Stabilizing the islanded Bornholm with V2G chargers

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Antonio Zecchino, Ph.D. student

antozec@elektro.dtu.dk

Center for Electric Power and Energy

DTU Risø Campus

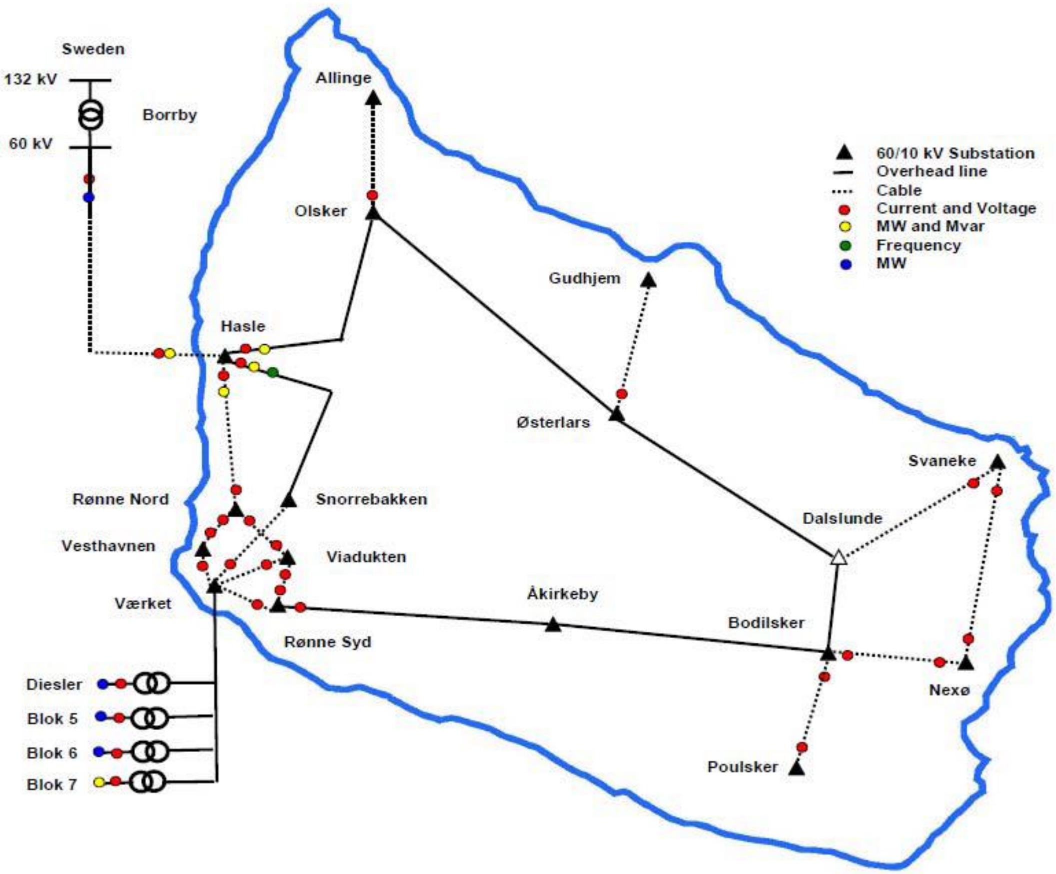
Outline

- Bornholm power system in a nutshell
- Getting the island islanded
- Conventional vs EVs
- Results on an equivalent single-bus system
- Results on the Bornholm power systems

Foreword – HV grid layout (60 kV)

- Bornholm power system is normally connected to the mainland (Sweden) via a sea cable (60 kV) with a transfer capacity equal to 60 MVA (480 A on 3x240 Cu), 43.5 km offshore (+2 larger OH sections onshore).

- Consumption:
  - Peak power (winter time) 60 MW
  - Minimum load 13 MW
  - energy 268 GWh (equal to 4870 h or 55% CF)



Foreword – normal operation (1/2)

- **The complete generation set (May 2018) includes:**

CGUs

- 16 MW biomass CHP, steam turbine (can be boosted to approx. 24/36 MW if running on coal/oil), named **Blok 6**, with droop ctrl (2%) and V ctrl. Ramping rate 0.2 MW/min (=1.25%P_{nom}/min) (total 2H=6.4s; 46.8 MVA)
- 2*1 MW biogas CHP, gas turbine no droop (each 2H=5.6s; 1 MVA)

RES

- 37 MW wind (24 machines <100 kW; 16 machines between 100 and 1000 kW; 17 machines> 1000 kW)
  - Of which 2 Vestas parks/6 DFIG machines (11.25 MW= 3*2 MW + 3*1.75 MW) with power capping capability
- 22 MW PV (8 MW on rooftops at 0.4 kV + 2 new 7.5 MW plants at 10 kV)

- **58 MW reserve** (used during islanded operation) – see next slide

Foreword – normal operation (2/2)

- **58 MW reserve (used during islanded operation) include:**

CGUs

- 25 MW (oil), steam turbine, named **Blok 5** with droop ctrl (2%) and V ctrl. The droop is generally not used in conjunction with Blok 6 due to hunting issues (non linearity in the response characteristic, probably). Ramping rate 2.5 MW/10 min (=1%Pnom/min) (2H=8.6s; 29.4 MVA)
- 18 (=4x4.5) MW old diesel (built between '67 and '72), no name, with droop ctrl and V ctrl (each 2H=8s; 5.8 MVA & 6.3 MVA)
- 15 (=10x1.5) MW new diesel (2007) with NO droop nor V ctrl, named **Blok 7.** Ramping rate 1 MW/min (66%Pnom/min) (each 2H=1.1s; 2MVA)

What about replacing some reserve provided by CGUs with green units?

…

Electric Vehicles!!!

Islanded situation – data analysis

- In Autumn 2017, the cable was de-energized for maintenance from **18 Sept till the end of the month**.
- **General approach is to disconnect all non-controllable renewables and limit WT output.**

From analysed measurements:

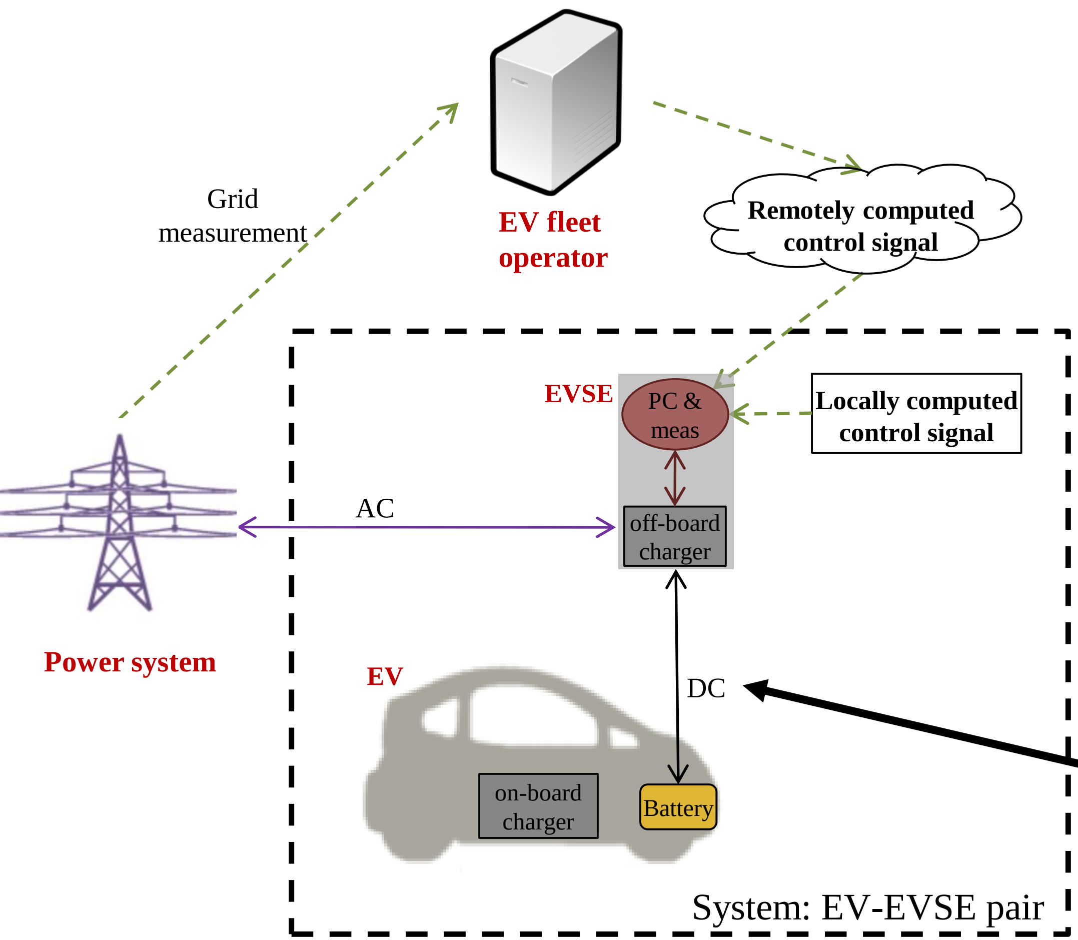
- Given the warm season period, electric consumption was relatively low (daily peak 30 MW)
- No significant frequency fluctuations were observed

Enhancing the operation during island mode

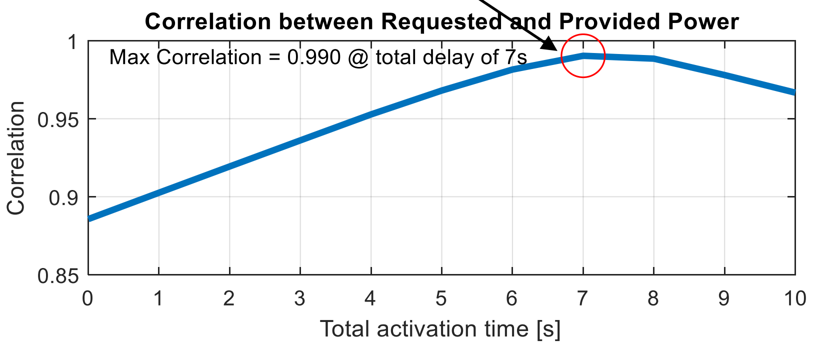
- Can EVs in Bornholm contribute to frequency regulation during islanded situations?
- Can they help increasing the amount of wind during islanded situations?
- Is the total response time of commercial hardware (EVs + V2G chargers) critical?
- To what extent is it possible to replace primary reserve from CGUs with V2G EVs?

Control architecture

The tested ±10 kW DC chargers are remotely controlled and the response time was assessed



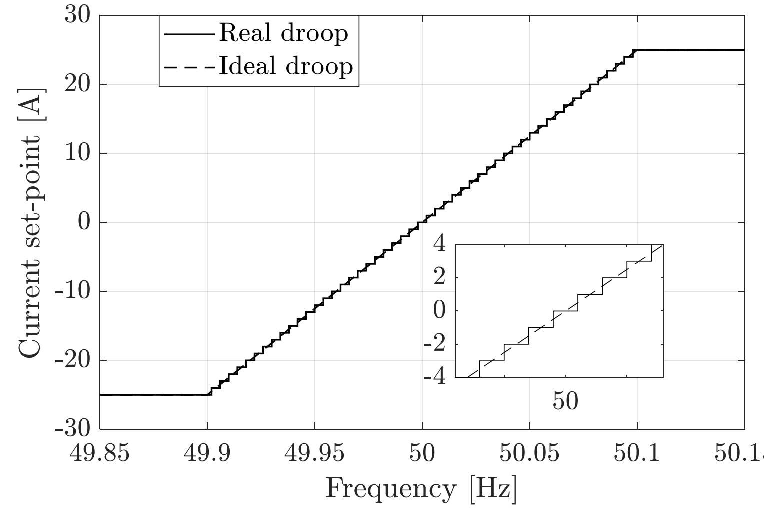
Average response time including both communication and hardware: **7 seconds**

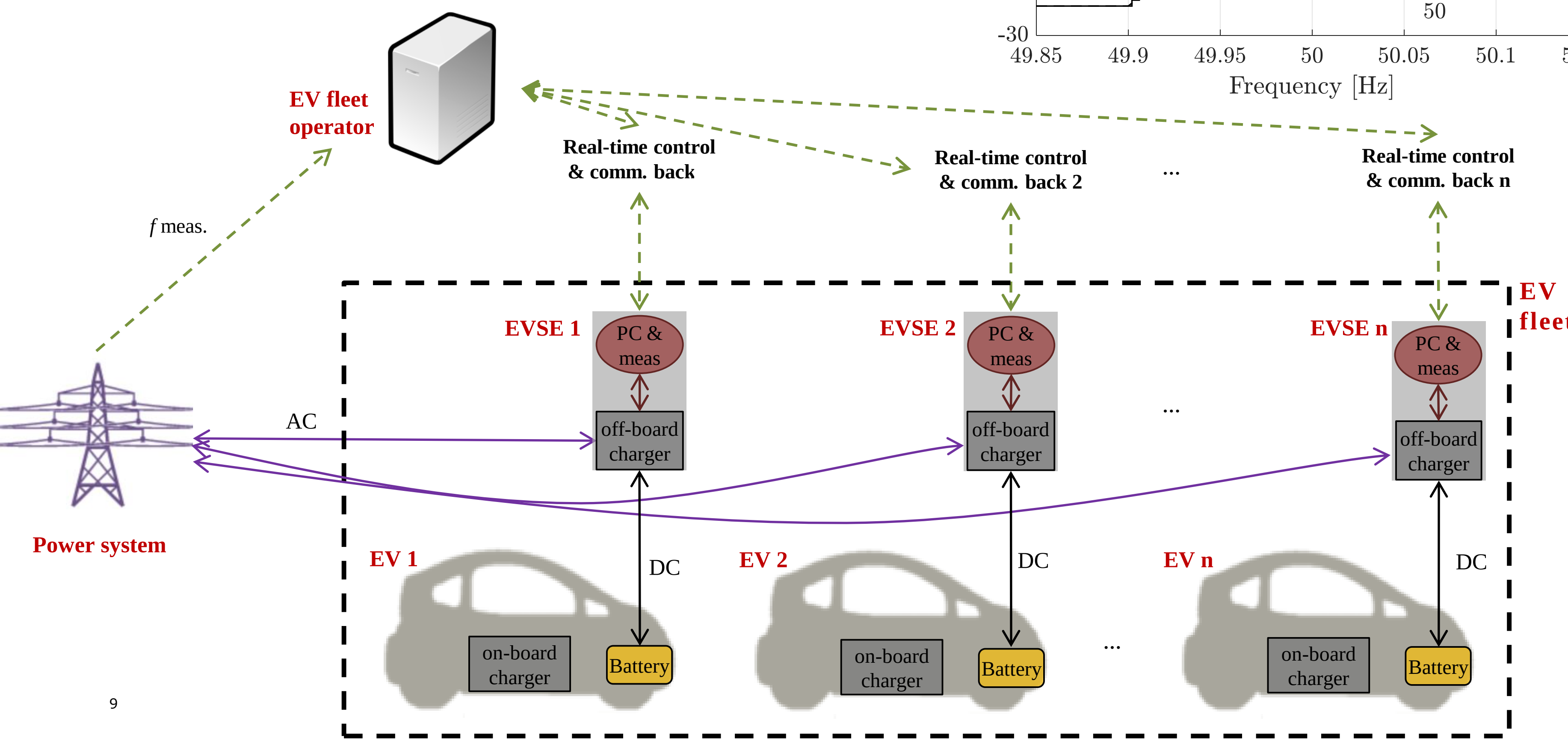


The requested power is set on the DC side (as current set-point)

Control architecture

The tested ±10 kW DC chargers are currently used in several locations in DK for providing frequency control following this droop characteristic.





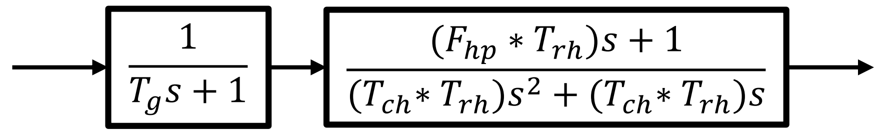
Understanding the difference between the response of conventional power plants and EVs aggregation

From the literature:

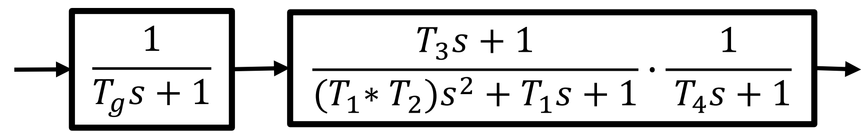
Models in the frequency domain

1. CGUs

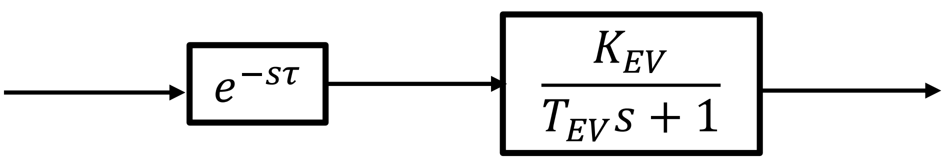
   Steam turbine with re-heat



   Diesel with electric control box



2. Aggregate EVs model



K_{EV}	1	Battery coefficient
T_{EV}	0.1	Time constant of battery

Investigating the response on an equivalent 1-bus system (1/2)

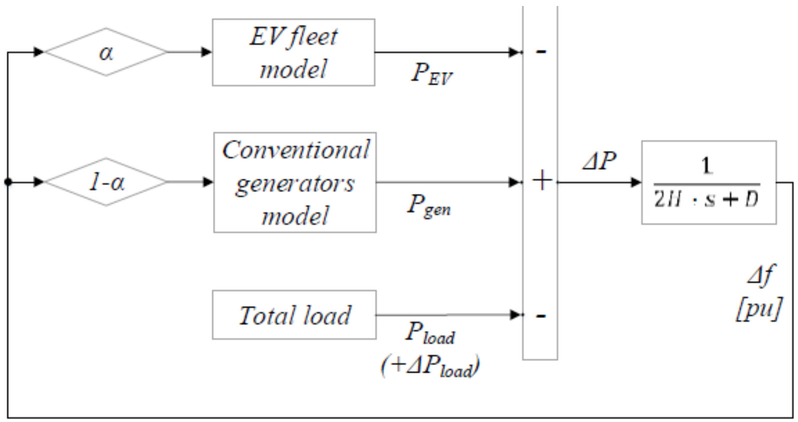


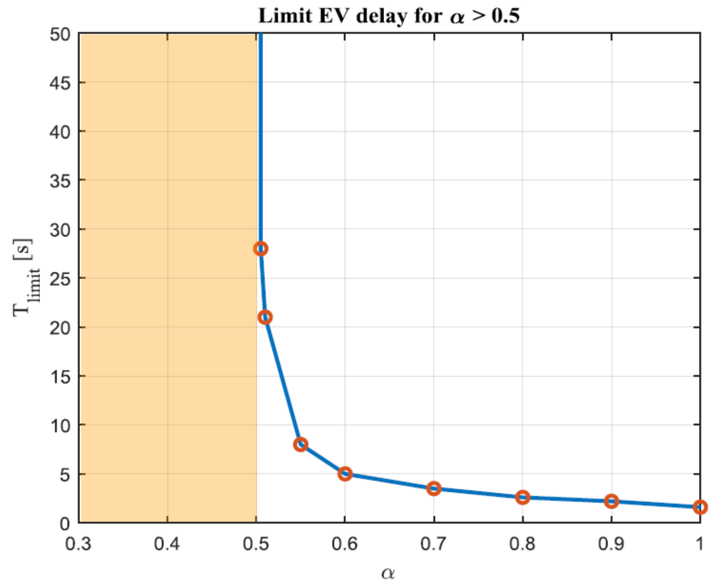
Fig. 3. Simplified power system with the classical single-bus layout.

α is defined as the ratio between the reserve provided by EVs and the total reserve capacity

$$\alpha = \frac{P_{res\_EV}}{P_{res\_tot}}$$

TABLE 1. SYSTEM PARAMETERS

Parameter	Symbol	Value	Unit
Base Frequency	ω_0	314	rad/s
Inertia constant	H	3.6	s
Rated power	S_{rated}	108.2	MVA
Damping factor	D	0	%
Total load	P_{load}	60	MW
Primary reserve	$P_{reserve}$	10	MW
Primary frequency control normalized droop gain	$droop$	2	%



In an equivalent 1-bus system, characterized with diesel genset dynamics, latency is not an issue as long as the share of primary reserve from EVs is < 50%

Recommendation 1:
α <0.5

Investigating the response on an equivalent 1-bus system (2/2)

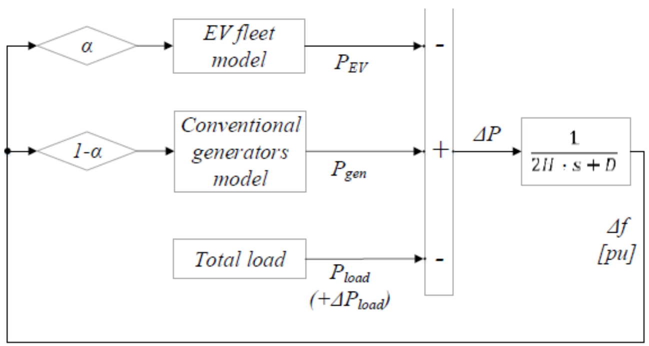
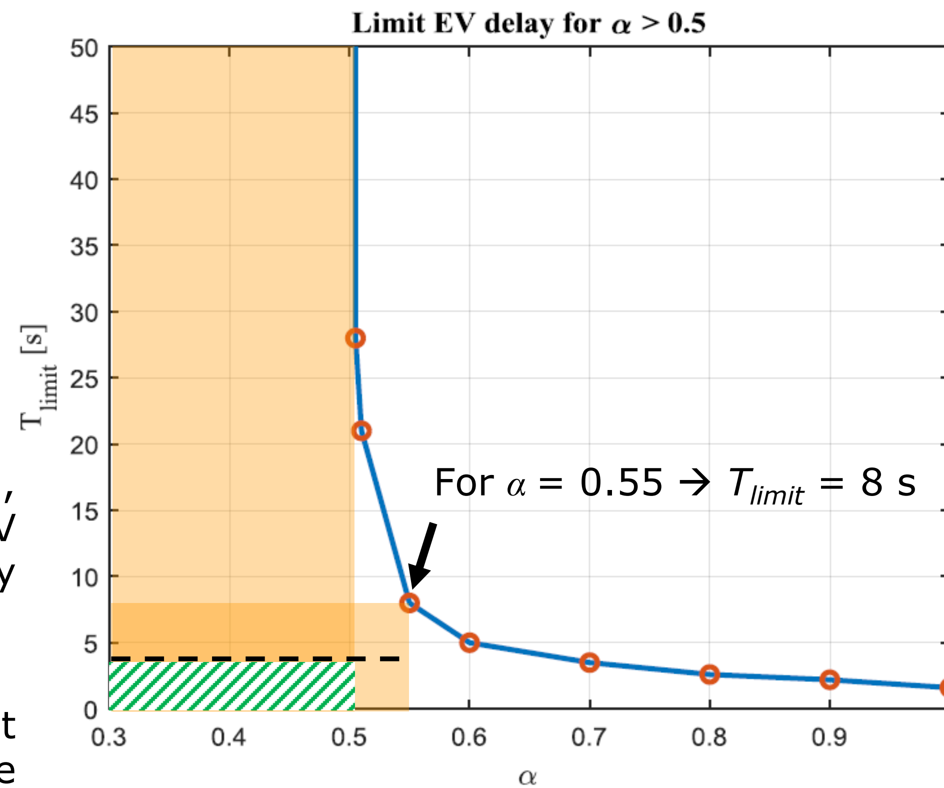


Fig. 3. Simplified power system with the classical single-bus layout.



An additional recommendation is included, which sets a limit time value T_{limit} for the EV response. This is calculated for a α slightly above the 0.5 limit: $\alpha = 0.55$.

2 is a safety factor, introduced to prevent operating too close to the limit and to take into account possible imperfections in the calculation of T_{limit} for the power system under exam.

→ ***Recommendation 2:***
$\tau < T_{limit}/2$

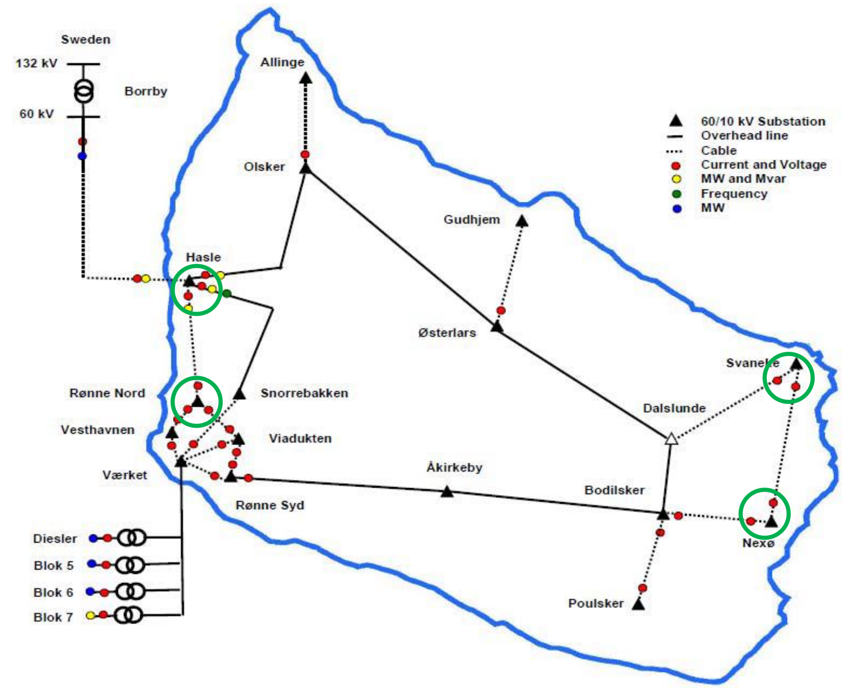
Replacing the diesel genset for providing frequency reserve along with the steam unit – test on the whole Bornholm power system (1/2)

- 60 MW load
- 30 MW wind generation
- 30 MW from CGUs

(**blok 5** and **blok 6**)

- **Loss of 2 MW wind turbine**

- 5 MW of reserve from **blok 5** over 200 mHz
- Either 4.5 MW diesel or **450 EVs** with ±10 kW V2G chargers performing frequency regulation

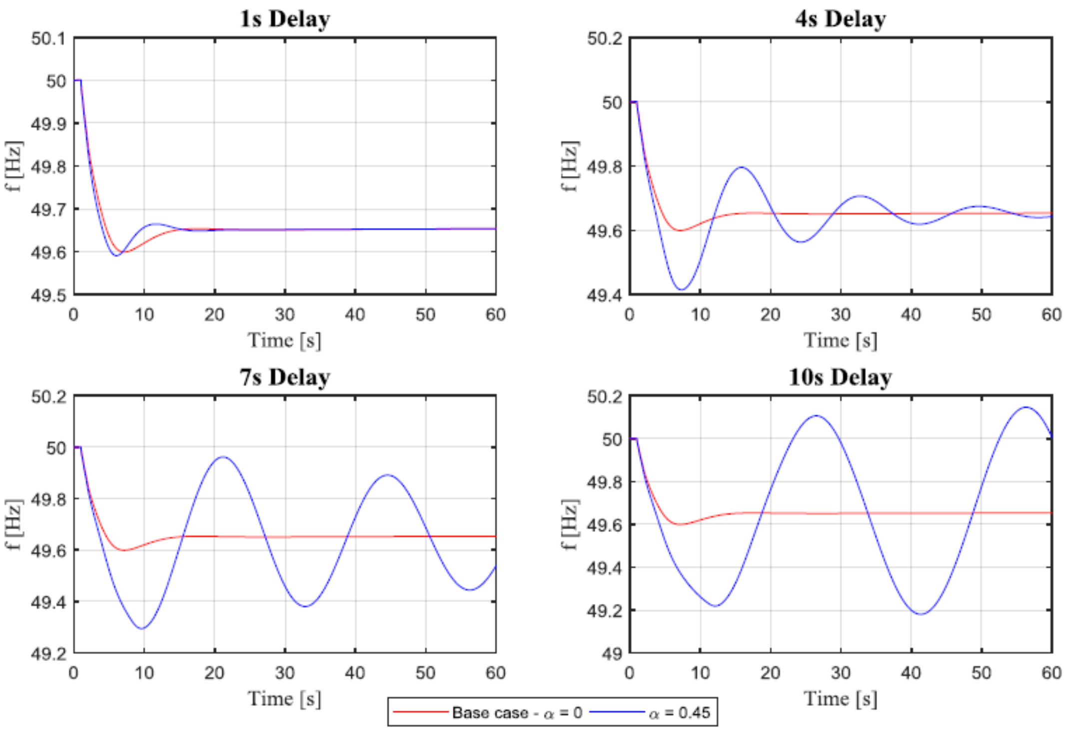


EV fleets:

EV fleet #1: Rønne (225 EVs)
EV fleet #2: Hasle (75 EVs)
EV fleet #3: Nexø (75 EVs)
EV fleet #4: Svaneke (75 EVs)

A. Zecchino, A. M. Prostejovsky, C. Ziras, M. Marinelli~, "Large-scale Provision of Frequency Control via V2G: the Bornholm Power System Case," Electric power system research, full paper under review.

Replacing the diesel genset for providing frequency reserve along with the steam unit – test on the whole Bornholm power system (2/2)



Power system frequency behavior for α = 0 and α = 0.45 with increasing EV response times

Stability conclusions

- **On the equivalent 1-bus system we derive:**
  - ***Recommendation 1*** requires to operate with a share of primary reserve from EVs that would not exceed the reserve from CGUs ($\alpha < 0.5$).
  - ***Recommendation 2*** requires response times below the half of a limit value T_{limit} that can be calculated as function of the system inertia, of the total primary reserve over the rotating generation capacity, and of the employed droop gain.

- **On the Bornholm power system**
  - Results show that for EV response times of 1 s and 4 s the stability was assured, whereas for 7 s (very close to the calculated T_{limit} = 8 s), slowly damped oscillations appeared before settling to the steady-state frequency value (with a share of reserve equal to 45%)

Thank you.

Antonio Zecchino
Technical University of Denmark, DTU
antozec@elektro.dtu.dk
+45 93511257

Back-up slides

2040 scenario with 50% EV penetration → **8500 EVs**

Evening hour (18:00-19:00) when 40% of the EVs are charging at home at 3.7 kW (Mode 2), leading to about 12 MW of total extra load. This is added to the high evening load condition (48 MW) → **total load of 60 MW**

A portion of the remaining EVs not charging at home are connected to V2G chargers and are available for grid frequency regulation: 5% of the total EVs → **450 EVs**

Considering each vehicle interfaced with a ±10 kW charger, the total regulation capacity is → **±4.5 MW**

$$\xi = \frac{P_{reserve}}{E_{rotating}} \quad , \quad E_{rotating} = \sum_{i=1}^{n} P_{n,i} 2H_i$$

$$T_{limit} = \begin{cases} a_k \cdot droop + b_k & with\ a_k, b_k\ function\ of\ (2H, \xi) \\ a_{iner} \cdot 2H + b_{iner} & with\ a_{iner}, b_{iner}\ function\ of\ (droop, \xi) \\ a_\xi \cdot \xi + b_\xi & with\ a_\xi, b_\xi\ function\ of\ (droop, 2H) \end{cases}$$

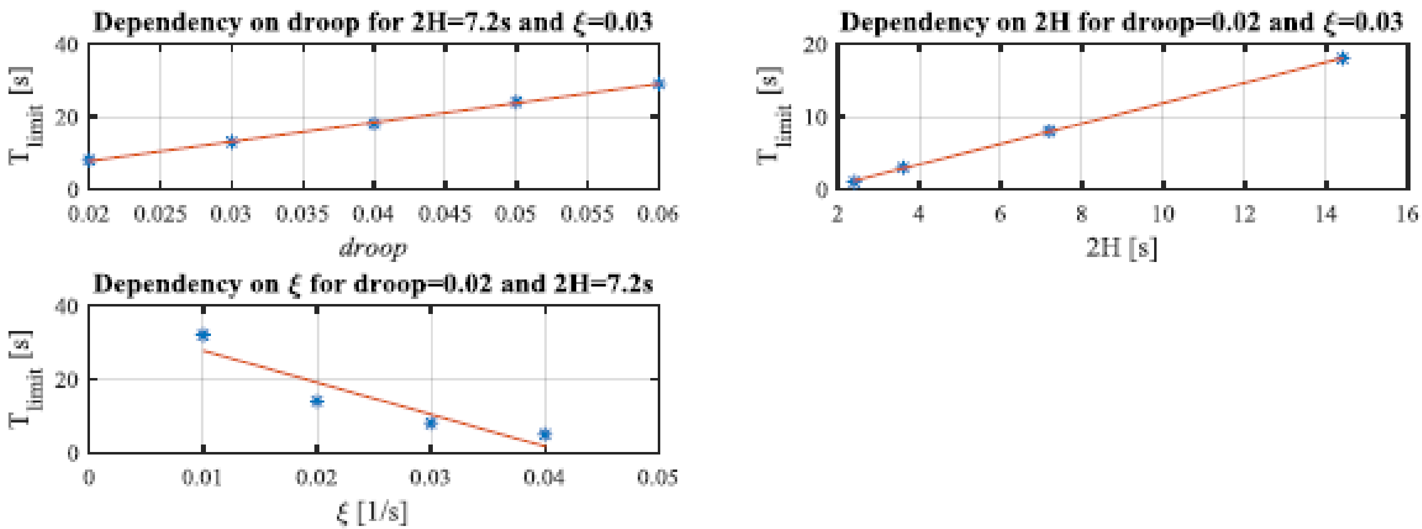


Fig. 6. Dependency of the limit time T_{limit} for different system parameters. It can be noticed that the approximation to a first-order equation for the dependency of the three parameters causes a relatively small error in the calculation of T_{limit}.

TABLE 2. COEFFICIENTS TO CALCULATE T_{LIMIT} AS FUNCTION OF *droop*

		2H [s]			
		2.4	3.6	7.2	14.4
ξ [s^{-1}]	0.01	a = 570 ; b = -2,2	a = 860 ; b = -2,2	a = 1720 ; b = -3	a = 3360 ; b = -2,4
	0.02	a = 270 ; b = -2,4	a = 400 ; b = -2	a = 800 ; b = -2	a = 1710 ; b = -5,4
	0.03	a = 170 ; b = -2,4	a = 250 ; b = -2,2	**a = 530 ; b = -2,8**	a = 1000 ; b = -2
	0.04	a = 111 ; b = -2,12	a = 164 ; b = -1,9	a = 360 ; b = -2,4	a = 720 ; b = -2,8

TABLE 3. COEFFICIENTS TO CALCULATE T_{LIMIT} AS FUNCTION OF THE SYSTEM INERTIA *2H*

		droop				
		0.02	0.03	0.04	0.05	0.06
ξ [s^{-1}]	0.01	a = 4.74 ; b = -2.20	a = 6.89 ; b = -1.29	a = 9.08 ; b = -0.66	a = 11.67 ; b = -1.55	a = 13.96 ; b = -0.81
	0.02	a = 2.24 ; b = -2.20	a = 3.25 ; b = -1.66	a = 4.48 ; b = -2.40	a = 5.74 ; b = -2.88	a = 7.01 ; b = -3.37
	0.03	**a = 1.41 ; b = -2.20**	a = 2.10 ; b = -2.26	a = 2.81 ; b = -2.40	a = 3.31 ; b = -2.23	a = 4.17 ; b = -1.77
	0.04	a = 0.98 ; b = -2.12	a = 1.39 ; b = -2.02	a = 1.98 ; b = -2.40	a = 2.59 ; b = -3.12	a = 2.94 ; b = -2.26

TABLE 4. COEFFICIENTS TO CALCULATE T_{LIMIT} AS FUNCTION OF ξ

		droop				
		0.02	0.03	0.04	0.05	0.06
2H [s]	2.4	a = -281 ; b = 10.35	a = -441 ; b = 17.35	a = -610 ; b = 24	a = -740 ; b = 30	a = 870 ; b = 36.5
	3.6	a = -441 ; b = 17.35	a = -680 ; b = 27.5	a = -870 ; b = 36.5	a = -1100 ; b = 46	a = -1350 ; b = 57
	7.2	**a = -870 ; b = 36.5**	a = -1290 ; b = 55	a = -1710 ; b = 74	a = -2180 ; b = 95	a = -2600 ; b = 113.5
	14.4	a = -1740 ; b = 75	a = -2570 ; b = 111.5	a = -3360 ; b = 148	a = -4280 ; b = 189	a = -5200 ; b = 229