Potential for interconnection of isolated power systems with ENTSO-E network
Example of Cyprus power system

Presenters:
Part I: Andriy Vovk, TYNDP PMO Advisor
Part II: George Ashikalis, Director of Operations and Personnel, TSO Cyprus

Tenerife, 9 May 2018

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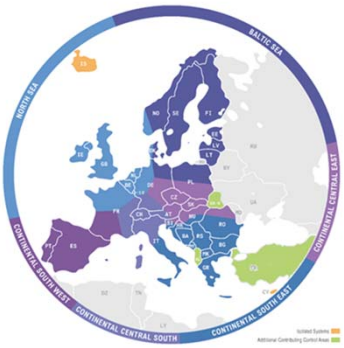
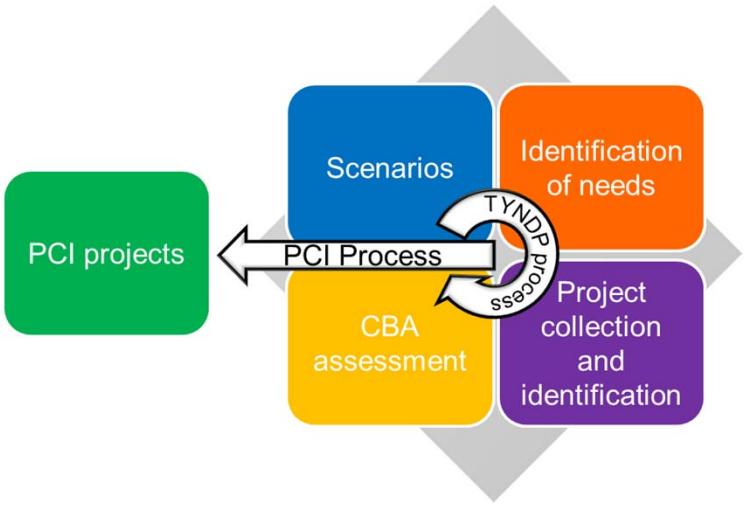
CONTENT

- Introduction – TYNDP 2018 Workflow
- TYNDP2018 Scenario Building Storylines
- Interconnection Tagets;
- Evolution of the generation mix – case of Cyprus;
- Marginal cost yearly average, Unserved energy – RG CSE;
- Interconnection Benefits – Case of Cyprus



Introduction – TYNDP 2018 Workflow



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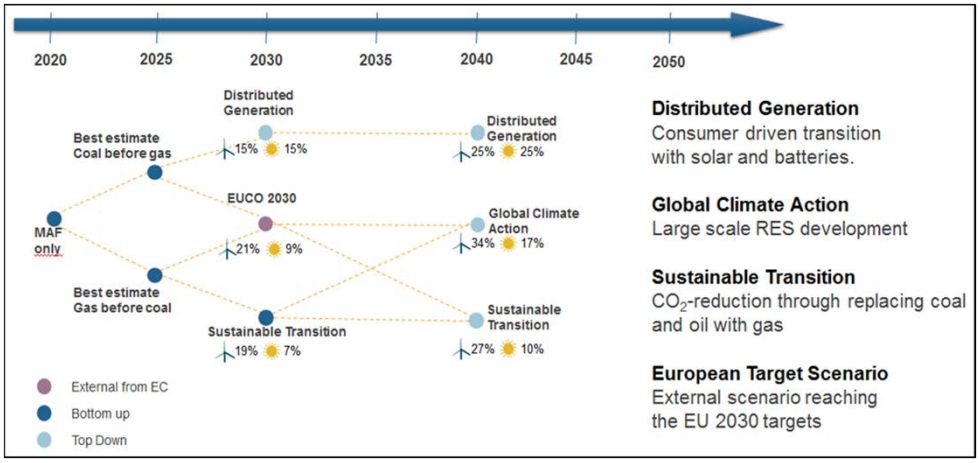
TYNDP2018 SCENARIO BUILDING STORYLINES



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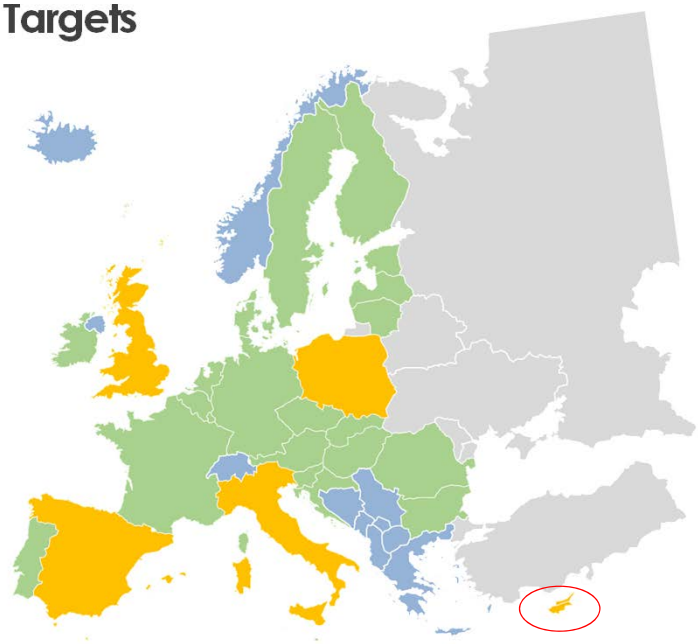
Interconnection Targets

Interconnection target 10% criteria 2020

Color code:

- Below 10% threshold
- Above 10% threshold
- not considered



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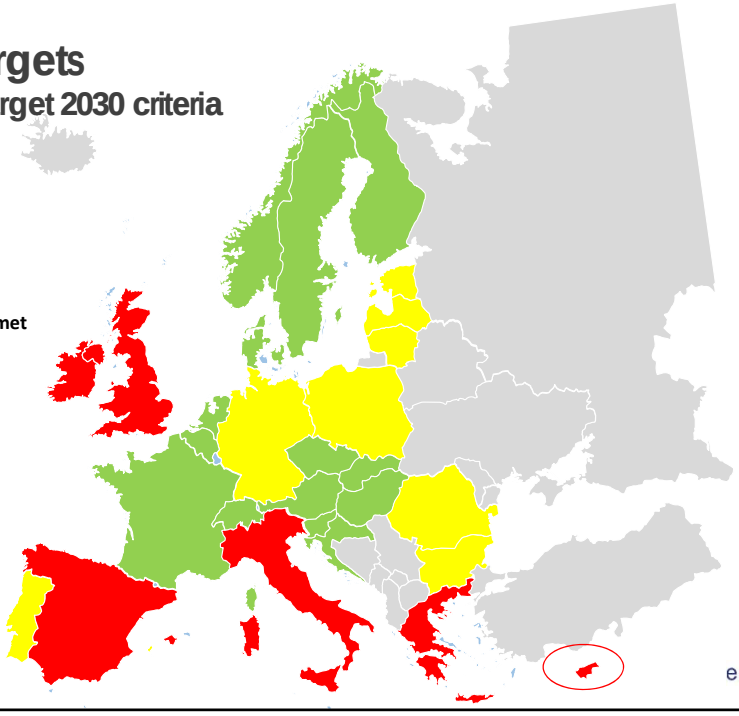
Interconnection Targets

New Interconnection Target 2030 criteria

- -all three thresholds met
- -two of the thresholds met
- -one or none of the thresholds met



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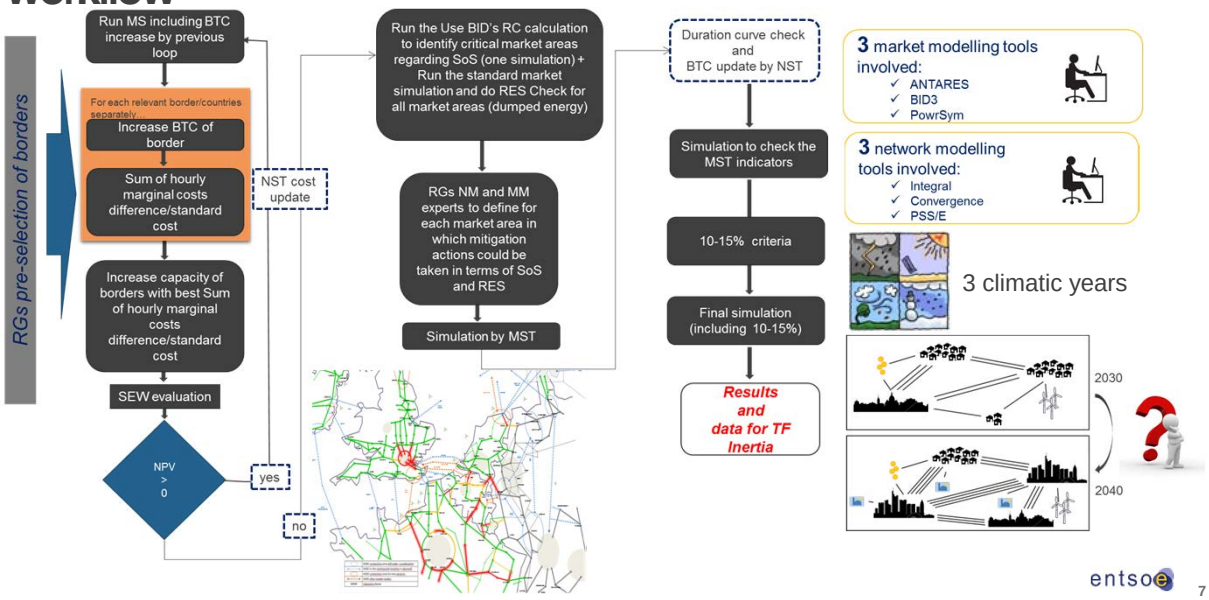
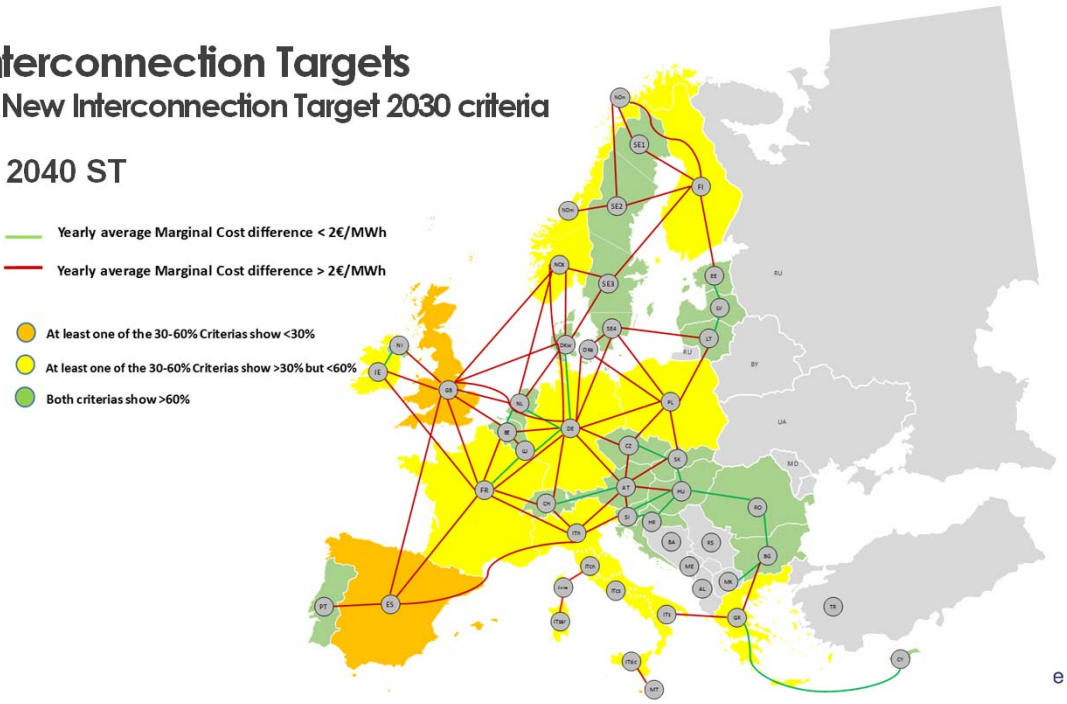
Interconnection Targets – Identification of the System Needs workflow



Interconnection Targets

New Interconnection Target 2030 criteria

2040 ST



Interconnection Targets

New Interconnection Target 2030 criteria

2040 GCA

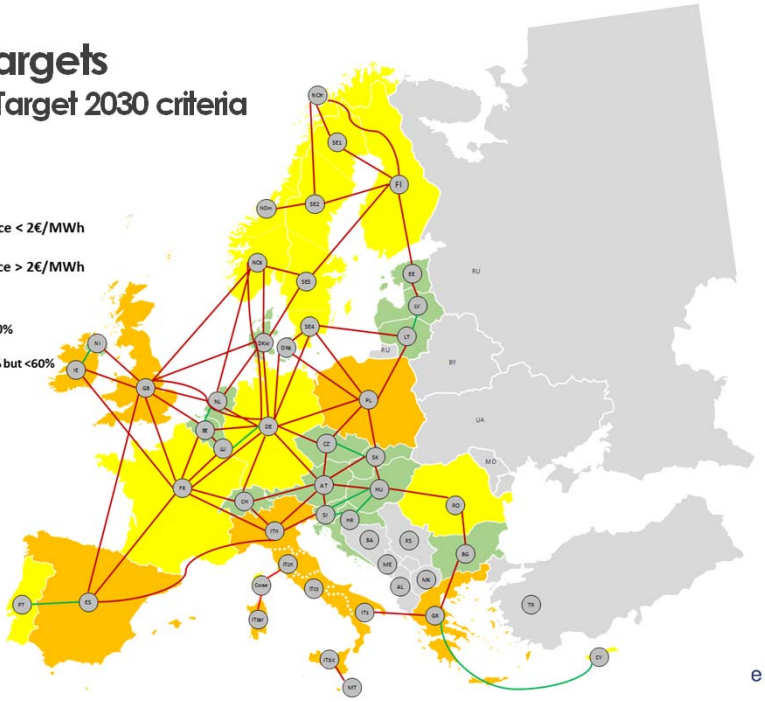
Yearly average Marginal Cost difference < 2€/MWh

Yearly average Marginal Cost difference > 2€/MWh

At least one of the 30-60% Criterias show <30%

At least one of the 30-60% Criterias show >30% but <60%

Both criterias show >60%



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Interconnection Targets

New Interconnection Target 2030 criteria

2040 DG

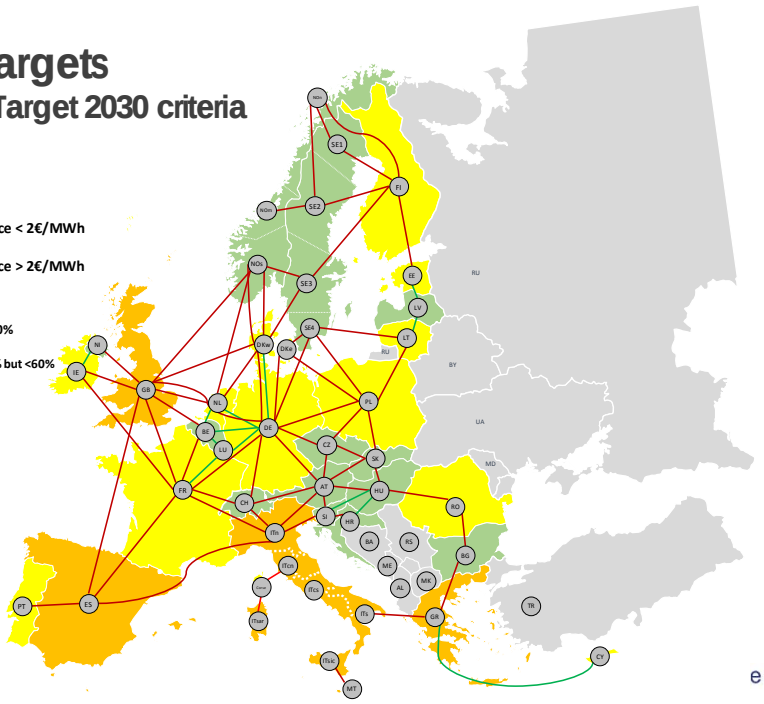
Yearly average Marginal Cost difference < 2€/MWh

Yearly average Marginal Cost difference > 2€/MWh

At least one of the 30-60% Criterias show <30%

At least one of the 30-60% Criterias show >30% but <60%

Both criterias show >60%



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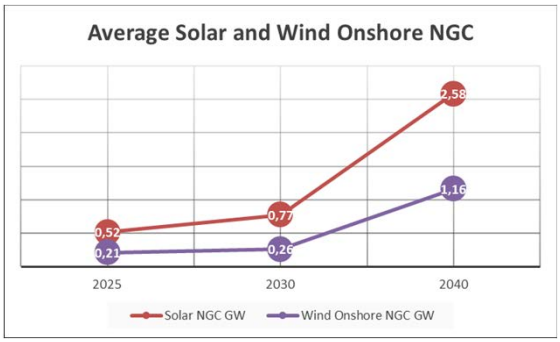
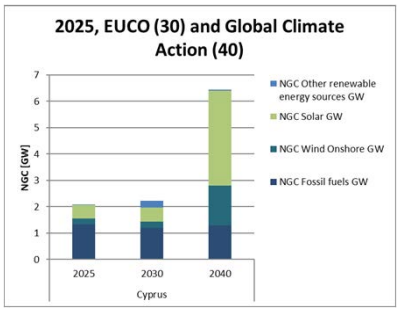
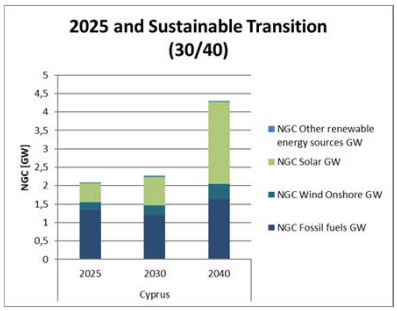
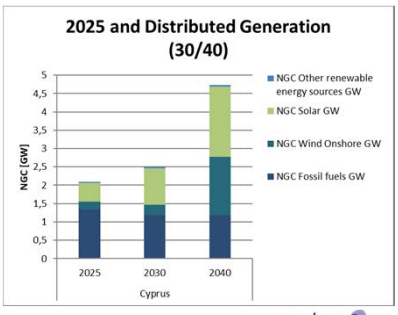
Evolution of the generation mix - NGC

Case of Cyprus









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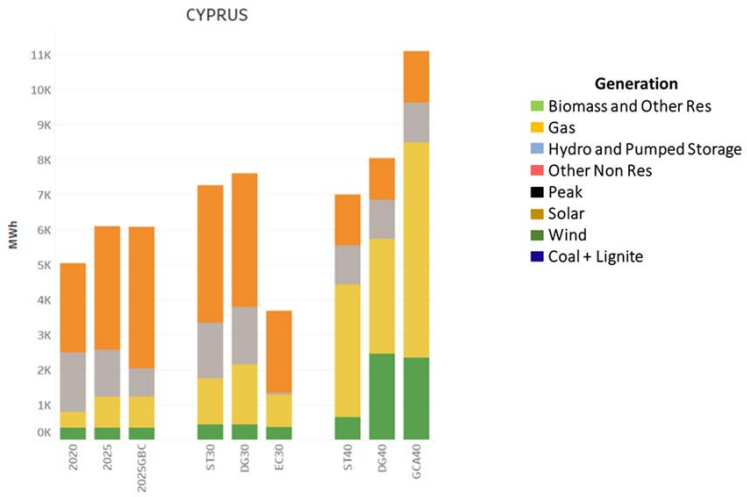
Evolution of the generation mix - Generation

Case of Cyprus



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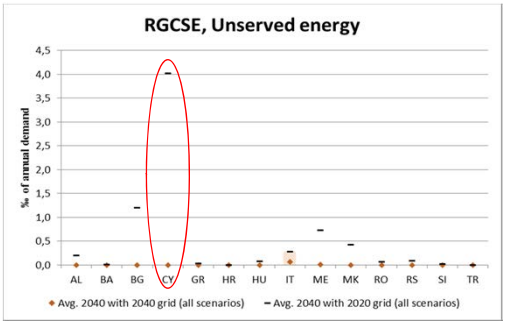
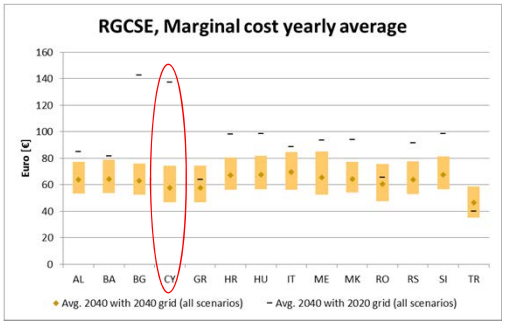
Marginal cost yearly average, Unserved energy

RG CSE





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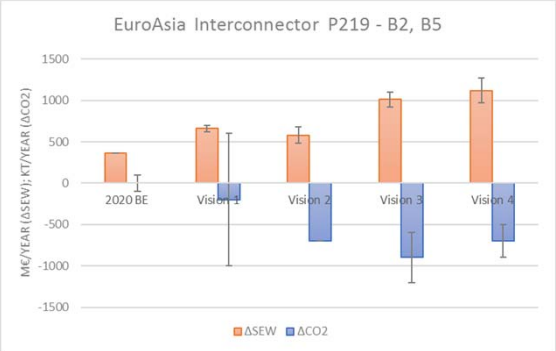
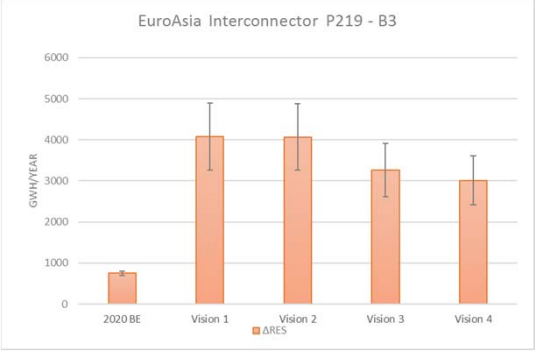
Interconnection Benefits – Case of Cyprus

EuroAsia Interconnector CBA – TYNDP 2016

Scenario specific CBA indicators	EP2020	Vision 1	Vision 2	Vision 3	Vision 4
B1 SoS (MWh/yr)	N/A	N/A	N/A	N/A	N/A
B2 SEW (MEuros/yr)	360 ±40	660 ±100	580 ±90	1010 ±150	1120 ±170
B3 RES integration (GWh/yr)	750 ±50	4080 ±820	4070 ±810	3260 ±650	3010 ±600
B4 Losses (GWh/yr)	1250 ±125	1100 ±110	1100 ±110	1225 ±122	2050 ±205
B4 Losses (Meuros/yr)	54 ±5	59 ±6	51 ±5	73 ±7	137 ±14
B5 CO2 Emissions (kT/year)	±100	-5600 ±800	-6800 ±	-2300 ±300	-1300 ±200





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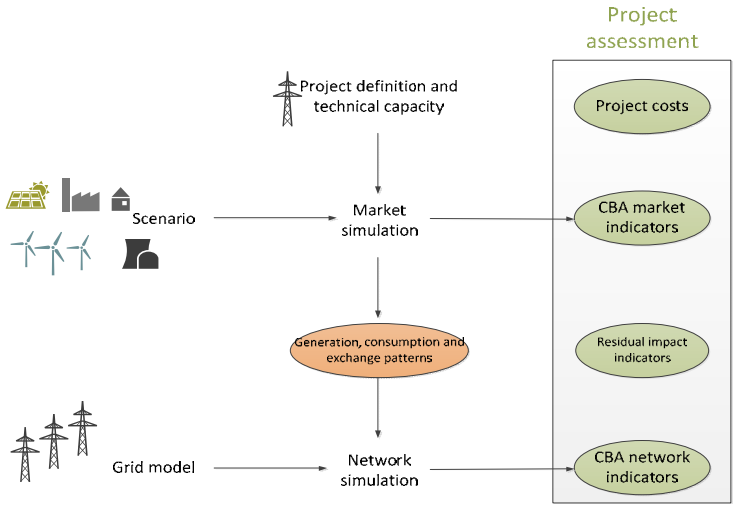
Reliable Sustainable Connected

Schematic project assessment process



PART II: Study for Secure Penetration of Renewables in conjunction with Cyprus' National RES 2015-2020 Action Plan in the Electricity System Of Cyprus

Workgroup:

TSO Cyprus

Eur Ing **George Ashikalis** BSc(Hons), PGcertEM, MSc, MBA, MIET, CEng, CMgr, MCMI, Chartered FCIPD, FCyHRMA
WG Co-ordinator
Director of Operations and Personnel

Christos Hadjilaou – Asst. Manager

Christos Kokkinos – Asst. Manager

EAC/Transmission System Owner

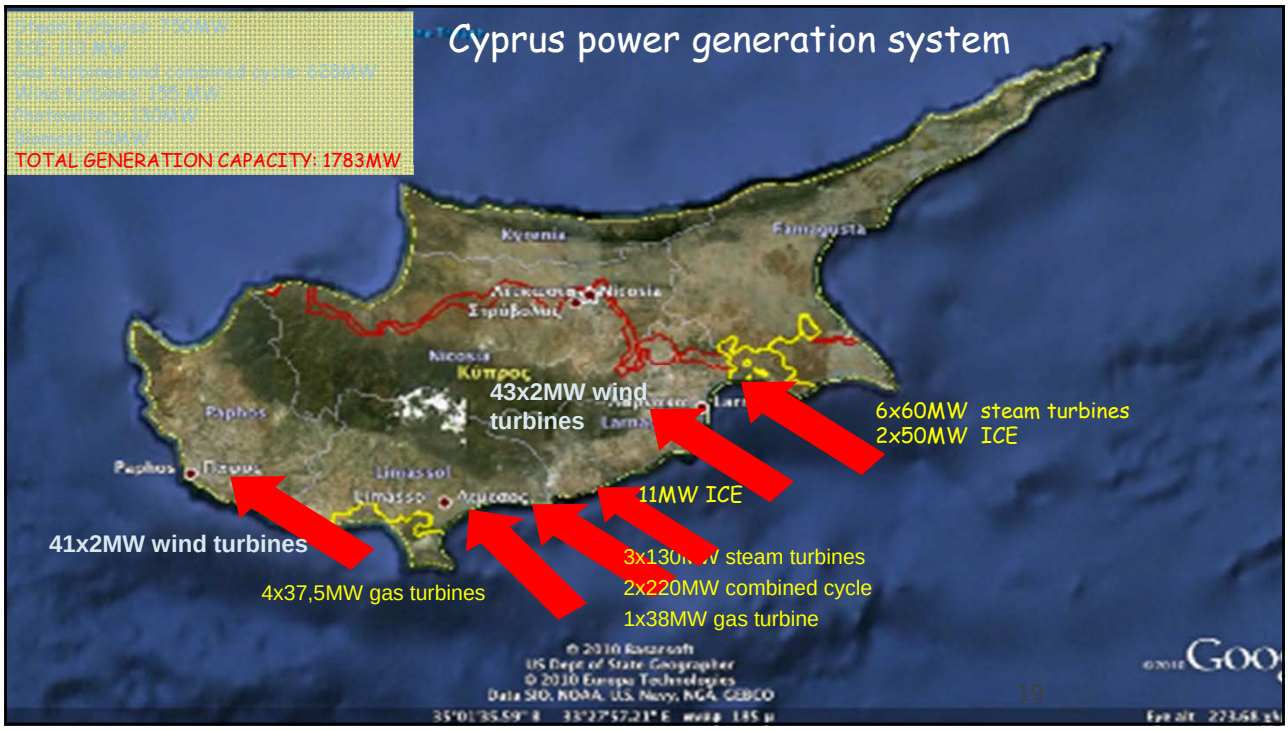
Zenon Achilides – Asst. Networks Manager

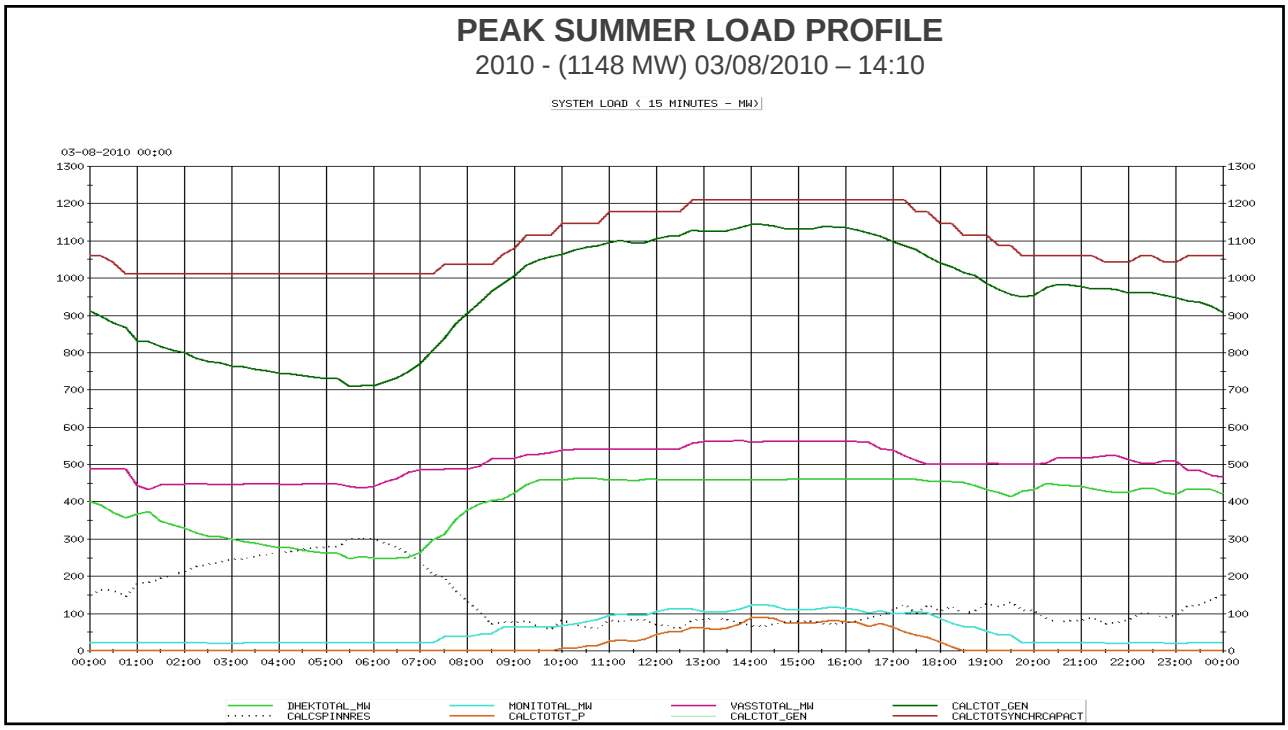
Savvas Papadouris – Network Engineer

MAY 2018 – Tenerife, Spain

Αρχή Ηλεκτρισμού Κύπρου

ΔΣΜΚ


Cyprus power generation system
TOTAL GENERATION CAPACITY: 1783MW
43x2MW wind turbines
6x60MW steam turbines
2x50MW ICE
11MW ICE
41x2MW wind turbines
4x37,5MW gas turbines
2x220MW combined cycle
1x38MW gas turbine


PEAK SUMMER LOAD PROFILE
2010 - (1148 MW) 03/08/2010 – 14:10
SYSTEM LOAD (15 MINUTES - MW)
03-08-2010 00:00
DHEKTOTAL_MW
CALCSPINNRES
MONITOTAL_MW
CALCTOTGT_P
VASSTOTAL_MW
CALCTOT_GEN
CALCTOT_GEN
CALCTOTSYNCHRCAPACT

Terms of Reference

(As given by the Cyprus Regulatory Authority)

Determination of the Static and Dynamic Security of the Electric System of Cyprus in conjunction with the RES penetration, according to the National RES Action Plan 2015-2020, and put forward suggestions for adopting a secure operational framework for the System, indicating the maximum allowable RES penetration on a number of selected system Operation scenarios.

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National Action Plan on RES 2015-2020

Within the National RES Action Plan two fundamental alternative scenarios have been developed for RES penetration, based on the accession date of RES to the Competitive Electricity Market in Cyprus. These scenarios determine the quantities of the various RE technologies under conditions of security, reliability and economy, so as to fulfill the national targets of the Republic of Cyprus for RES Penetration.

SCENARIO 1	SCENARIO 2
Supposition: A Competitive Electricity Market will operate fully in 2019, so RES generation will accede the Electricity Network according to the Electricity Trading and Settlement Rules.	**Supposition: A Competitive Electricity Market will not operate until 2020.**
The penetration of the various RE technologies for the fulfillment of Cyprus' national targets, until the end of 2018, are determined as follows: • **Photovoltaic generation: 148 MW** • **Wind generation: 167.5 MW** • **Biomass generation: 15 MW** • **Solar-thermal generation: 0 MW** **TOTAL: 330 MW**	**The penetration of the various RE technologies for the fulfillment of Cyprus' national targets, until the end of 2018, are determined as follows:** • **Photovoltaic generation: 258 MW** • **Wind generation: 175 MW** • **Biomass generation: 15 MW** • **Solar-thermal generation: 50 MW** **TOTAL: 500MW**

Study of the Security of the Electrical System

Static security of the Electrical System

Has been studied in previous studies and it was deemed unnecessary to repeat it.

Dynamic security of the Electrical System

Defined as the capacity of the System, after a disturbance which drives most variables of the System to their limits, to reach an acceptable operating point so that the Electrical System as a whole stays practically steady.

Harmonic Distortion Analysis

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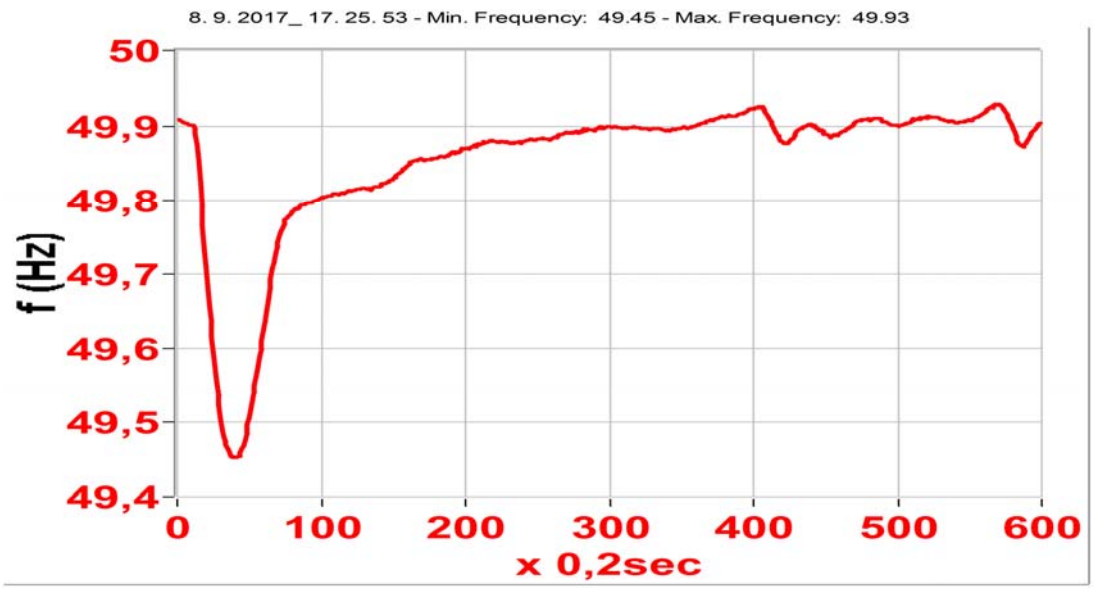

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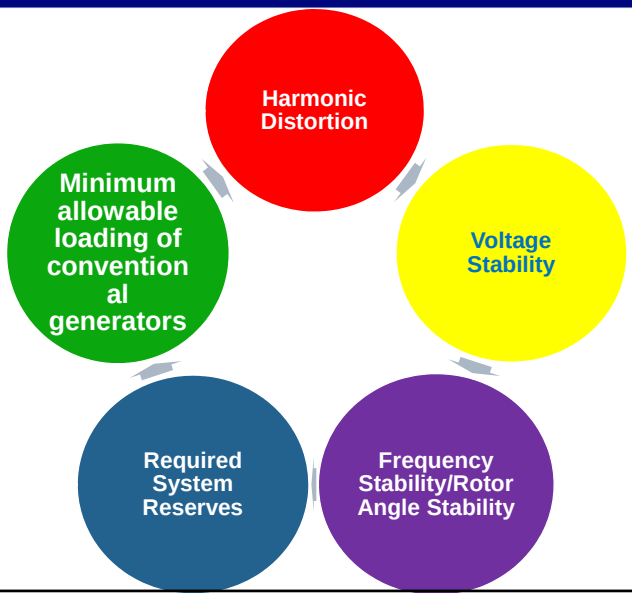
Evaluation of Dynamic Security

For evaluating the dynamic Security of the System and the determination of the Operating Margin (OM) for RES penetration we used criteria concerning:



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VOLTAGE STABILITY STUDY

Voltage Stability refers to the ability of the Electrical System to maintain voltage level within acceptable limits on all busbars under normal operating conditions and under disturbance conditions.

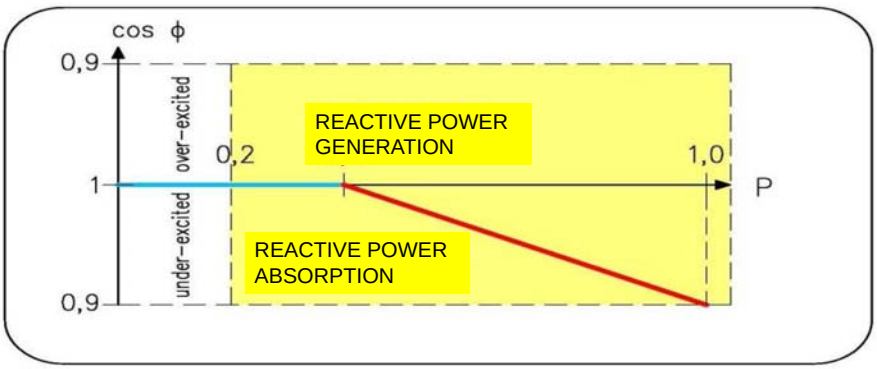
Voltage instability occurs when the System loses the ability to keep the right balance of reactive power.

METHODOLOGY

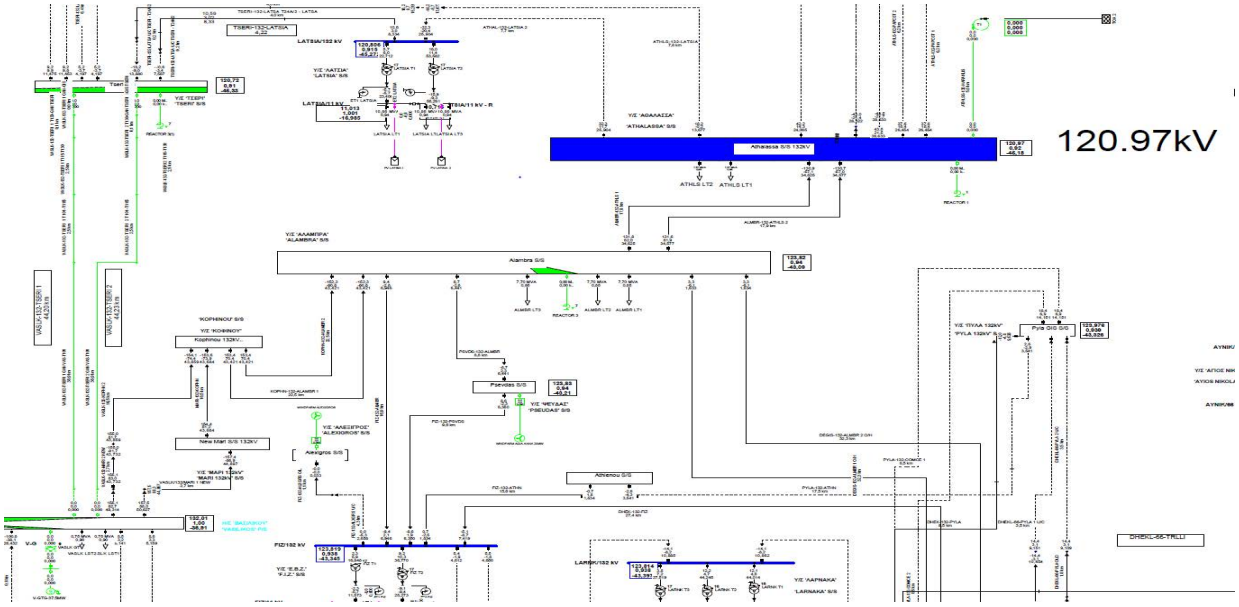
- The Modeling and the simulation of the System was done using **DigSilent** software tool.
- The estimation of the Peak Power is as per TSO Cyprus' 10-year Forecast for 2016-2025 and each Transmission Substation maximum loading.
- Three scenarios were used to analyse system behavior based on 2016-2025 forecasts for year 2020.
  - Minimum loading (420 MW)
  - Medium loading (655 MW)
  - Maximum loading (1145 MW)

  under loss conditions
  - N-1 (transformer loss)
  - N-2 (double circuit 132 kV line)
- The Inverters of PV systems are programmed so that the power factor at the connection point of Photovoltaic installations, follows the characteristic curve (pf Vs Δ generated active power), as per DSO guidelines i.e PV Parks generate active power up to 40% of their installed capacity with unity power factor.
- For generation above 40%, the power factor is linearly reduced, for increased absorption of reactive power with power factor down to 0.9, for voltage stability.

TYPICAL CURVE OF PF VARIATION WITH CHANGE IN PHOTOVOLTAIC ACTIVE POWER GENERATION



MAXIMUM SYSTEM LOADING 1145MW / PHOTOVOLTAIC PENETRATION 455MW
LOSS OF DC LINE K.PETROU-VASSILIKOS 1&2



RESULTS

Results determined loading level and max RES penetration limit in the System:

- **Maximum loading**: In this scenario the maximum allowable PV penetration is 455MW. Under normal operating conditions no Voltage Stability problem exists but under N-2 criterion, the observed voltage drop on the 132kV System busbars is the maximum allowable (10%). Under criterion N-1, no significant deviation is observed even at PV penetration of 455MW.
- **Medium and Low loading**: No significant voltage deviations are observed in these scenarios even at maximum RES penetration (455MW and 200MW respectively) at both N-1 and N-2 criteria.

HARMONIC STABILITY STUDY

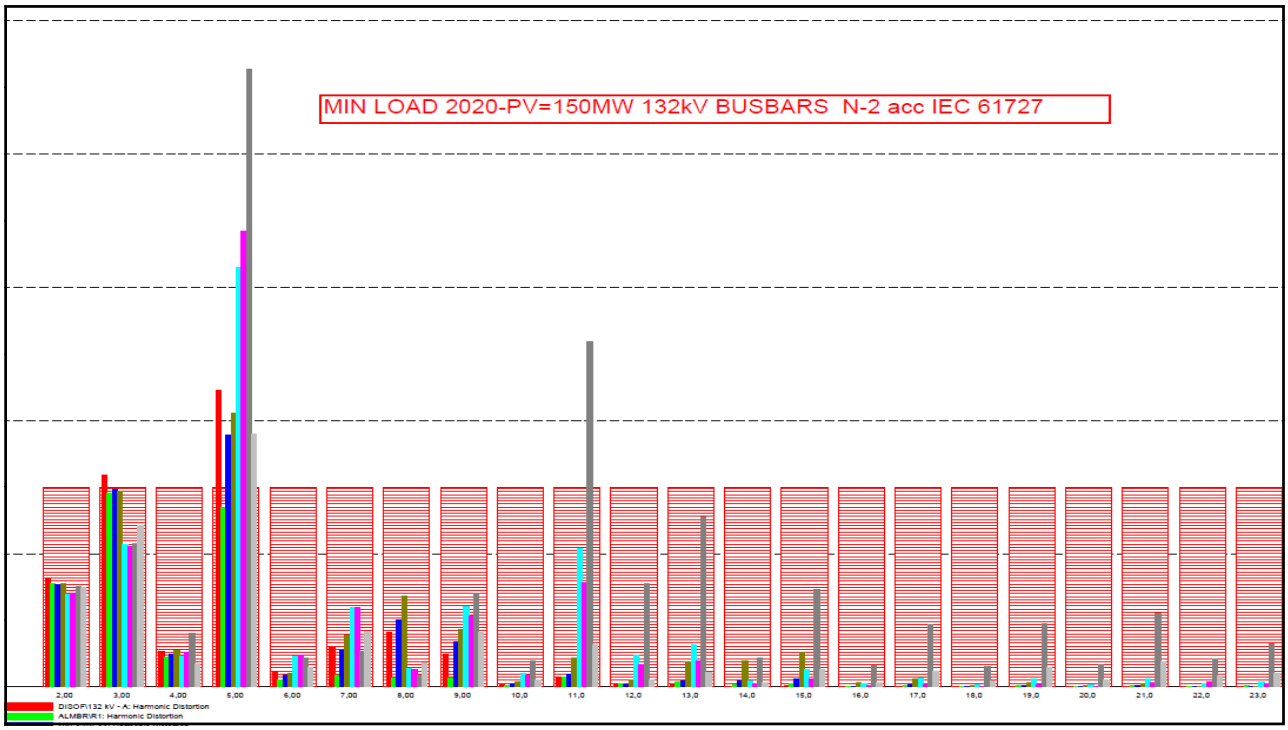
- Conversion of dc Photovoltaic generation into ac by Inverters creates current harmonics into the Electrical System distorting the System Voltage.
- Voltage distortion depends on:
  - The magnitude of the harmonic current in each frequency I(h)
  - The composite impedance of the Network as seen by each harmonic frequency Z(h)=> V(h) = I(h)*Z(h)

The greater the harmonic current and the greater the composite impedance of the Network, the greater is the resulting voltage harmonic distortion in the Network.

METHODOLOGY

- Modelling and Simulation of the System was done using **DigSilent**
- Modelling of the Inverter harmonics was done using two methologies:
  - **Measurements** from existing Photovoltaic parks.
  - Using the maximum allowable harmonic distortion as defined in the T/D Rules and in **Standard IEC 61727**.
- The System was analysed for 3 scenarios (based on 2016-2025 Forecast for year 2020)
  - Minimum loading (420 MW)
  - Medium Loading (655 MW)
  - Maximum loading (1145 MW)

  under loss conditions
  - N-1 (transformer loss)
  - N-2 (132 kV dc line loss)



RESULTS

Modelling Inverter harmonics based on measurements

For all scenarios and under any loss conditions (N-1 & N-2) PV penetration can reach up to 520 MW

Modelling Inverter harmonics / Standard IEC 61727

In this case the maximum allowable PV penetration is:

- 250 MW (for high loading)
- 200 MW (for medium loading)
- 150 MW (for low loading)

CONCLUSION

Penetration of PV is limited substantially due to the significant system voltage distortion in using Inverter modelling based on IEC Standard.

STUDY OF FREQUENCY STABILITY / ROTOR ANGLE

- Frequency Stability refers to the ability of an Electrical System to maintain frequency within a predetermined range after a disturbance which upsets the balance between generated and consumed power.
- Rotor Angle Stability refers to the ability of the connected synchronous machines to maintain synchronism both under normal operating conditions and after a disturbance.
- RES penetration has to be in balance with conventional generation, so as to secure Frequency/Rotor Angle Stability.
- **The study** examined the maximum RES penetration level in the Cyprus Electrical System in relation to conventional generation so as to remain stable during under-frequency disturbances.

Evaluation of the Frequency Stability

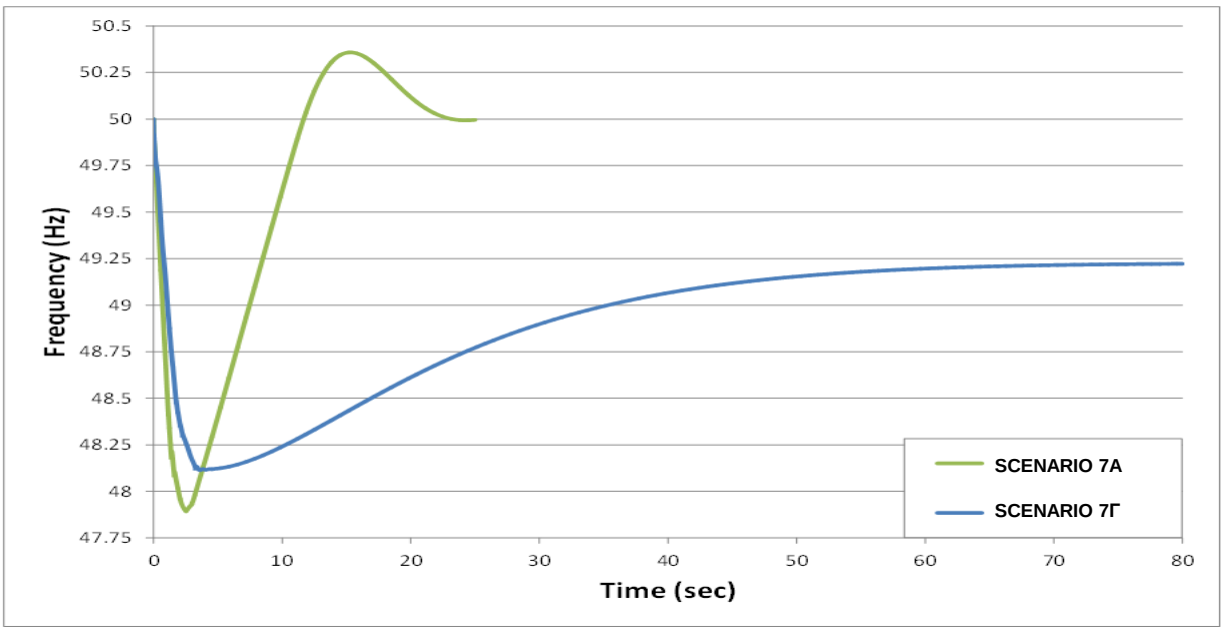
- Two software tools were used: **DigSilent** and **MatLab**
- Four scenarios were examined for operating conventional generating units under incremental penetration of RES and examining the loss of the largest conventional unit:
  - 2 ST@VASILIKOS PS + 2 ST@DHEKELIA PS
  - 2 ST@VASILIKOS PS + 3 ST@DHEKELIA PS
  - 3 ST@VASILIKOS PS + 2 ST@DHEKELIA PS
  - 3 ST@VASILIKOS PS + 3 ST@DHEKELIA PS
- Assessment of the frequency stability was based on the:
  - Rate of Change of the frequency (df/dt)
  - Minimum frequency level (fmin)
  - Frequency restoration time (t)
  - Frequency oscillations

GENERATION UNITS MIX : 2xDHEK-ST, 2xVASS-ST

SCENARIO	7A	7B	7Γ
Trip Event:	1 x Vassilikos ST trips	1 x Vassilikos ST trips	1 x Vassilikos ST trips
Generating Unit			
D1STG-60MW	37	39	39
D2STG-60MW	35	35	35
D3STG-60MW	-	-	-
V1STG1-130MW	125	125	125
V2STG1-130MW	65	65	65
V3STG1-130MW	-	-	-
PV Generation at Distribution Level (MW)	300	300	300
Generation of VPS P/S (MW)	190	190	190
Generation of VPS P/S (%)	34%	34%	34%
Generation of DPS P/S (MW)	72	74	74
Generation of DPS P/S (%)	13%	13%	13%
Wind Generation (at transmission) (%)	0%	0%	0%
PV Generation (at distribution) (%)	53%	53%	53%
Generation at Transmission Level (MW)	**262**	**264**	**264**
Generation at Distribution Level (MW)	**300**	**300**	**300**
Total System Generation (MW)	**562**	**564**	**564**
Generation Lost at Transmission Level (MW)	125	125	125
Generation Lost at Distribution Level (MW)	0	0	0
% of Total Generation Lost on Load Demand	22%	22%	22%
% of Total Generation Lost on Conventional Generation	48%	47%	47%
Percentage of Rotating Load (%)	0%	20%	30%

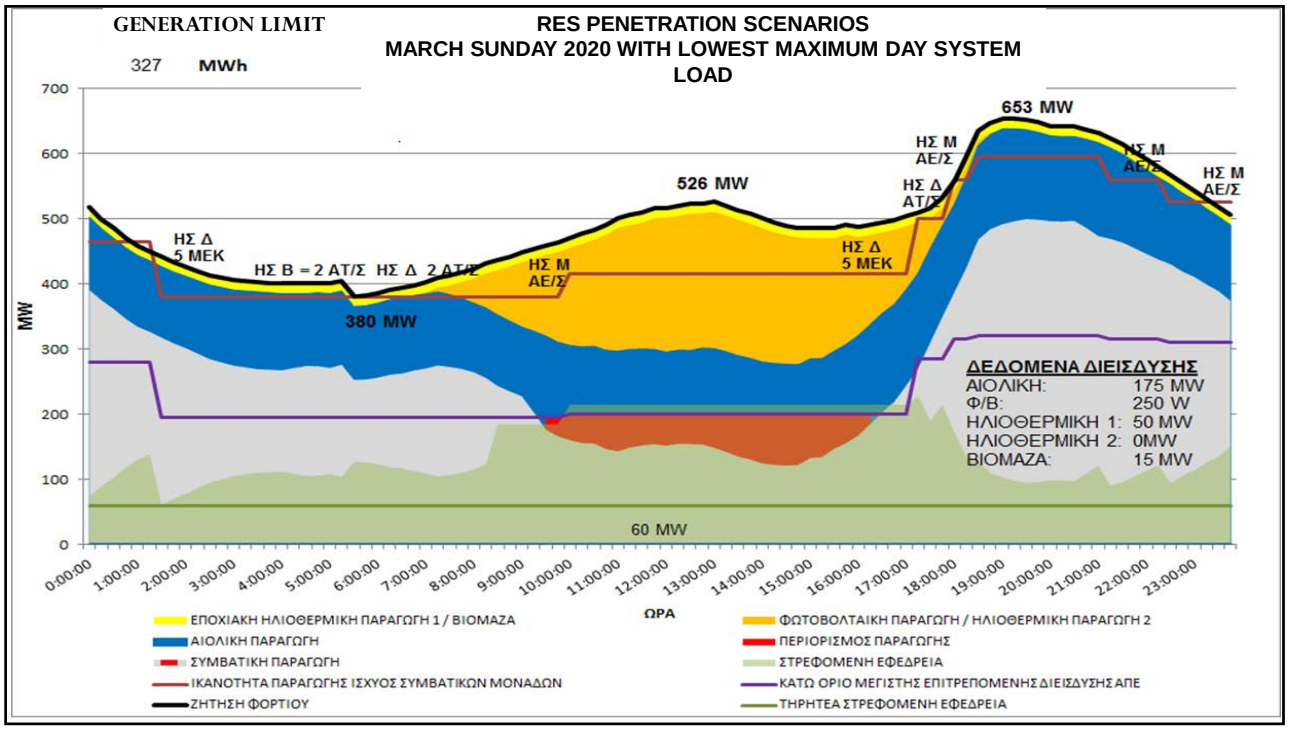
Lumped Model Simulations:

UFLS Stages Operated	11	10	10
Minimum Frequency (Hz)	47.89	48.06	48.11
Settling Frequency (Hz)	49.99	49.87	49.22
Time taken after the event for frequency recovery to 49.5 Hz (sec	9.50	19.85	never
Max Instantaneous df/dt (Hz/s)	-1.36	-1.40	-1.41
Average df/dt over 0.5 sec after the event (Hz/s)	-1.32	-0.83	-0.83
UF on Cables for Reactive Power Control Operated	Yes (2 stages)	Yes (2 stages)	Yes (2 stages)
Generators Protection Operated	No	No	No
Detection of Rotor Angle out-of-step	-	-	-
Integration Step Size (ms)	1	1	1
Simulation Time (sec)	25	40	80



Conclusions

- RES penetration and load structure, as regards its frequency dependence, affects the inertia of the System, which, under certain conditions disturbs the coordination of the Under-frequency system operation.
- Under generation loss, RES penetration has to be limited for avoiding system instability, so that the total system demand does not exceed 20-30% of the synchronised Conventional Power Generation Capacity.
- No Rotor Angle Stability issues.
- Secure operation of the Cyprus Electricity Network until 2020, calls for a minimum number of conventional generation units, i.e. two base units at Vassilikos PS and two ST at Dhekelia PS.
- The static operation of the Cyprus Electricity System does not present any problems until 2020 and RES penetration is only limited by the operational minimum stability limit of the synchronised conventional generation units.



Conclusions Summary

- RES Penetration can be adequately managed by keeping additional reserves for accommodating fluctuations in Wind and PV generation. 50% of Wind Generation and 10-15% of installed PV generation is kept as reserve.
- For covering the large variance between day and evening peaks in winter, synchronised conventional generating units need to be used plus 2-3 peaking GasT/ICE. This indicates anti-economic use of conventional generating base units and excessive use of expensive-to-run GasT, due to RES Penetration.
- RES curtailment to 2020 (National RES Action Plan) are contained to very low levels.
- No Rotor Angle Stability issues
- RES penetration and load structure, as regards frequency dependence, affects the inertia of the System, which, under certain conditions disturbs the coordinated operation of the Under-frequency System.

Conclusions cont.

- Voltage Stability Studies have shown that in case of maximum System loading (1145MW), the maximum allowable PV penetration is limited to 455MW. For low and medium loading there is no limit.
- Voltage Harmonic Distortion studies based on measurements have shown that for any System loading, the maximum allowable PV Penetration is limited to 520MW.
- Voltage Harmonic Distortion Studies based on the T/D Rules showed that:
  - in case of max System loading (1145MW), PV penetration is limited to 250MW,
  - in case of medium loading (655MW), PV is limited to 200MW, and
  - in case of min System loading (420MW), PV penetration is limited to 150MW.
- From Stability study and Harmonic Distortion results, it can be deduced that RES Penetration, within the National RES Action Plan, does not create any problems in the static and dynamic operation of the System, for the various System loadings.
- The RES Penetration Operating Margin is a function of the synchronised power generating ability and the loading of the System.

SUMMARY - METHODOLOGY AND RESULTS-OPERATIONAL RES MARGIN

SCENARIOS	MIN SYNCHRONISED GENERATION PLAN MIX	GENERATING CAPACITY	MIN STABLE GENERATION	DEMAND	MAX RES PENETRATION LIMIT BASED ON MIN STABLE GENERATION	MAX RES PENETRATION LIMIT BASED ON OPERATIONAL RESERVES	OPERATIONAL LIMIT BASED ON FREQUENCY STABILITY	MAX RES PENETRATION LIMIT IN DISTRIBUTION SYSTEM	MAX RES PENETRATION	MAX RES PENETRATION BASED ON NATIONAL RES PLAN
		MW	MW	MW	MW	MW	MW	MW	MW	MW
1	2 ST DHEK & 2 ST VASS	380	200	350	150	310 (160+150)	200	NA	150	150
	2 ST DHEK & 2 ST VASS	380	200	400	200				200	
	2 ST DHEK & 2 ST VASS	380	200	450	250				200	
2	3 ST DHEK & 2 ST VASS	440	230	500	270	430 (280+150)	350	200 (+150 WP/TS)	270	360
	3 ST DHEK & 2 ST VASS	440	230	550	320				320	
3	2 ST DHEK & 3 ST VASS	510	260	600	340	590 (440+150)	350		340	
	2 ST DHEK & 3 ST VASS	510	260	650	390				350	
4	3 ST DHEK & 3 ST VASS	570	290	700	410	710 (560+150)	370		350	
	3 ST DHEK & 3 ST VASS	570	290	750	460			250 (+150 WP/TS)	370	0.1% Curt.