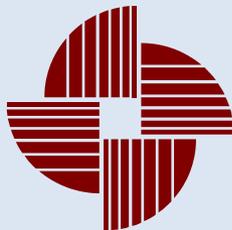


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**Operation of a Greek island power grid under
various simulated scenarios of combined RES and
battery based storage systems**

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INTRODUCTION

- The exploitation of the intermittent RES technologies is limited in the islands, due to constraints imposed by the operation of the power grid, such as the minimum technical limits of the diesel generators as well as a maximum value of instantaneous RES penetration in order to avoid unsecure operation of the electrical system.
- The aim of this work is to study the energy benefits that can be achieved, concerning the potential increase of RES share in the total electricity production, by the use of battery storage systems in the electrical system of a typical Greek island. The energy benefits are achieved through the reduction of the curtailments of RES energy which are imposed by the operational constraints.
- Results derived by simulation of the operation of the electrical system of a typical island

GREEK ISLANDS

Example of Greek islands' basic electrical figures

| Island | Peak demand (MW) | Annual Energy demand (MWh) | Average Total Cost of electricity (€/MWh) | Average Variable Cost of electricity (€/MWh) |
|----------------|------------------|----------------------------|---|--|
| AG. EYSTRATIOS | 0.31 | 1,092.92 | 592.05 | 257.95 |
| AMORGOS | 3.15 | 10,233.84 | 359.94 | 217.09 |
| ANAFI | 0.50 | 1,296.75 | 617.09 | 253.31 |
| ASTYPALAIA | 2.21 | 6,447.56 | 374.83 | 221.08 |
| IKARIA | 6.70 | 25,219.22 | 422.78 | 254.35 |
| KARPATHOS | 11.30 | 32,823.33 | 233.26 | 100.31 |
| SAMOS | 29.60 | 112,161.55 | 164.41 | 87.20 |
| SIFNOS | 6.22 | 22,681.30 | 348.31 | 206.62 |
| THIRA | 42.80 | 180,769.51 | 183.24 | 115.33 |
| MEGISTI | 0.91 | 3,539.66 | 480.70 | 245.28 |

OPERATION OF ELECTRICAL SYSTEM(1)

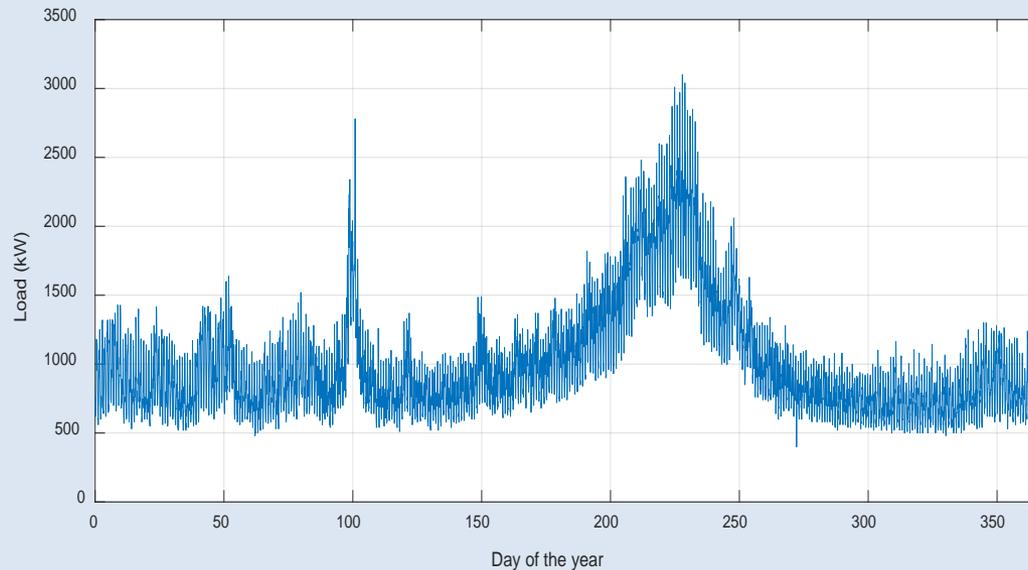
- HEDNO is responsible for the technical and economic management of the system according to the legislative framework defining the technical requirements, policy, planning, operation procedures and connection standards for generating units in the non-interconnected islands (NIIs) as included in the NIIs Code
- According to the NIIs Code a Day Ahead Scheduling is foreseen, defining the dispatch algorithm of dispatchable diesel generators, as well as the maximum level of power injection for all RES/CHP and hybrid stations in order to ensure secure operation, according to the security and operational standards specified in the Code. The procedures are implemented by Central and Local Energy Control Centers
- The System operator should prioritise the absorption of energy from the RES plants. RES plants however are subject to operational constraints that result to curtailments of their output, due to the technical minimum values of conventional generators and due to a 'dynamic penetration limit'. The Code defines a minimum limit of 30% for small and medium NIIs.(The typical practice by the operators is to use a value of 35% for dynamic penetration limit)

OPERATION OF ELECTRICAL SYSTEM(2)

- A Hybrid Station is a power station, which uses at least one form of RES and combines energy storage systems. The fundamental principle for the operation is to store the RES energy instead of injecting it directly to the grid. The energy could be used later, in a controllable way, replacing expensive thermal units. Furthermore, the Hybrid Stations replace not only energy but also capacity from the conventional thermal units. In order to guarantee the provision of firm capacity, it is allowed to store energy from conventional thermal units if the RES unit of the Hybrid Station cannot produce the necessary energy.
- Hybrid Station receive payments for both the energy and the capacity. Law 4414/16 describes the pricing policy. Namely the prices of the energy injected directly from RES are the same as the prices of RES stations of similar technology. The price of the energy coming from the storage systems is 50% higher than the RES price.

CASE STUDY

Annual load profile of a typical island, used for the case study



Annual demand: 8737MWh

Peak demand: 3.1MW

Lowest demand: 0.4MW

Conventional generators : 3 Diesel generators of 1 MW and 4 Diesel generators of 0.3MW

Annual capacity factor for PV plants : 19.5%

Annual capacity factor for wind plants :30%

Battery : Lead-acid , 60% Depth of Discharge

Simulation of the electrical system on an hourly basis, based on realistic time-series of load and RES production, for various scenarios of operation

RESULTS – SCENARIO 1

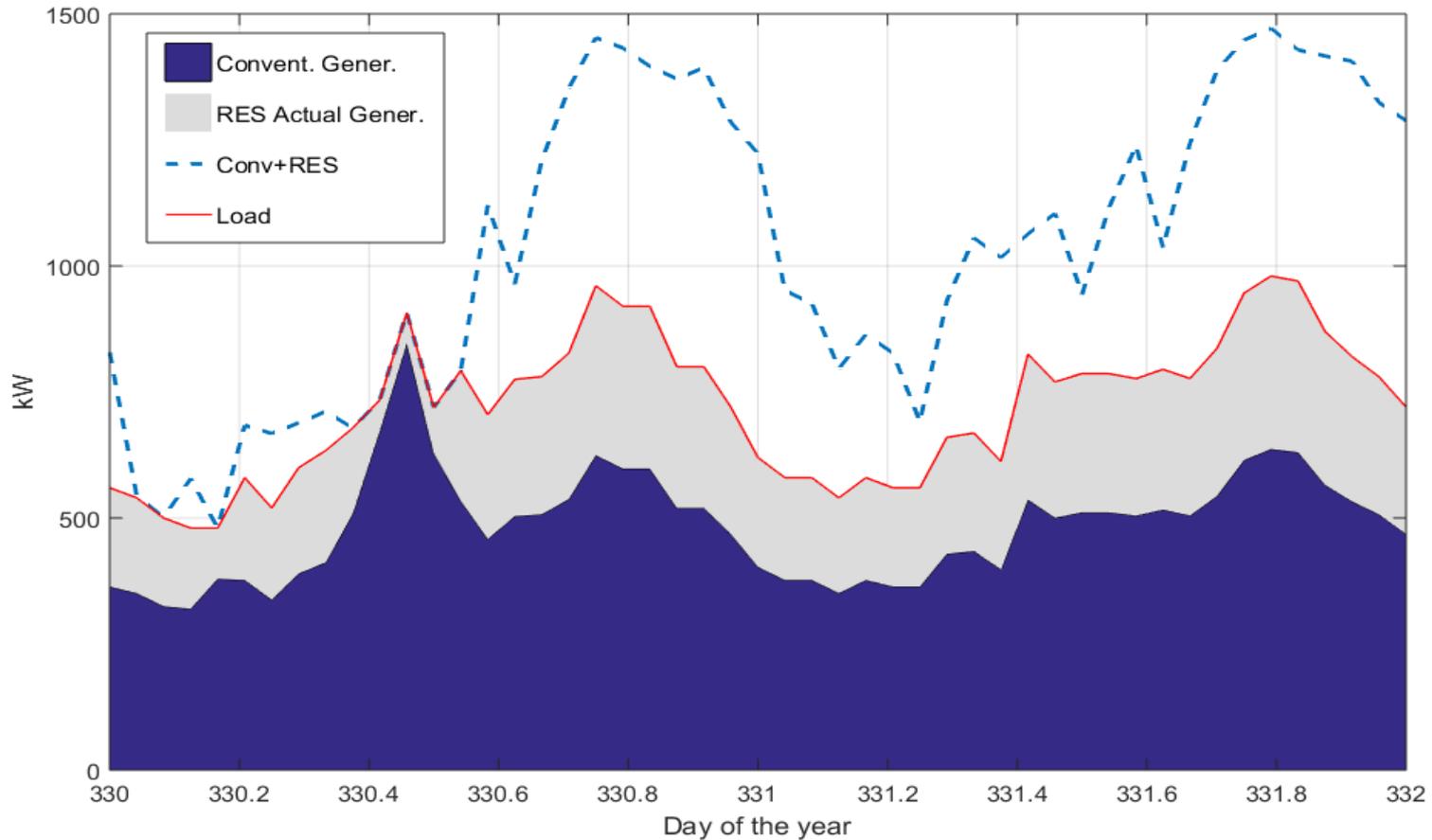
Scenario 1 : No storage. Wind generator 500 or 900 kW.

Dynamic penetration limit of 35% of load

| | Convent. Gener. (MWh) | PV gener. (MWh) | Wind gener. ideal (MWh) | Wind gener. actual (MWh) | Wind curtailments (MWh/%) | RES share actual (%) | RES share maximum- ideal (%) |
|---|-----------------------------|-----------------------|----------------------------------|-----------------------------------|---------------------------------|-------------------------------|------------------------------------|
| Base case – PVs 240kWp | 8359.49 | 406.94 | 0 | 0 | 0/0 | 4.66% | 4.66% |
| Addition of wind generator 500kW | 7309.66 | 406.94 | 1239 | 1020.6 | 218.4 / 17.68% | 16.34% | 18.8% |
| Addition of wind generator 900kW | 6981.55 | 406.94 | 2256 | 1348.73 | 907.8 / 40.23% | 20.1% | 30.5% |

RESULTS – SCENARIO 1

Example of operation with wind generator 900kW, for two days of a year



RESULTS – SCENARIO 2

Scenario 2: Addition of battery in order to use RES energy instead of curtailing it.
Same dynamic limit for energy injected to the grid

Results for wind generator 500kW

| Converter size (kW) | Battery size (kWh) | Energy charged (MWh) | Energy discharged (MWh) | 'RES' share (%) | Conv. Gener. (MWh) |
|---------------------|--------------------|----------------------|-------------------------|-----------------|--------------------|
| 0 | 0 | 0 | 0 | 16.34 | 7309.7 |
| 100 | 500 | 51.05 | 40.89 | 16.8 | 7268.8 |
| 100 | 1000 | 67.4 | 53.99 | 16.95 | 7255.7 |
| 250 | 1000 | 75.4 | 60.4 | 17.03 | 7249.3 |
| 500 | 1000 | 75.49 | 60.47 | 17.03 | 7249.2 |
| 500 | 2000 | 100.9 | 80.8 | 17.26 | 7228.9 |
| 500 | 4000 | 137.5 | 110.15 | 17.6 | 7199.55 |

Curtailed energy:218MWh

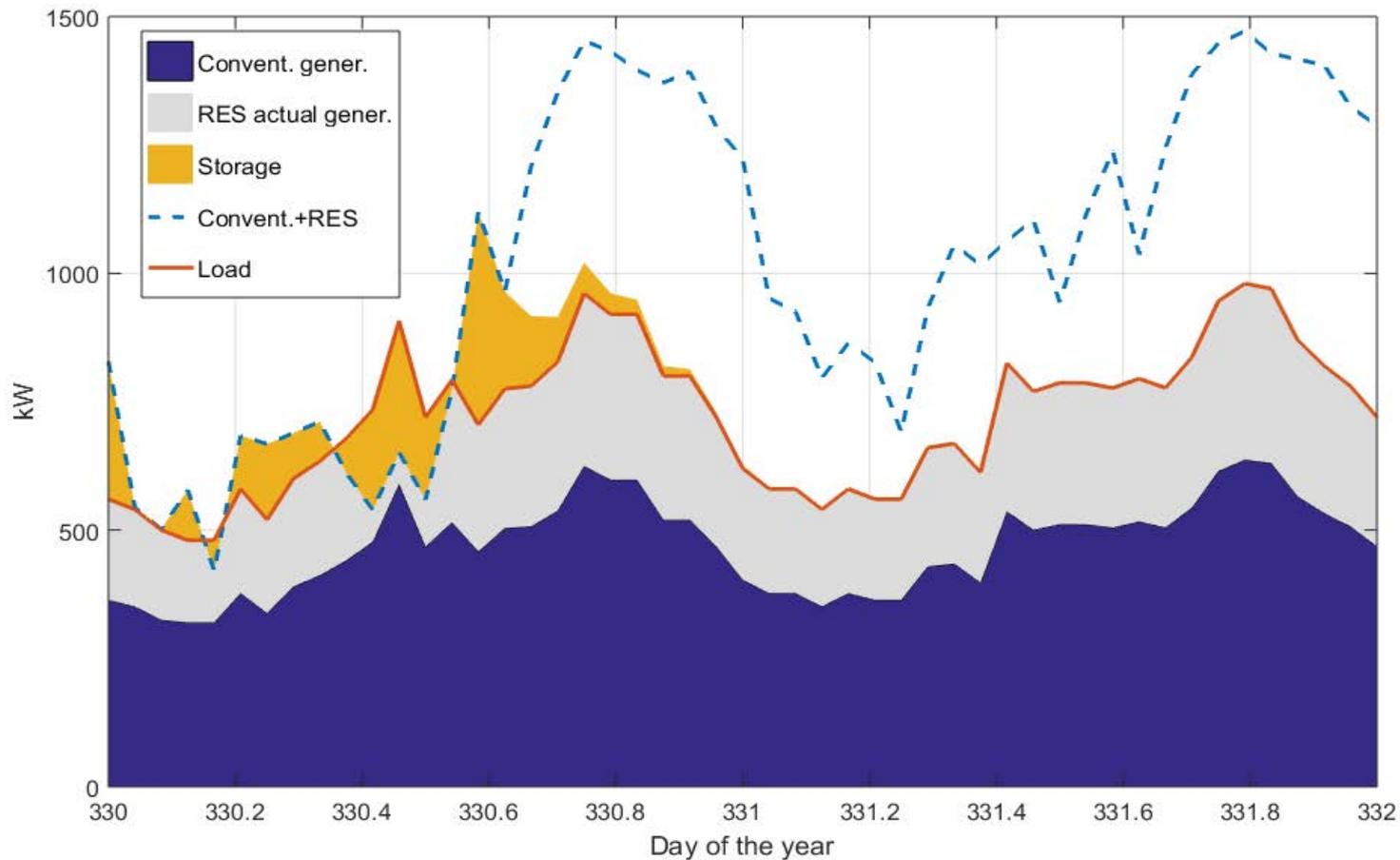
Results for wind generator 900kW

| Converter size (kW) | Battery size (kWh) | Energy charged (MWh) | Energy discharged (MWh) | 'RES' share (%) | Conv. Gener. (MWh) |
|---------------------|--------------------|----------------------|-------------------------|-----------------|--------------------|
| 0 | 0 | 0 | 0 | 20.1 | 6981.55 |
| 100 | 500 | 83.21 | 66.65 | 20.86 | 6914.91 |
| 100 | 1000 | 116.56 | 93.36 | 21.16 | 6888.2 |
| 250 | 1000 | 135.2 | 108.3 | 21.3 | 6873.26 |
| 500 | 1000 | 136.02 | 108.95 | 21.34 | 6872.6 |
| 500 | 2000 | 199.87 | 160.1 | 21.92 | 6821.46 |
| 500 | 4000 | 289.52 | 231.91 | 22.75 | 6749.65 |

Curtailed energy:908MWh

RESULTS – SCENARIO 2

Example of operation with wind generator 900kW, storage 500kW/2000kWh, for two days of a year



RESULTS – SCENARIO 3

Scenario 3: Hybrid system of wind generator 900kW, converter 760kW and battery 5500kWh

Operation based on a day ahead scheduling

The RES energy of the hybrid system is used at first priority for charging of the storage, and can be used later in a controllable way (avoiding the dynamic limit obstacle). The RES that cannot be charged, is directly fed to the grid, with a dynamic limit applied.

| | PV gener. (MWh) | Wind gener. ideal (MWh) | Hybrid system injection (MWh) | Wind energy loss (MWh/%) | RES share (%) |
|---|--------------------|----------------------------|----------------------------------|-----------------------------|------------------|
| Hybrid system of wind generator 900kW, storage 760kW/ 5500kWh | 406.94 | 2256 | 1847 | 409 / 18.1% | 25.8% |

CONCLUSIONS

- Quantitative results have been presented concerning the energy benefits of the use of battery-based storage systems in a typical Greek island
- Grid connected battery systems will become more attractive in the near future, as according to predictions the cost of batteries will drop rapidly.
- Additional benefits that may be introduced by the storage system have not been taken into account. Modern battery converters may operate in a 'grid supporting' mode, allowing high instantaneous penetration of RES and consequently high values of annual share of RES in electricity production. There is a need for pilot plants to demonstrate these solutions.