DIPARTIMENTO DI
INGEGNERIA ELETTRICA ELETTRONICA E INFORMATICA

Impact of the Renewable Energy System on a Electrical Power System

Focus on the strategic role of new power generation assets for the security of the future Italian power system

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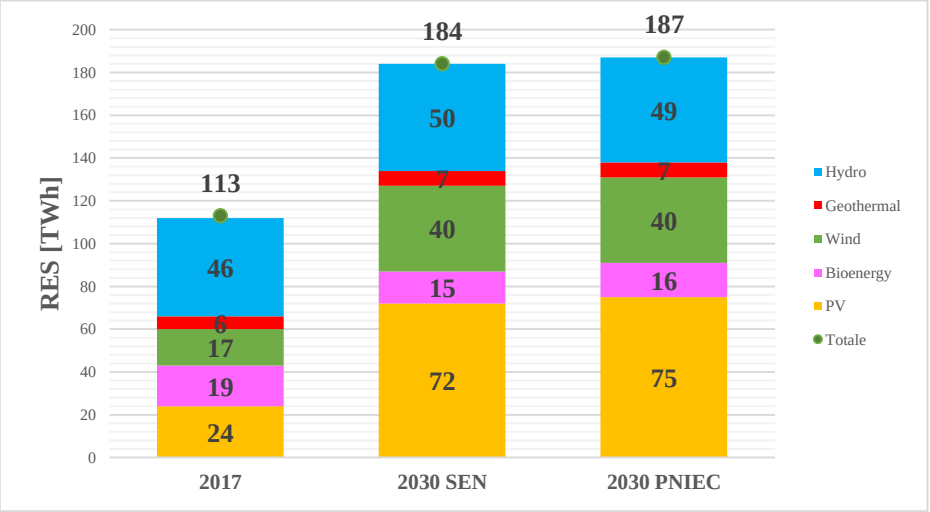
Introduction

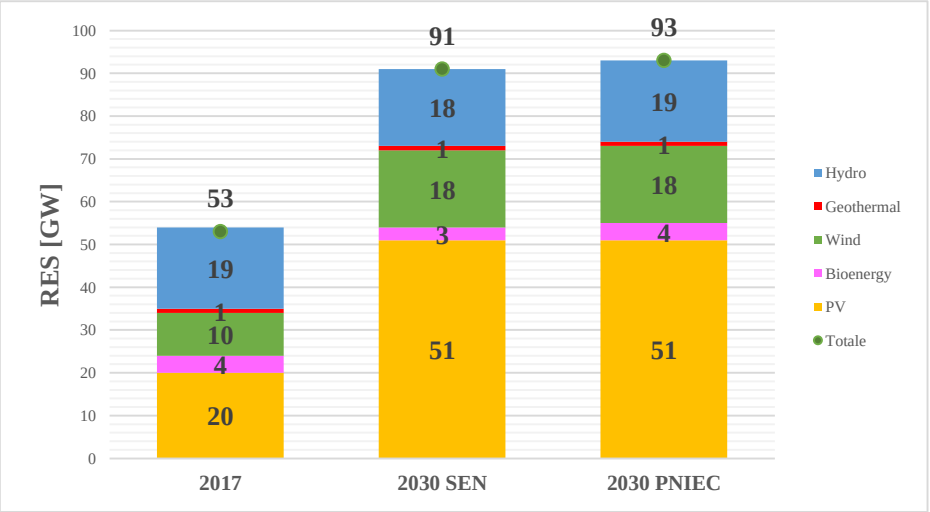
The Italian power system is undergoing a period of important changes linked to the development prospects of the new National Energy Strategy (SEN) and the **Energy and Climate Integrated National Plan (PNIEC)** to reach the environmental target imposed by the EU (32% of gross final consumption at 2030 satisfied by RES). PNIEC considers:

- A total target of 30% for Italy, with + 2% compared to the target provided by SEN. For sectoral level, the RES target is set at **55.4%** of the gross consumption of electricity, estimated at 337.3 TWh corresponding to **187 TWh** of RES production.

- **Total decarbonization of the electric sector by 2025**.

- Provide **6 GW** of new storage systems (at least 50% pumped hydroelectric plants), **3 GW** of new gas capacity and about **3.5 GVAR** of new synchronous compensators. This is very important to manage adequacy, overgeneration and in general, of the security of electrical power system.





Risk of instability

The strong growth of renewables, in particular FV, may entail a risk in terms of stability of the power system due to the lower contribution that these technologies give in terms of inertia and frequency regulation.

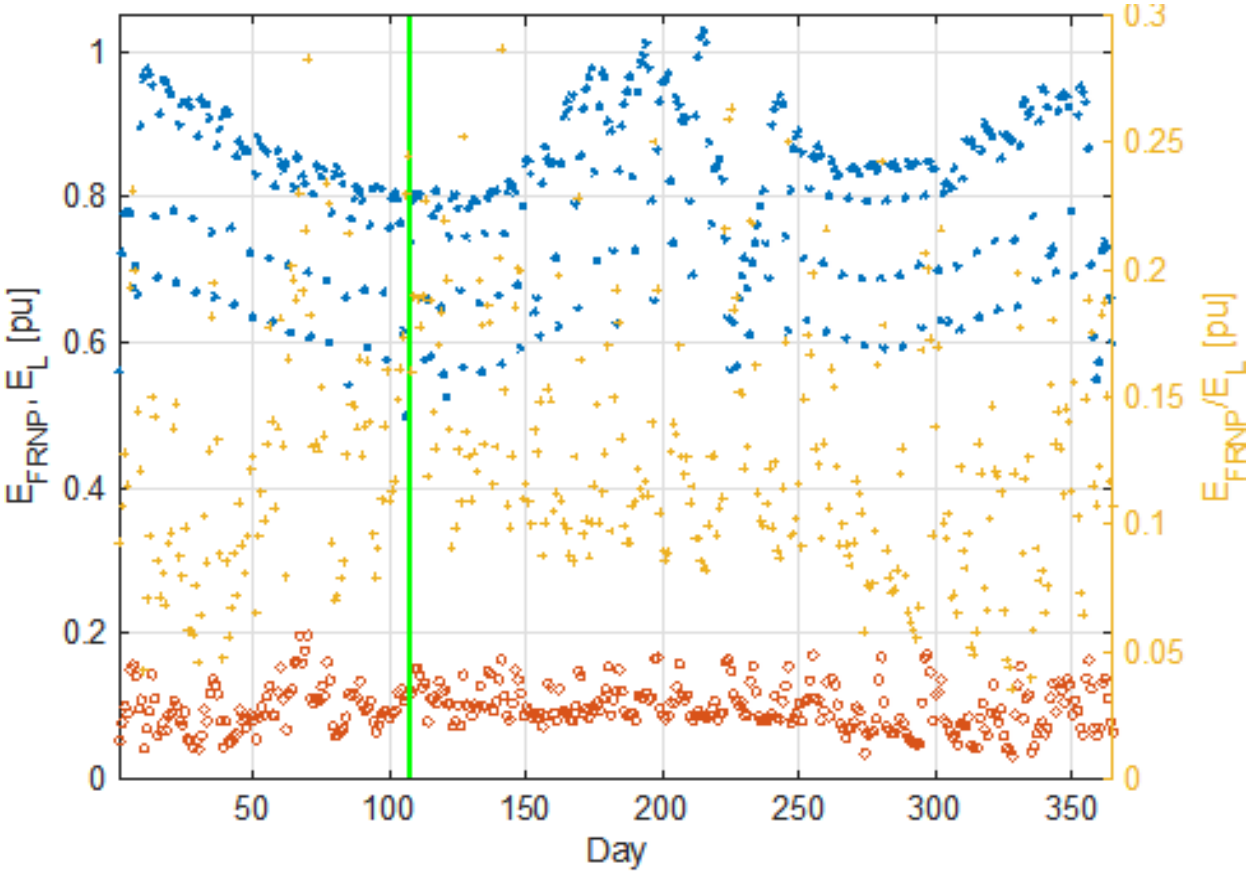
On this regards the work is organized in two main parts, in particular:

- In the first part, under some future scenarios the assessment of the values of **inertia constant** of Italian power system is developed;
- In the second part the results about **transient stability simulations** of the present Sicilian power systems under different real operating conditions characterized by different percentage of RES are reported;

Inertia constant analysis: Base Scenario

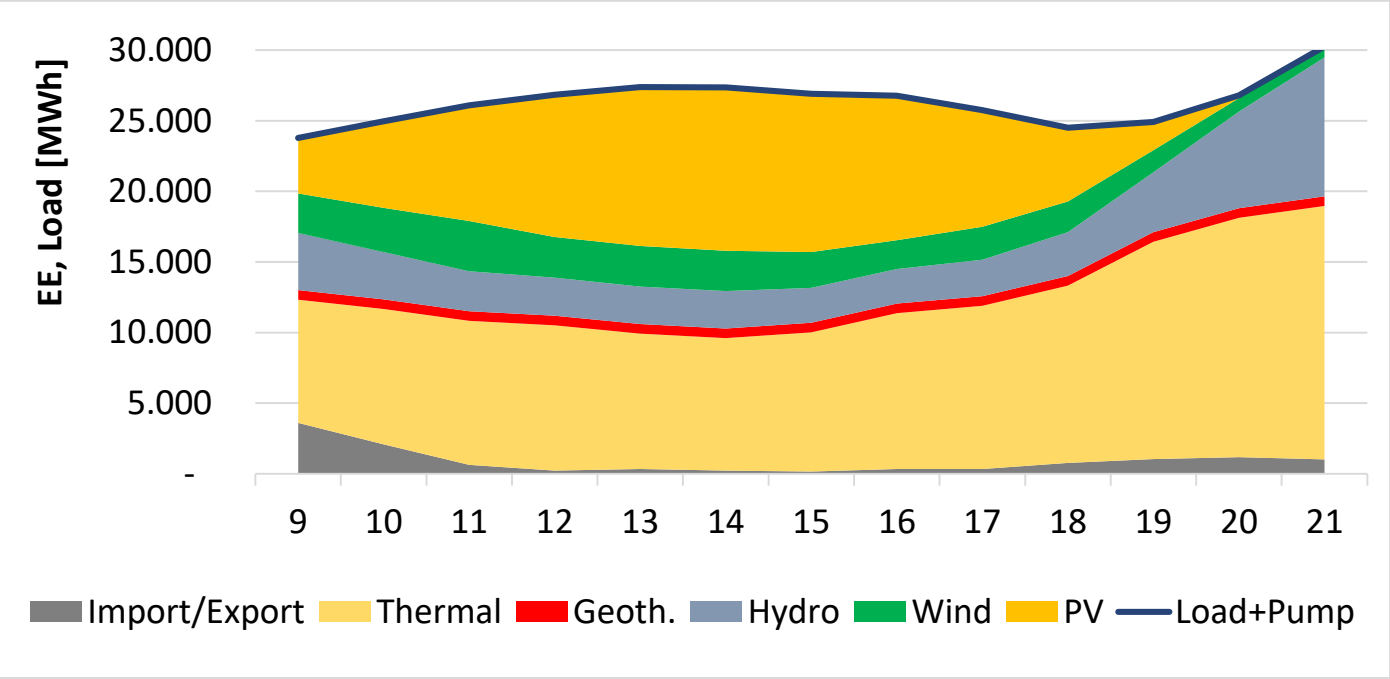
To define the reference scenario, the Italian daily demand (**blue markers**), and FRNP generation EFRNP (**red markers**) have been analysed.
It has been also evaluate the ratio between E_{FRNP} and E_L, (**yellow markers**).

The day selected as a Base Scenario (BS) is a spring holiday day, i.e. the 17th of April 2017 (107 is progressive day number).



Inertia constant analysis: Base Scenario

This is certainly a very critical situation for the stability of a power system. For the given day, the figure shows the hourly Load plus pump consumption (from 9:00 a.m. to 9:00 p.m.) and the contribution of the different types of power plants in covering such demand.



Spring day 2017	Demand	PV	Wind	Hydro	Geoth.	Thermo	Import	Ppump
(GWh)	572.7	89.4	54.7	90.8	17.1	276.7	61.5	-16,7

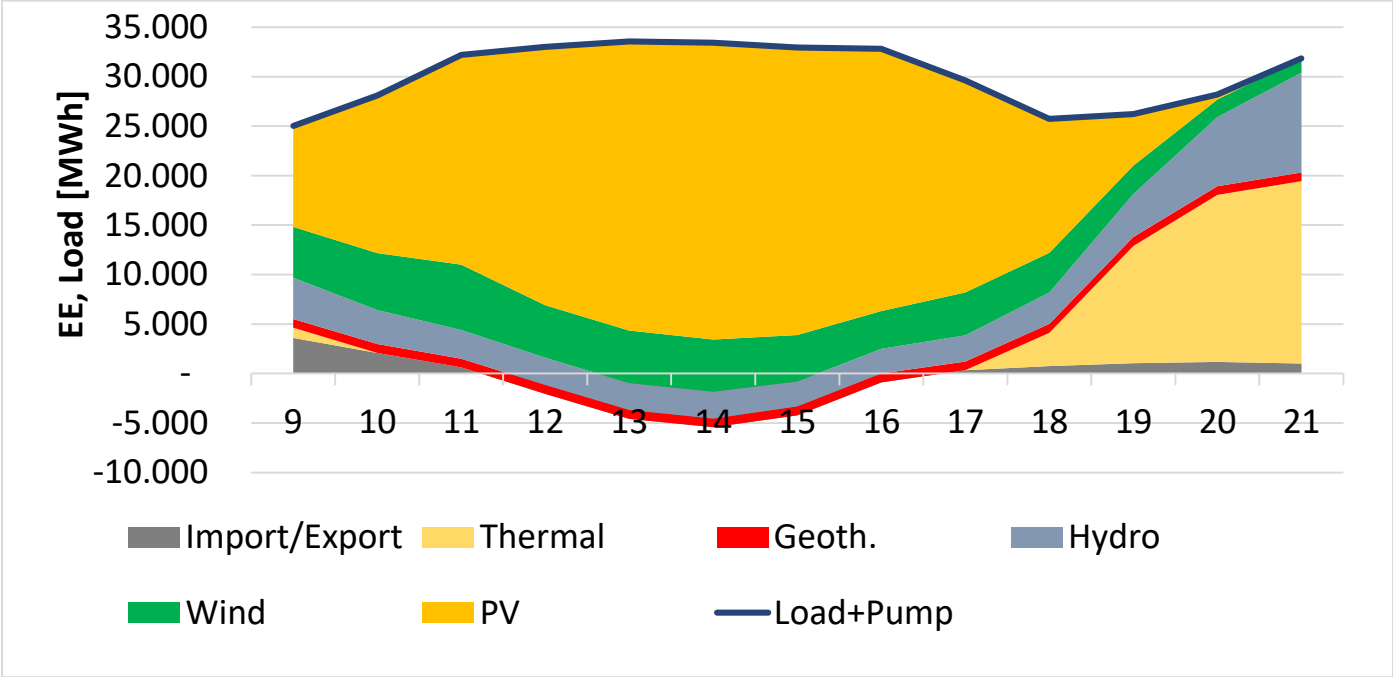
Inertia constant analysis: 2030 Scenario

Starting from base scenario, projections to 2030 are made, in order to recreate a no working in April 2030. To do so, the following percentage changes have been applied to the main variables respect with the reference day 17/04/17:

- for the **demand**, the ratio between the annual energy expectation requested in Italy by 2030 by the PNIEC and the value recorded for 2017;
- for the **FER production**, the ratio of the installed capacity forecast to 2030 in the PNIEC and the installed capacity to 2017

From the analysis of the time profiles obtained it was possible to note that, despite a total zeroing of thermoelectric production in the central hours of the day (from 10 to 17), there is still an important overgeneration that required the use of 6 GW of accumulation envisaged by the PNIEC (considered an average availability factor of 80%) plus an export of energy to foreign countries.

	2017	2030	Δ%
Demand (TWh)	321	337	+5%
FRNP - PV (GW)	20	51	+159%
FRNP - Wind (GW)	10	18	+81%
Prog. - Hydro (GW)	19	19	-



Spring day 2030	Demand	PV	Wind	Hydro	Geoth.	Thermo	Import	Ppump
(GWh)	602.6	231.7	101.1	92.9	21.3	162.6	43.1	-49.9

Inertia constant analysis: system minimum value

After defining the balance of powers in the 24 hours of the day of analysis, the work in question had as its objective the precise calculation of the **inertia** of the electrical system in the hypothesis that the **3 GW of new gas capacity** are able to guarantee a functioning as a synchronous[1]compensator, thus contributing to the regulation of **voltage and inertia even with active power input nothing**.

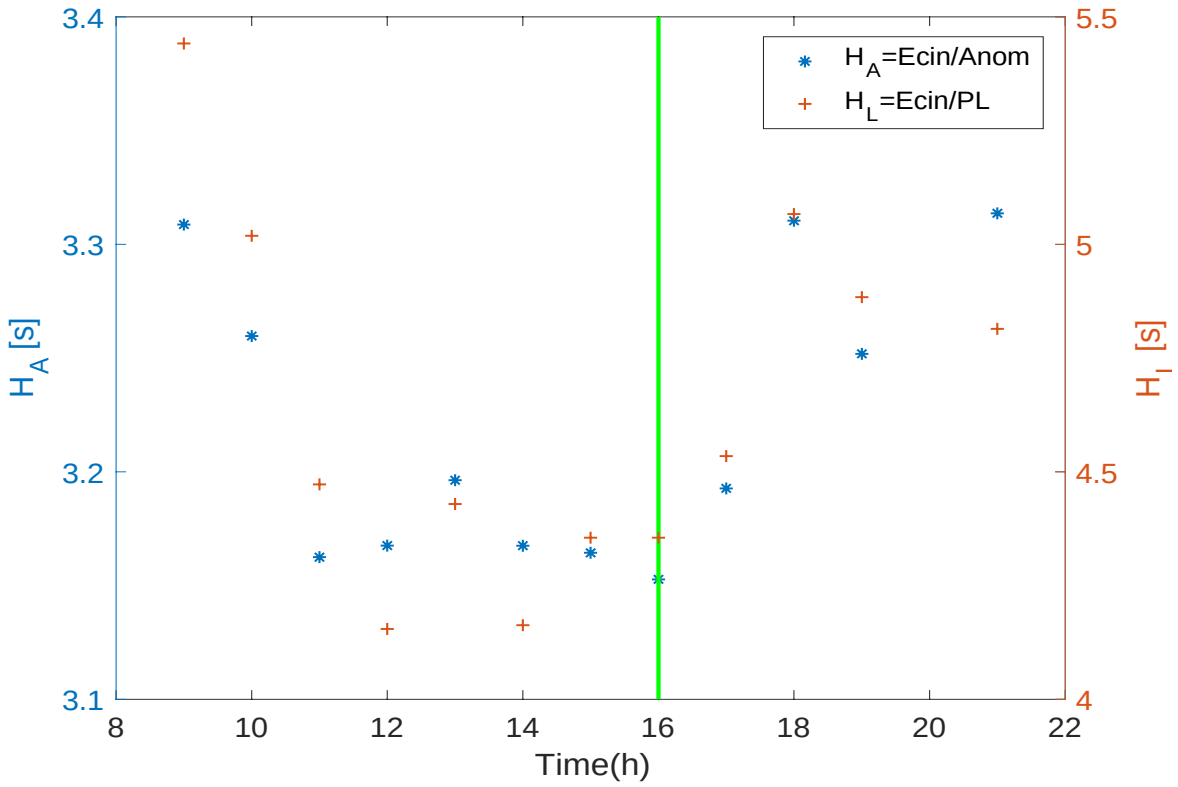
A second analysis was carried out on a "**subscriber**", in which the increase in kinetic energy related to the operation by **synchronous compensators of 1.8 GW** of SG now present in the electric system and converted to guarantee synchronous compensator operation.

[1] **PNIEC does’nt specify this condition. This is a his is a hypothesis, however, very realistic if the service were remunerated as we are starting to experiment in Italy.**

Inertia constant analysis: system minimum value

In the considered day, e.g. base scenario, analysing the hourly production for all the dispatched production units (UPs), the **most critical hour**, that is 16:00, characterized by lowest value of kinetic energy available in the daytime has been detected.

Given the defined scenarios, Ecin and H values are evaluated under the hypothesis that **wind and PV systems do not contribute to the total inertia and the load does not change with the frequency**. Under these hypotheses a safety margin respect to the limit of stability is taken into account.



Values of H_A and H_L

Inertia constant analysis: system minimum value

From this derives a natural decrease in the available kinetic energy, that is an absolute index of the transitory stability capacities of a power system. The obtained values are shown in Table II, where 45% drop in the kinetic energy is evident

	2017	2030	
P_{prog} [MW]	8425	1117	-87%
Ecin [MVAs]	112151	61132	-45%
Anom [MVA]	34165	17381	-49%

$$RoCoF_{max} = \left.\frac{df}{dt}\right|_{max} = \frac{\Delta P_{imb}}{P_{load}} * \frac{f_n}{T_N} \; [Hz/s]$$

In order to establish if these values are sufficient to guarantee the transient stability, reference limits must be considered. Specifically made by ENTSO-E[2], considering a given perturbation, e.g. variation of the demand (p_{imb}[%]), and the maximum gradient of the frequency, RoCoFmax [Hz/s], (**RoCoF =Rate of Change of Frequency**), the minimum starting time of the system, Tm,min, (where Tm is the double of the inertia constant, H) is provided.

p_{imb}[%]	RoCoFmax [Hz/s]	H_{min} [s]
5	0,5	2,50
5	1	1,25
5	2	0,63
5	3	0,42
10	1	2,50
10	2	1,25
10	3	0,83
15	1	3,75
15	2	1,88
15	3	1,25
20	2	2,50
20	3	1,67
30	2	3,75
30	3	2,50
40	3	3,33

[2] ENTSO-E: Frequency Stability Evaluation Criteria for the Synchronous Zone of Continental Europe, Requirements and impacting factors.

Inertia constant analysis: system minimum value

After that, we have moved on to the analysis of the kinetic energy values available for the base scenario, normalized for the relative demand values indicated in Table below.

	2017	2030	
P_L [MW]	23561	24791	5%
H [s]	4.76	2.47	-48%

There is a 48% decrease in the inertia constant, similarly to the variation of the available kinetic energy. The gap of 3% between the two values 2017 and 2030 is given by the increase in demand, in the face of a decrease in kinetic energy.

By comparing the values obtained with the limits indicated by ENTSO-E, it is possible to identify the perturbations that the scenarios are capable of withstanding, in terms of transitory stability. For the base scenario the results are reported in Table

p_{imb} [%]	RoCoFmax [Hz/s]	H_{min} [s]	2017	2030
5	0,5	2.50	✓	-
5	1	1.25	✓	✓
5	2	0.63	✓	✓
5	3	0.42	✓	✓
10	1	2.50	✓	-
10	2	1.25	✓	✓
10	3	0.83	✓	✓
15	1	3.75	✓	-
15	2	1.88	✓	✓
15	3	1.25	✓	✓
20	2	2.50	✓	-
20	3	1.67	✓	✓
30	2	3.75	✓	-
30	3	2.50	✓	-
40	3	3.33	✓	-

Inertia constant analysis: system minimum value

The same operations were carried out for the study of the sub scenario.

Data analysis at 16:00h for base and 2030 sub-scenario.

	2017	2030
$P_{prog.}$ [MW]	8425	1117
E_{cin} [MVAs]	112151	63412
A_{nom} [MVA]	34165	19214
P_L [MW]	23561	24791
H [s]	4.76	2.56

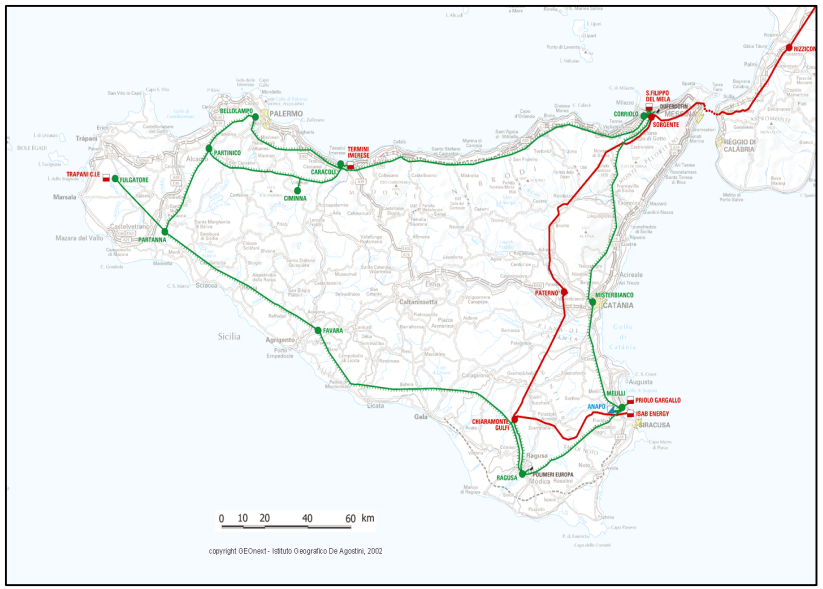
In the sub scenario it is possible to notice *a lower decrease of kinetic energy (therefore of the inertia constant) with respect to the base scenario.* This difference is due to the fundamental contribution that the units considered active provide to the system, in terms of kinetic energy and it guarantees a greater margin from the limit value.

p_{imb} [%]	RoCoFmax [Hz/s]	H_{min} [s]	2030	2030 SS
5	0,5	2.50	-	✓
5	1	1.25	✓	✓
5	2	0.63	✓	✓
5	3	0.42	✓	✓
10	1	2.50	-	✓
10	2	1.25	✓	✓
10	3	0.83	✓	✓
15	1	3.75	-	-
15	2	1.88	✓	✓
15	3	1.25	✓	✓
20	2	2.50	-	✓
20	3	1.67	✓	✓
30	2	3.75	-	-
30	3	2.50	-	✓
40	3	3.33	-	-

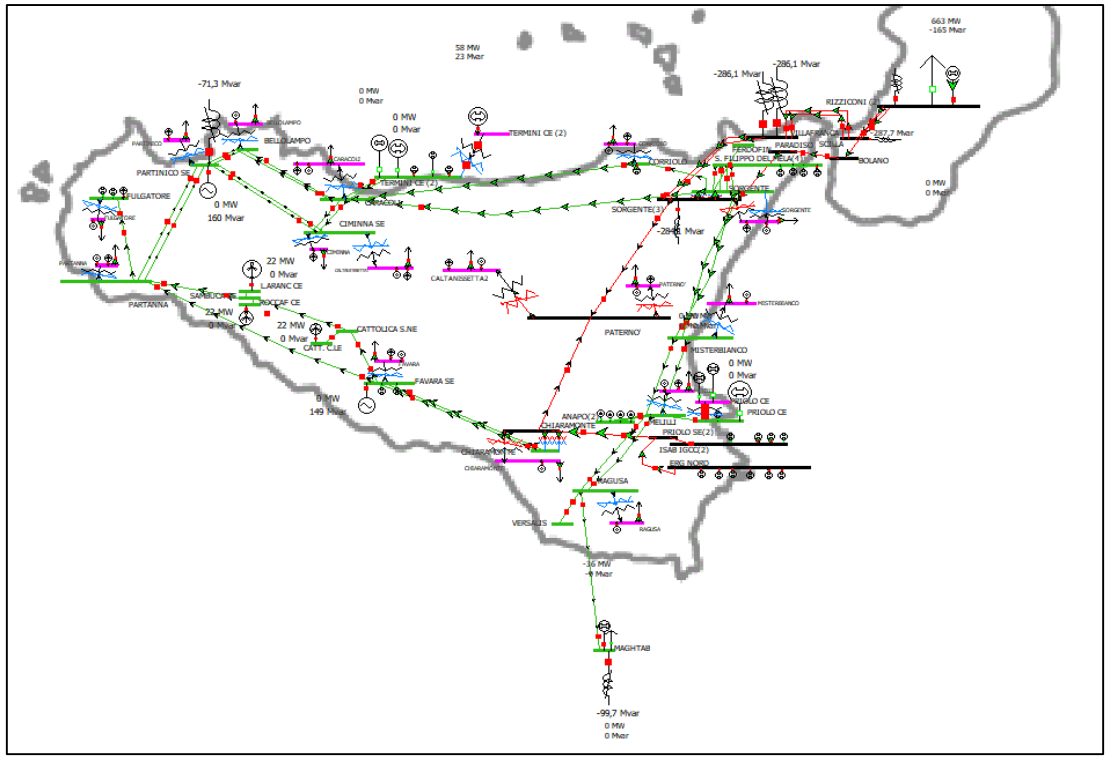
Sicilian Power System Analysis

The second case is based on the transient stability analysis of the Sicilian high voltage power grid (380 kV and 220 kV), by means of the software Powerworld®.

The Sicilian power system is synchronously interconnected to the continental power system via a single 380 kV, 1000 MVA AC link; during planned or unplanned outage periods of the tie-line. Sicily is operated as an islanded system.



PowerWorld Corporation



Sicilian Power System Analysis

The most serious perturbations are the loss of export (overfrequency) and loss of import (urderfrequency).

Real hourly Sicilian power system data in 2018 have been used to detect 6 meaningful scenarios.

Specifically, for both under-frequency and over-frequency conditions, 3 different scenarios have been chosen, each characterized by a different percentage of RES.

Hp:

1) RES generation does not participate in frequency regulation
2) RES generation does not does not provide any inertial response
3) the load does not provide any frequency response.

	Overfrequency cases		
Case	1	2	3
Date **Hour**	09/05/2018 h22	04/05/2018 h16	02/05/2018 h14
Export [MW]	253	284	291
FRNP [MW] (%Ptot)	153 (6%)	966 (46%)	1539 (72%)
Pprog [MW]	2221	1123	590
P_L [MW]	2054	1710	1721

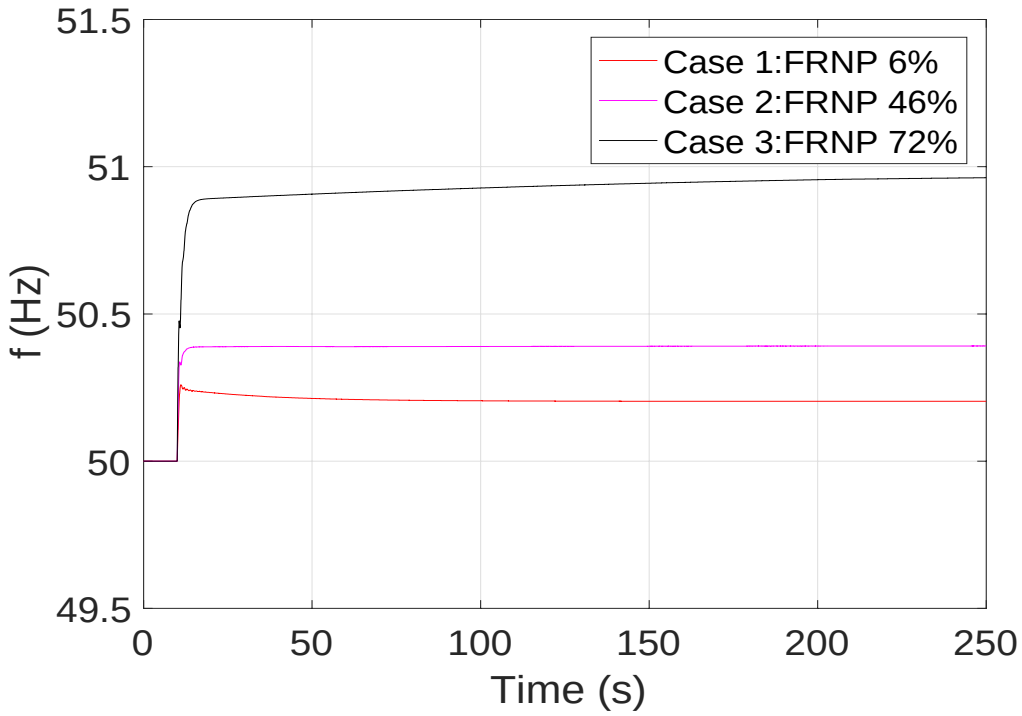
	Underfrequency cases		
Case	4	5	6
Date **Hour**	25/05/2018 h21	14/05/2018 h19	14/05/2018 h12
Import [MW]	698	681	663
FRNP [MW] (%Ptot)	92 (7%)	512 (35%)	738 (49%)
Pprog [MW]	1.294	952	753
P_L [MW]	2104	2044	2165

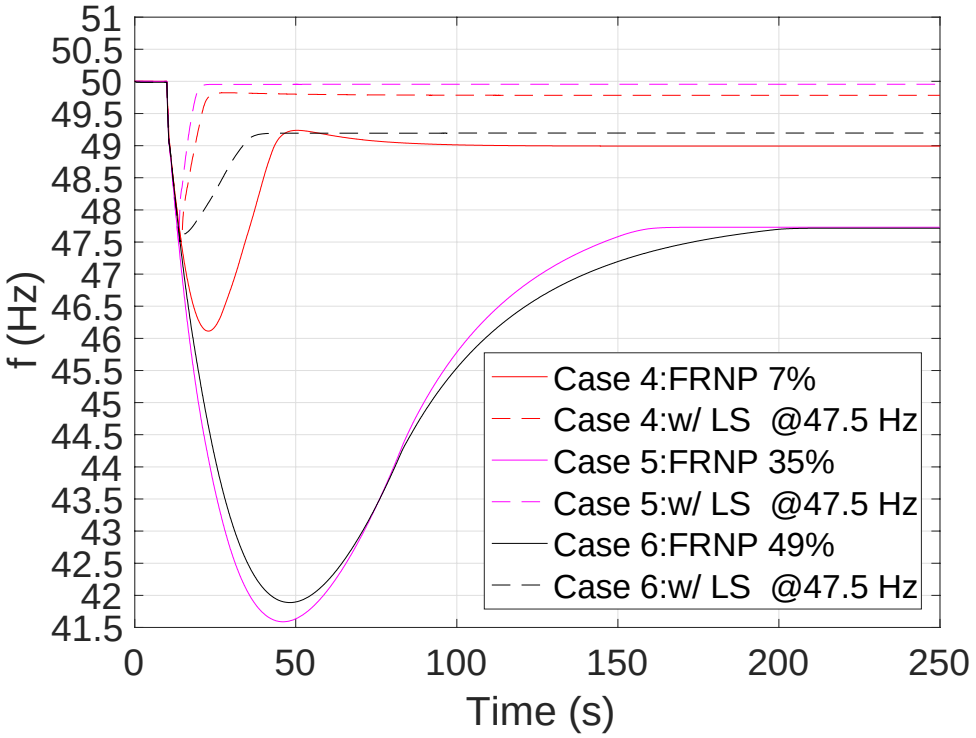
Sicilian Power System Analysis

The aim of transient stability simulations, considering different percentages of RES, is to assess:

1) how the power system dynamic response changes,

2) how different is the use of the primary frequency regulation service and the regulatory energy available in the system.





Sicilian Power System Analysis: indices

The **Primary Reserve Bandwith Available** is the sum of available rising power for each generator, starting from its own power setpoint generated before the disturbance, up to the maximum deliverable power. From here it was then possible to calculate how much of the regulation band reserved for Terna (1.5% of the nominal power) was eroded during the disturbance.

The **Regulating Energy** is the ratio between the power imbalance and the deviation from the nominal frequency value.

The **Total Primary Regulation** Available is the sum of the power available from the generators, before the use of the primary reserve.

The **Use Factory primary Regulation** is the ratio between the primary regulation band used during the contingency ($\Delta P_{Setpoint}$) and the Total primary regulation Available.

Variables	Case 1	Case 2	Case3
$\Delta P = P_G - P_L$ [MW]	253	284	291
Steady-state Frequency [Hz]	50.203	50.39	50.97
Regulating energy [MW/Hz]	1243	730	298
Regulating energy/Generated power [%]	52%	35%	14%
Primary Reserve Bandwidth Available [MW]	43	24	10
Primary Reserve Bandwidth Used [MW]	0	0	0
Reserve used [%]	-	-	-
Total primary regulation available. [MW]	2,437	1,339	569
$\Delta P_{Setpoint}$ (absolute value) [MW]	264	282	284
Use factor primary regulation [MW]	11%	21%	50%

Sicilian Power System Analysis: Overfrequency cases

The final frequency values are consistent with the regulating energy values: the lower the value, the higher the frequency in steady-state condition.

The available regulating energy is inversely proportional to the percentage of presence of RES generation systems.

The power for the primary regulation is directly proportional to the RES percentage.

From this it can be inferred that an increase in FER percentage brings the system into more stressful stability conditions.

Variables	Case 1	Case 2	Case3
$\Delta P = P_G - P_L$ [MW]	253	284	291
Steady-state Frequency [Hz]	50.203	50.39	50.97
Regulating energy [MW/Hz]	1243	730	298
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Use factor primary regulation [MW]	11%	21%	50%

Sicilian Power System Analysis: Underfrequency cases

- The system, even at low penetration RES, reaches frequency levels that **require the load shedding to intervene.**
- Excluding load shedding it is possible to notice that the value of the **minimum frequency is largely influenced by the different intrinsic inertia of the system as the RES grows**.
- Even in under-frequency conditions, the amount of regulating power and the amount of regulating energy available are closely linked to the percentage of RES present, in the same ways as previous cases.

Scenario	Case 4	Case 5	Case 6
$\Delta P = P_G - P_L$ [MW]	-698	-681	-663
Steady-state Frequency [Hz]	48.99	47.73	47.72
Regulating energy [MW/Hz]	694	300	290
Regulating energy/Generated power [%]	50%	20%	16%
Primary Reserve Bandwidth Available [MW]	35	25	23
Primary Reserve Bandwidth Used [MW]	19	20	20
Reserve used [%]	54%	80%	89%
Total primary regulation available. [MW]	2.026	1.497	1.382
$\Delta P_{Setpoint}$ (absolute value) [MW]	716	640	635
Use factor primary regulation [MW]	35%	43%	46%

Scenarios, with Load-Shedding @ 47.5 [Hz]	Case 4	Case 5	Case 6
Load Reduction [MW]	263	639	300
Primary Reserve Bandwidth Used [MW]	6	11	15
Reserve used [%]	16%	46%	66%
Total primary regulation available. [MW]	2.026	1.497	1.382
$\Delta P_{Setpoint}$ (absolute value) [MW]	364	375	404
Use factor primary regulation [MW]	18%	25%	29%

Conclusions

- The **Pniec** sets **challenging goals** regarding the development of RES generation resources in Italy.

- The **development of these generation resources**, associated with the simultaneous **phase-out of coal**, could determine **critical impacts** on the operational safety of the power system if not properly synchronized and coordinated with the development of the network, of conventional generation resources able to provide fundamental regulation services and appropriate regulatory changes.

- The **new conventional thermal generation resources** provided by the PNIEC provide an **important contribution** to system stability, even more if they are able to provide synchronous compensator operation.

- Furthermore, following a circular economy and sustainable development approach, even the **assets that are close to being disposed** of, if properly converted and repowered, can still provide a **fundamental contribution** to the security of the electricity system.

RESEARCH ACTIVITIES DURING THE ACADEMIC YEAR

❑ Papers:

- G. M. Tina, D. Stefanelli, S. Licciardello "Strategic role of new power generation assets for the security of the future Italian power system", published for the 19th IEEE EEEIC, Genova
- G. M. Tina, D. Stefanelli, S. Licciardello "Conventional Techniques for improving Emergency Control of Transient Stability in renewable-based power systems", published for the 10th IREC Conference, Hammamet (Tunisia)

❑ Others and Future Works:

- Developing of a new study one the stability of the Italian Electrical System for a more critical day;
- Study of the Italian EPS from a economic point of view, for the electrical market
- Support for the course and new undergraduates