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Low inertia systems and the case of Cyprus grid

A support for the operators to efficiently manage a network with high share of RES and other emerging technologies

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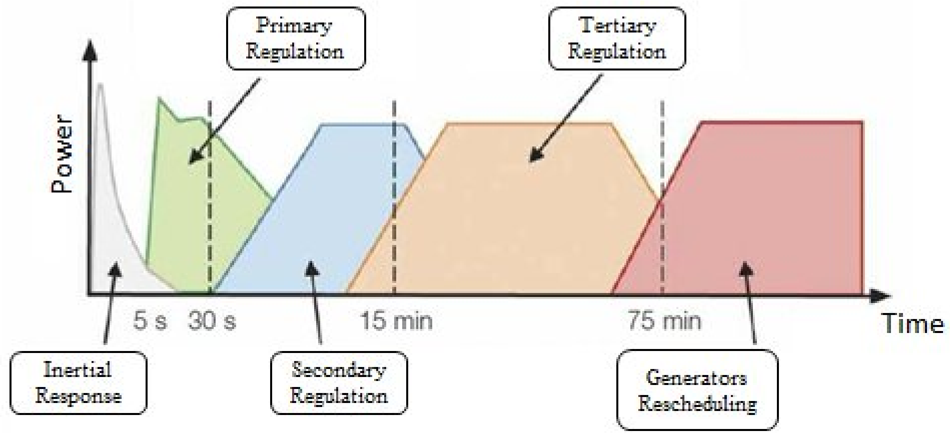
The stability challenge of the grid

* One of the main issues expected to affect the operation of the power grid is the impact of inverter-based technologies to the **power system inertia** and hence to **system stability**.

* Consequently, the **main challenges** of the future grid are:
  - the evaluation of the frequency stability in the presence of inverter-based systems a
  - how the aforementioned technology can support frequency without the help of the rotating masses of the traditional power grid systems.

Main impact of the system operation

- The system's inertial response is critical since it is the very first and the fastest system's response.
- The hierarchical frequency support and generation rescheduling that follows has supporting role and usually undertakes adjustments to restore frequency to nominal value.

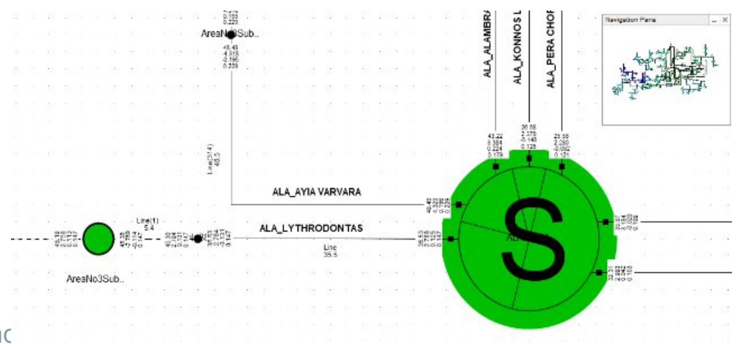


These new challenges will have impact on issues such as:
- optimal power flow (OPF)
- power quality
- voltage control
- system economics and load dispatch.

Cyprus grid under investigation

* The grid system under investigation models a part of the real physical grid area of Cyprus in 2019. It comprises of transmission substations with terminals of **132 kV** voltage level. Also, it comprises of distribution substations operating at voltage levels of **11 kV** and **400 V** phase to phase.

* The model contains a total of 1721 lines, 3009 busbars (4891 terminals), 1006 transformers, 1925 loads (including 962 electric vehicle loads), and 1931 generators (962 PV systems, 2 Synchronous machines, 962 battery energy storage systems, 2 Hydro systems, 2 Wind Farm systems and 1 biomass unit). In addition, it provides 2284 protection devices (993 fuses) and 1291 breakers/switches.



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The projection scenario-2030

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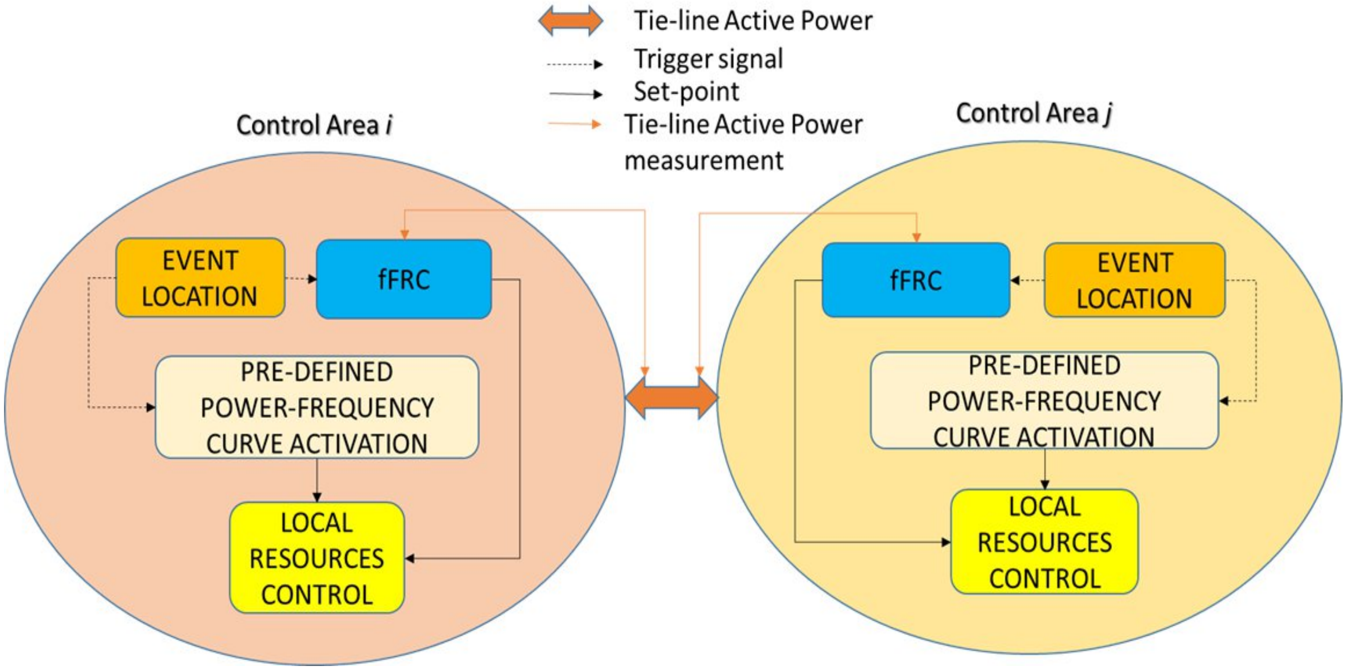
* Scenario - Nominal Capacity per power source type (MVA)						
* Scenario Cases	* Solar	* Wind	* Hydro	* Biomass	* Conventional	* Pump Storage
* 2030	* 42.2	* 42.3	* 48.9	* 9.2	* 22.5	* —

Stability Analysis Scenario for 2030 - Loss of generation capacity [MVA] (affected source type marked with orange color) - Fault in Area 1	
Source Type	Capacity
Solar	42.3
Wind	42.3
Hydro	34.2
Biomass	6.4
Conventional	15.8

Hierarchical controllers approach

- Each transmission substation constitutes a different control area with distributed generation, storage, electric vehicles, and loads.



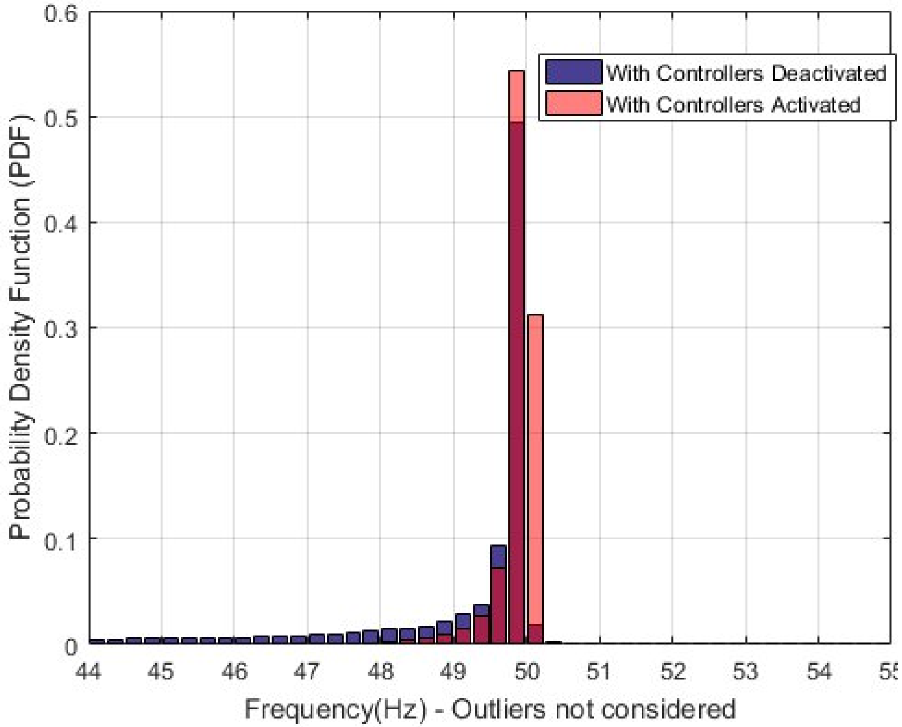
The main local controller functions are:

- **Event Location;**
- **fFRC - fast Frequency Restoration Control;**
- **Pre-defined Power-Frequency curve calculation;**
- **Local Resources Control;**

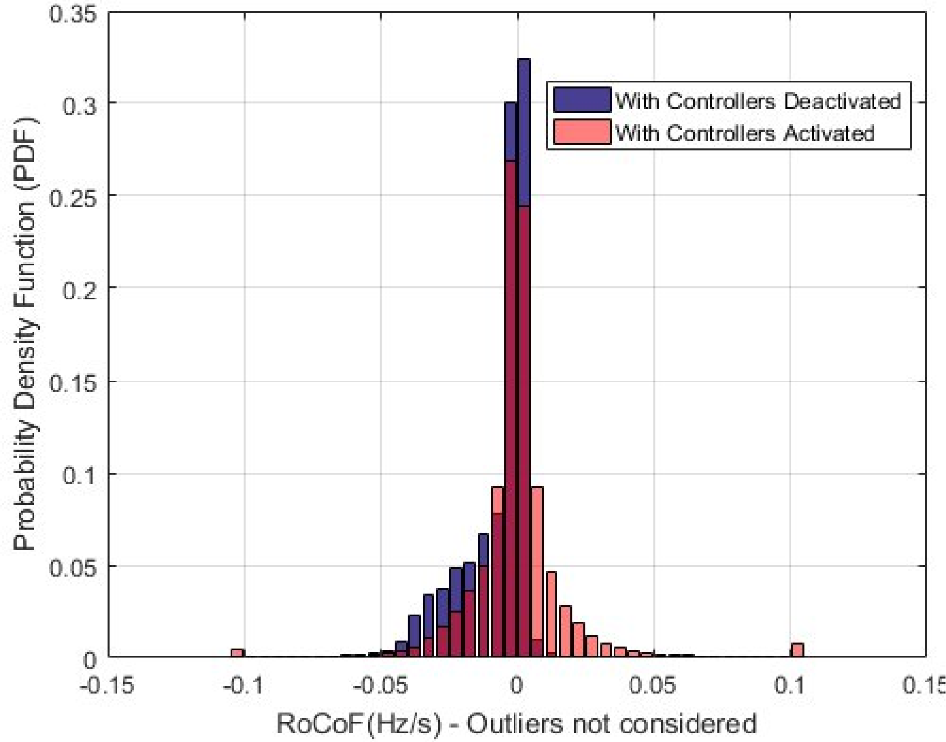
Measuring the impact and controllers reliability

	ID	Name	Formula
Key Performance Index	**1**	Frequency restoration control effectivity	$F_{restoerd} - F_{nom} \leq \varepsilon, \varepsilon \rightarrow 0$
	2	Frequency nadir	$max(f_n - f)\ [Hz]$ f_n $-$ $nominal\ frequency\ [Hz]$ f $-$ $system\ frequency\ [Hz]$
	3	Frequency zenith	$min\ (f_n - f)\ [Hz]$ f_n $-$ $nominal\ frequency\ [Hz]$ f $-$ $system\ frequency\ [Hz]$
	4	Rate of Change of Frequency (RoCoF)	$\frac{df}{dt} = \frac{P_g - P_l}{2H_{sys}}$ $\frac{df}{dt}$ $-$ $rate\ of\ change\ of\ frequency\ [Hz/s]$ P_g $-$ $generators'\ active\ power$ [pu] P_l $-$ $demand\ active\ power\ [pu]$ H_{sys} $-$ $system\ inertia\ [s]$
	5	Indication of Stability	Boolean variable (YES/NO)

Results on Frequency Stability

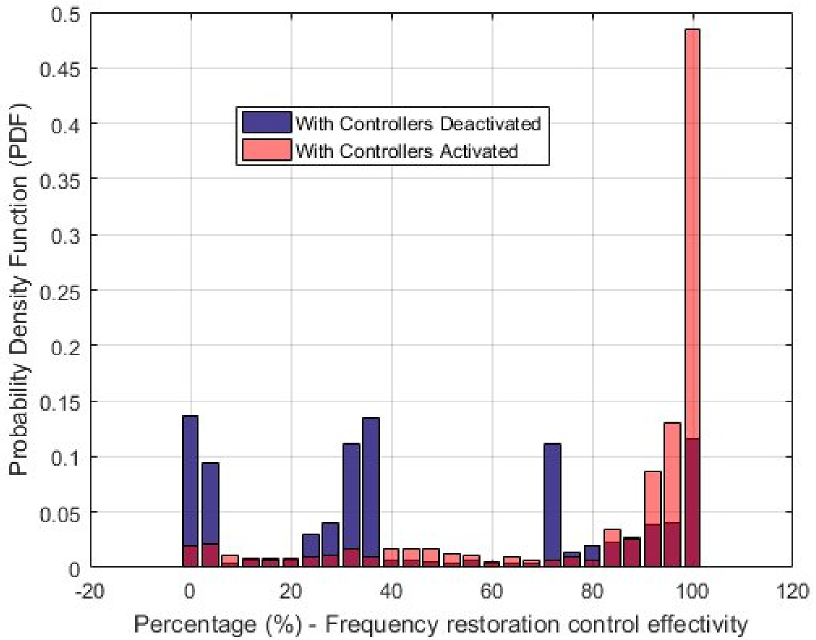


Frequency variation during the fault event with and without the controllers enabled (dark red is the combination of the two cases: with and without)

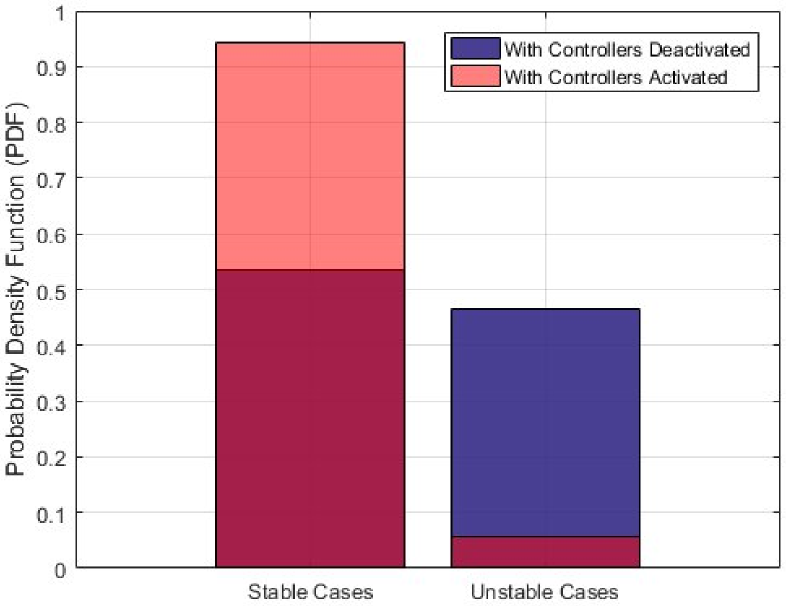


RoCoF variation during the fault event with and without the controllers enabled (dark red is the combination of the two cases: with and without)

Controller evaluation



Control Effectiveness index with and without the controllers enabled (dark red is the combination of the two cases: with and without)



Stability Index calculated with and without the controllers enabled (dark red is the combination of the two cases: with and without)

Discussion-Conclusions

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* The low inertia system of the future presents many operational challenges to handle.
* Utilization of the active sources of the grid down to the distribution substation level for frequency control / support, are needed.

Major contribution of the paper are:

- the introduction of hierarchical controllers capable of managing the active sources of the integrated grid
- A two-level hierarchical control for effective Fast Frequency Control (FFR) including distributed local control
- A realistic implementation in a complex real system

Thank you for your attention!

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