852.61
Interconnected operation	1432687	361363	736.6	837.67
Percentage Difference	3.42%	-7.88%	-2.00%	-1.75%

30

Consumption and Fuel costs

- Reduction of the operating cost of the unified power systems by **15million €** compared to even the most economic operation of the separate power systems. RES remuneration leads to slight reduction of the annual benefits to 14.9 million €.
- Average thermal cost when two power systems are interconnected is **97.48€/MWh** which is by 2 €/MWh lower than the one for independent operation of the power systems.
- If RES remuneration is taken into account the average energy cost for the interconnected power system is 100.45€/MWh, by 1.73€/MWh lower compared to independent operation.

31

Emissions

- Due to higher emissions level of HFO for CO_2, 3.2 kg/Kg compared to 2.45kg/kg of diesel, the CO_2 emissions of the unified power system are slightly increased.
- Increase in annual CO_2 emission of Cyprus during 805,000 Tn.
- Reduce annual CO_2 emission of Crete during 782,000 Tn.

✓ Since production in Cyprus is substantially increased, there should be a significant revision of the emissions.

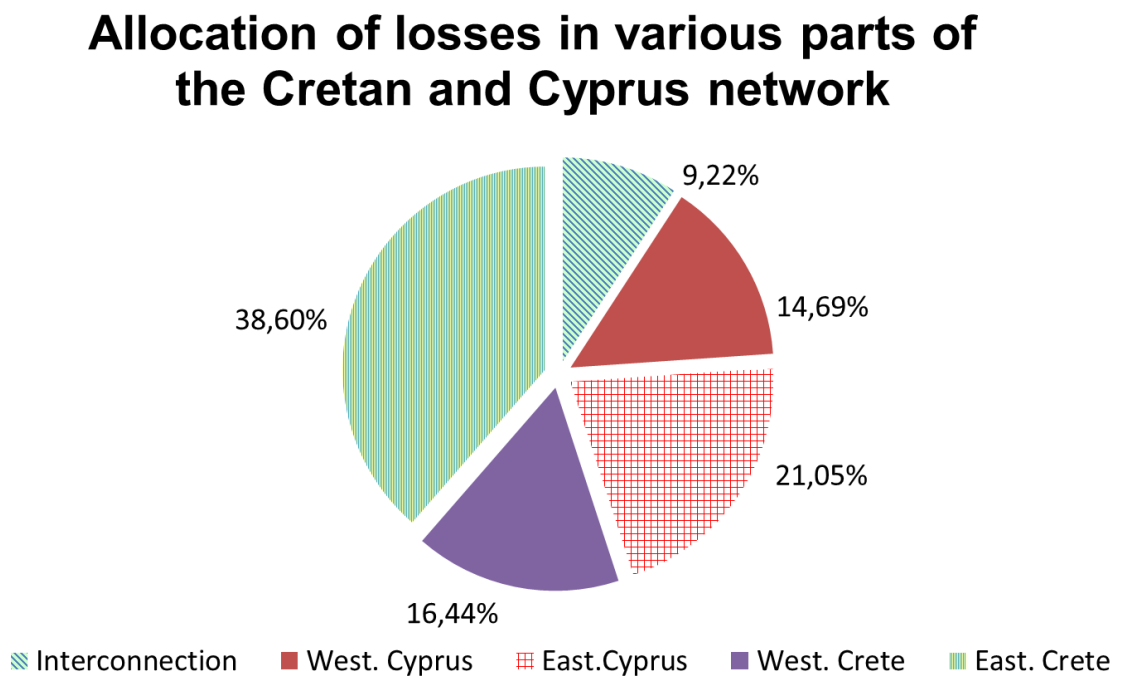
32

Losses of Network

- Each island has been separated into western and eastern part with center Vasilikos and Linoperamata Power Stations respectively.
- 63.99GWh are lost and 0.7% of the transferred energy between the two power systems is lost in the Interconnection.
- Maximum value of active power losses during August is 28.79MW. The maximum active power losses are 22.26MW on Crete in June while on Cyprus the maximum losses are 8.14MW.

33

Losses of Network



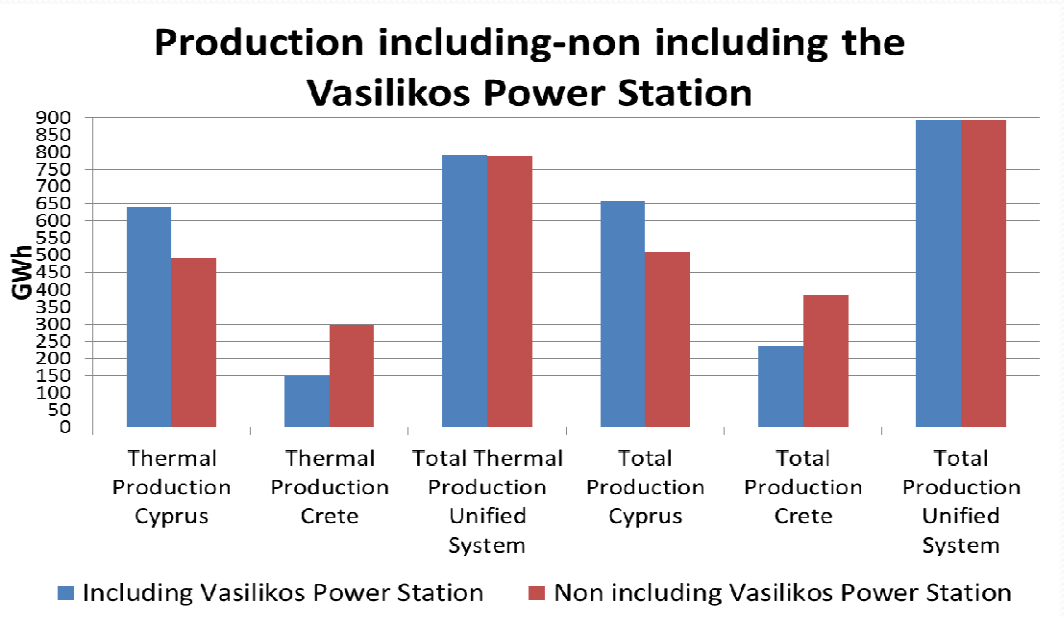
34

Sensitivity Analysis

Presents the results of simulations of sensitivity analyzes for the Unified power system.

Scenario A: Shutdown Vasilikos power station

- This scenario simulates the Mari explosion with devastating consequences at Vasilikos power station.
- The simulation was indicative for July.



36

Scenario A: Shutdown Vasilikos power station

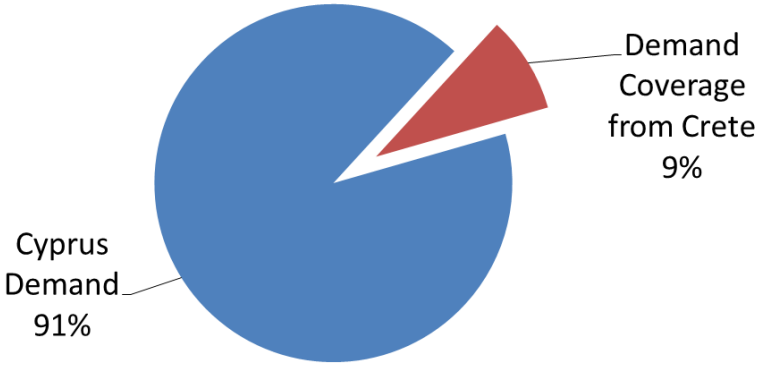
- An increase of production of all thermal units in unified system.
- All thermal units reach at some time their maximum capacity apart from the old Gas turbines of Chania power station.
- Significant increased fuel consumption HFO and diesel.
- Fuel costs increase by 15.4 million € and 20% for average
- Significant reduction energy flow from Crete to Cyprus.

	Energy flow to Crete(GWh)	Energy flow to Cyprus(GWh)	Total Energy Flow(GWh)
Non Including Vasilikos power station	2.1	53.6	55.8
Including Vasilikos power station	96.9	0	96.9

37

Scenario A: Shutdown Vasilikos power station

Coverage Quota of demand from Crete,non including the Vasilikos Power Station



Conclusion

✓Interconnection of two islands can ensure stability of operation even if a catastrophic event takes place with significant economic costs however.

38

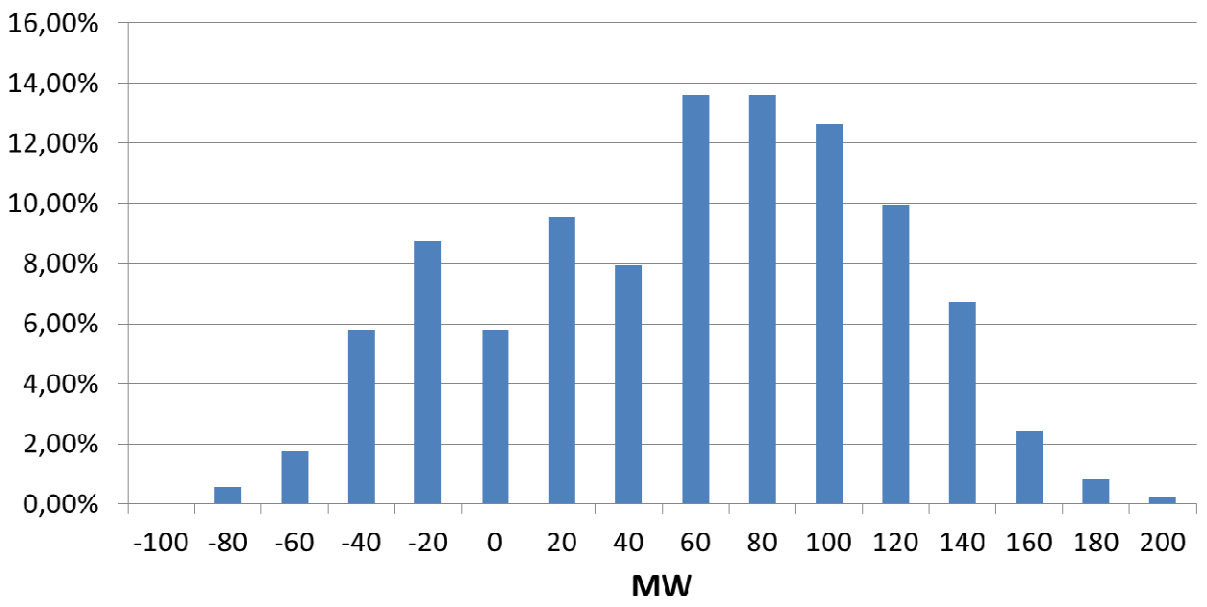
Scenario B: Single fuel price

- In this scenario, we assumed a uniform price HFO and diesel fuel in thermal power units of Cyprus and Crete respectively.
- 341 € / Tn for HFO
- 482 € / Tn for diesel
- The simulation was indicative for July.

	Thermal Production Cyprus in the Unified system(GWh)	Thermal Production Crete in the Unified system(GWh)
July with single fuel price	586.93	202.66
July with different fuel prices	640.33	149.25

39

Scenario B: Single fuel price



40

Scenario B: Single fuel price

Results

- Reducing HFO consumption and increase fuel diesel consumption . (Intense production Chania CC)
- Reduce overall energy flow by 46%.
- Reducing energy flow from Cyprus to Crete to 51%
- Showing energy flow from Crete to Cyprus 4.2 GWh.
- Decrease of demand coverage of Crete about 50%.

Conclusions

- ✓ The thermal units of Crete and especially the intermediate load units, they become more attractive for integration in production.
- ✓ Generally the single price of fuel affects the flow of power between the two islands, but coverage rates of demand.

41

Scenario C: Increase putative technical minimum CC of Chania at 10 MW

The scenario considered in case there is some limitation to the unified system.

- We demanded increase the technical minimum of CC Chania from 50 MW to 60 MW, because the voltage of the scales of western Crete for 212 hours of July was below 98% of nominal voltage.

Results

- The production of CC Chania increased about 20%.
- The production of ST units Dhekelia decreased by 3.7%.
- The cost of fuel increased by 25000 €.
- The energy flow between these times is presented entirely from Cyprus to Crete. (Reduced about 2.1 GWh)
- The coverage rate of demand of Crete from Cyprus stands at 29.2% compared with 31.7%.

42

Conclusions

- ✓ With the increasing technical minimum of CC Chania limited the hours during which the voltage of the scales of western Crete is below 98% of nominal voltage.
- ✓ The ST units Dhekelia affected the vast majority of their hours and have reduced production.

General Conclusions

General Conclusions

- ✓ The unified systems are protected even if a catastrophic event takes place.
- ✓ Since HFO is cheaper and the fact of using efficient units at more efficient operating points, the operating cost of the unified power system by 14.9 million €, or 1.75% of the operating cost if RES remuneration is taken into account.
- ✓ This money would suffice for 209 million € investment on the cable at 30 years basis and 6% interest rate
- ✓ Significant flow from Cyprus to Crete, accounting for 33% of the annual demand on Crete.
- ✓ If the fuel prices were equal the units on Crete would increase their production

45

General Conclusions

- ✓ Higher usage of HFO compared to diesel oil and as a consequence, slight decrease in CO2 emissions quota required for both systems.
- ✓ RES penetration is not expected to change significantly since interconnection does not reduce RES curtailment.
- ✓ Scenarios with increased RES capacity and even greater diversity of units, including decommissioning of some old Steam Units (perhaps in Moni and Linoperamata power stations) in favour of ICE will be the topic of a future paper.
- ✓ Further RES installation should focus on producing during the summer peak periods. To the same direction shifting of the demand, to morning hours could provide substantial aid for RES integration.
- ✓ Unless some upgrades are made on Western Cyprus the benefits cannot be fully deployable.

46