The need of SYNCHRONOUS INERTIA in autonomous power systems with increasing shares of renewables

The study case of Madeira Island's hybrid power system

May 9, 2018

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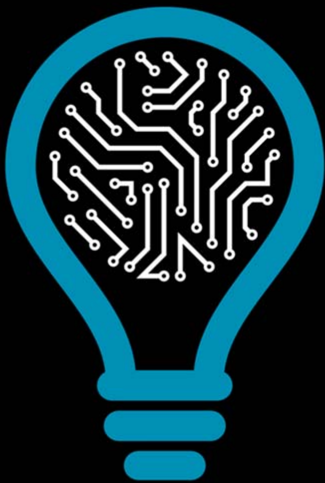

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3rd International Hybrid Power Systems Workshop 8 - 9 May 2018 Tenerife, Spain

Session 7A – Stability Issues

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Introduction

- **Study case: Madeira Island**
- A **large growth** of **renewable generation integration** is expected for the **2020–2025 horizon**.
- **Oversupply during off-peak hours** – need to increase pumped hydro as energy storage / power arbitrage solution
  - Reversible hydro power stations equipped with separate pumps and turbines with a single penstock configuration
- **Goal: secure system operation without thermal units**
- **Battery storage systems** providing fast power-frequency regulation.
- Several **hydro generators** operating as **synchronous condensers** to provide voltage/var support and inertia.

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Madeira Island | the study case

- Monthly **peak loads** varying between 120 MW and 140 MW (2017).
- Monthly **valley loads** varying between 65 MW and 80 MW (2017).
- About **30% renewable energy share** (2016 & 2017).
- Significant amounts of hydro pumping power planned to explore a **hybrid storage system** with a high wind and solar energy integration.

Foreseen installed capacity growth by source

		2018	2025
Hydro	generation	47 MW	110 MW
	pumping	7 MW	55 MW
BESS		0 MW	20 MW
Solar		19 MW	78 MW
Wind		45 MW	73 MW / 103 MW
Geothermal		0 MW	30 MW / 0 MW
Waste-to-energy		9 MW	9 MW
Diesel/NG		177 MW	61 MW

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Valley hours operation | Dynamic stability

- During valley hours, grid operation will be relying on:
  - 2 **batteries** operated in grid-tied mode
  - **renewable energy sources** (wind, solar)
  - **fixed** and **variable speed hydro pumps**
  - **synchronous** generators (sync. cond., small hydro, 1 waste-to-energy unit).
- During grid faults, most of the power associated to **converter-interfaced units** is significantly affected due to the fault-ride-through reaction and subsequent active power recovery gradients:
  - **voltage dip-induced frequency deviation**
  - Consequently, **large frequency transients** are induced in the grid.
- Problem: **Strict load shedding criteria based on RoCoF and frequency deviation.**
  - $\Delta f/\Delta t = -1.5$ Hz/s
  - $\Delta f = -1.0$ Hz

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Alternative options to increase system security

- **BESS power increase**
  - The system operator foresees the installation of two BESS with 15 MW and 5 MW maximum power, with energy capacity for 15-20 min.
  - Possibility of increasing each BESS power, up to a total installed power between 30 MW and 40 MW (two cases).
- **Supercapacitor**
  - A solution specifically projected for fast power injection.
  - A specific manufacturer's solution providing a peak power of 12 MW during 5 s.
  - Afterwards, the power injection decays exponentially to zero in about 15 s.
- **Increasing synchronous inertia**
  - **Retrofitting older diesel units**, converting them to operate in **synchronous condenser** mode.
  - Additionally, these units may need increased inertia constants by having flywheels mechanically coupled to the shaft.

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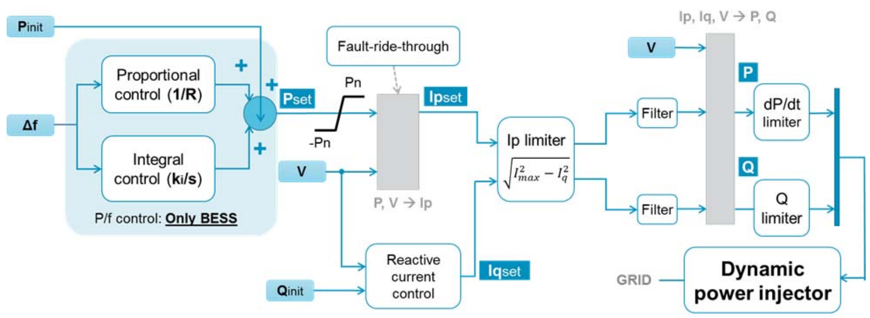
Dynamic simulation models

- *Simulation software: MATLAB/Simulink*
- **Custom models** for **power-converted-interfaced units** (**BESS**, modern **wind** and **PV** generators, **variable speed hydro** pumps) (with variants by source)
- Example: BESS dynamic model



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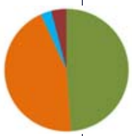
Operating conditions

Typical off-peak scenario

Generation	P [MW]
Diesel	–
Natural gas	–
Wind	58.4
Solar PV	53.0
Hydro	3.3
Waste-to-energy	4.8
BESS (5+15 MW)	0 (Ready)
Total	***119.5***



Load	P [MW]
Consumer load	90.8
Hydro pumping	24.9
Transmission losses	3.8
Total	***119.5***

- 12 connected synchronous units (11 hydro, 1 waste-to-energy) providing a **total inertia of 22.8 s**.
  (base: 10 MVA)
  - All synchronous units are either in synchronous condenser mode or providing constant power output.
- No conventional spinning reserve, **fast power-frequency regulation** provided only by **two BESS**.
- The primary load shedding criterion is set to:
  - Δf = -1.0 Hz **&** Δf/Δt = -1.5 Hz/s

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System disturbance

- A **symmetrical three-phase short-circuit** located in a high voltage (60 kV) transmission line.
- This line is one of the longest in the island and is often exposed to adverse weather conditions.
- Fault clearance occurs within **100 ms,** followed by line tripping.
- The voltage dip leads to:
  - **fault-ride-through activation** in all of power-converter-interfaced units (wind, solar, variable speed hydro pumps, BESS);
  - **disconnection** of the remaining wind generators and PV units, as well as all fixed-speed hydro pumps, due to the minimum voltage protection.

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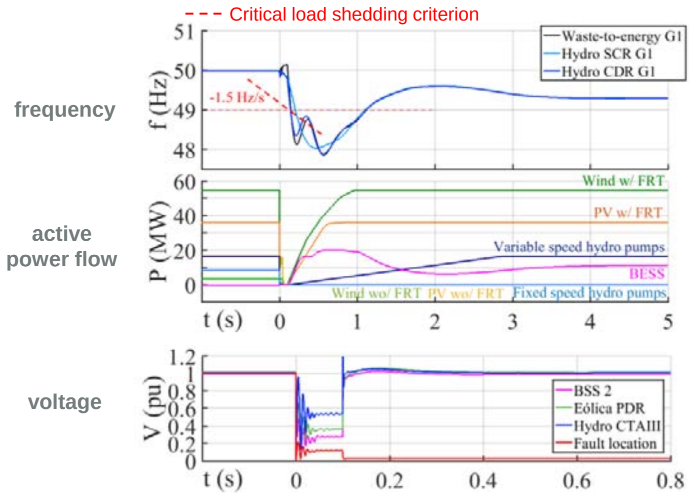
Simulation results | Base case

- There are the “base case” results, considering no additional measures.
- The criteria for the first load shedding level are violated, justifying the need for **additional action**.



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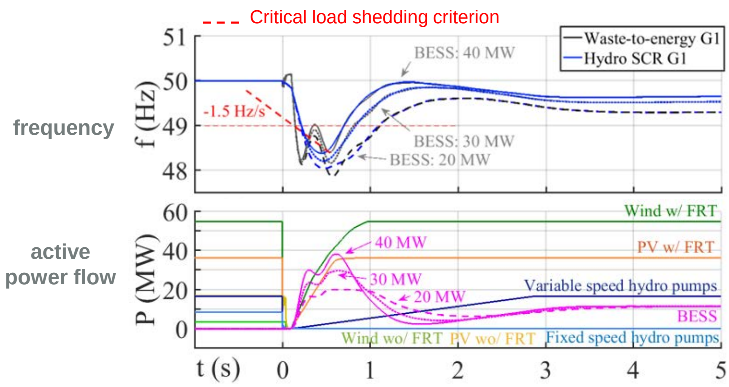
Simulation results | BESS capacity increase

- The results show that this solution provides only a **small contribution** to contain the **initial frequency excursion**.
- Power-converter-based sources entering in fault-ride-through mode as well as the subsequent recovering phase **precludes BESS** capacity increase to have a more effective contribution against frequency decay.



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Increasing the system inertia

- This table shows the influence in the system's global inertia, considering several combinations of additional synchronous condensers.

Inertia constant H [s]	Diesel units* retrofitted for synchronous condenser operation [H in 20 MVA base] G1	G2	G3	Total system inertia [s] [10 MVA base]	Increase vs. default
	-	-	-	22.8	0%
	1.5	-	-	25.8	+13%
	1.5	1.5	-	28.8	+26%
	1.5	1.5	1.5	31.8	+39%
	3.0	-	-	28.8	+26%
	3.0	3.0	-	34.8	+53%
	3.0	3.0	3.0	40.8	+79%
	4.5	-	-	31.8	+39%
	4.5	4.5	-	40.8	+79%
	4.5	4.5	4.5	49.8	+118%

*Rated power = 20 MVA

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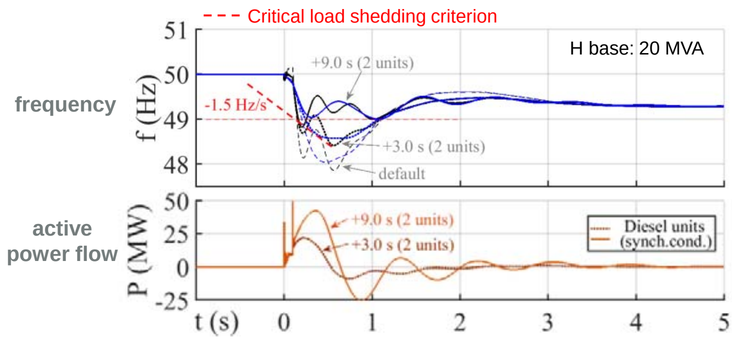
Simulation results | Increasing synch. inertia

- Adding 2 retrofitted diesel units with increased inertia leads to **very significant improvements** in the transient response to this disturbance.
- This occurs due to the increased active power feed provided by the **inertial response** in the moments subsequent to the disturbance.



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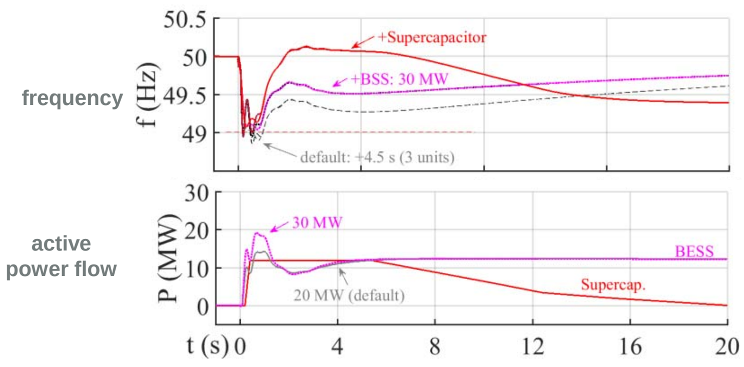
Simulation results | w/ Supercapacitor

- All presented cases consider 3 additional synchronous condensers.
- The results support the previous conclusion that power-electronics-interfaced units **face difficulties** to provide significant benefits in the immediate response to this short-circuit disturbance.



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Conclusions

- Operating this islanded power system without conventional thermal units requires **complementary solutions** to avoid dynamic security risks (load shedding).
- **BESS** can provide fast power-frequency regulation, but when considering **short-circuits** these units have a limited capacity for active power processing.
- This phenomenon rules out other solutions involving power electronics converters, such as connecting a supercapacitor.
- **Increasing physical inertia** proved to be the only solution capable of meeting the **strict load shedding** activation criteria.
- Alternatively, a suggestion of adjusting the **first stage of the load shedding activation criterion** needs to be carefully evaluated.

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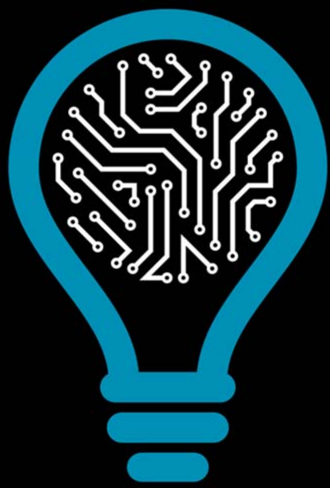
Thank you for your attention.



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