Robust Primary Frequency Control in Stand-alone Microgrids with High Penetration of Renewable Energy : Synthesis and Robustness Analysis

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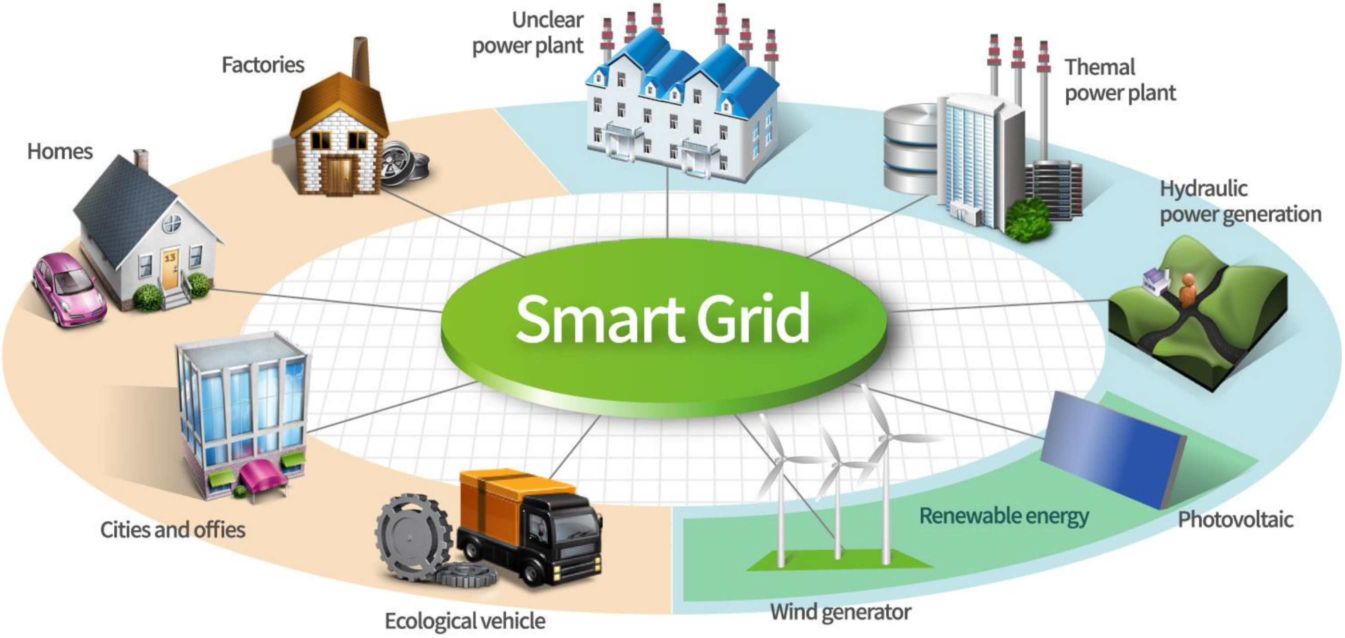
Outline

- Context of the study
- Microgrid description, coordinated strategy & choice of energy storage technology
- Modeling & design for H_∞ control
- Robustness analysis
- Numerical simulation results
- Conclusions & future work

Concept of microgrids

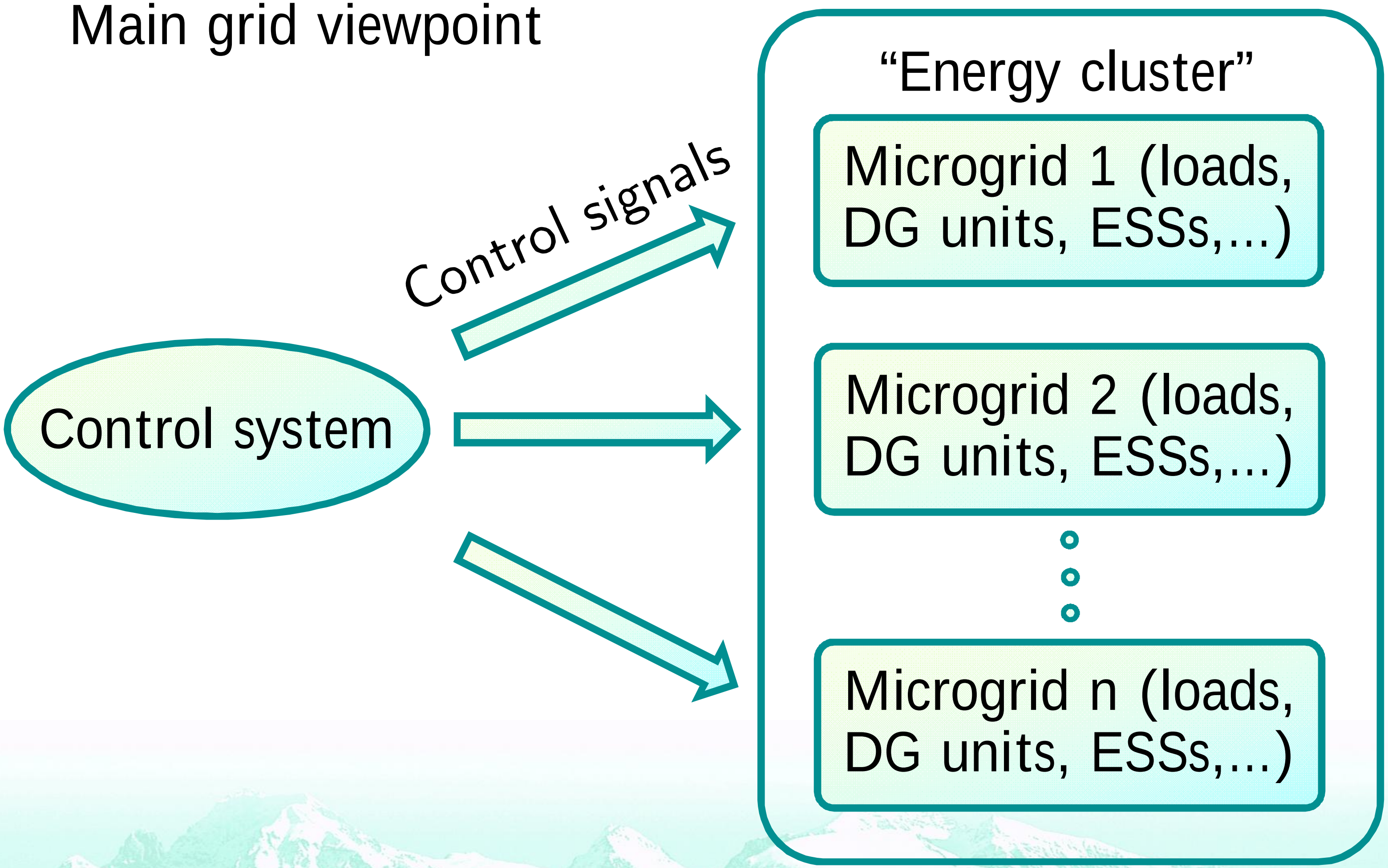
- Integrating distributed energy resources into power systems
- Global reliability to be enhanced, reduction of carbon footprint, all with smaller investment costs



An example of microgrids. Source : http://www.naonworks.com

Reliable operation of microgrids

- Design of special protection schemes & control systems
- Main grid viewpoint



Control system

Control signals

“Energy cluster”

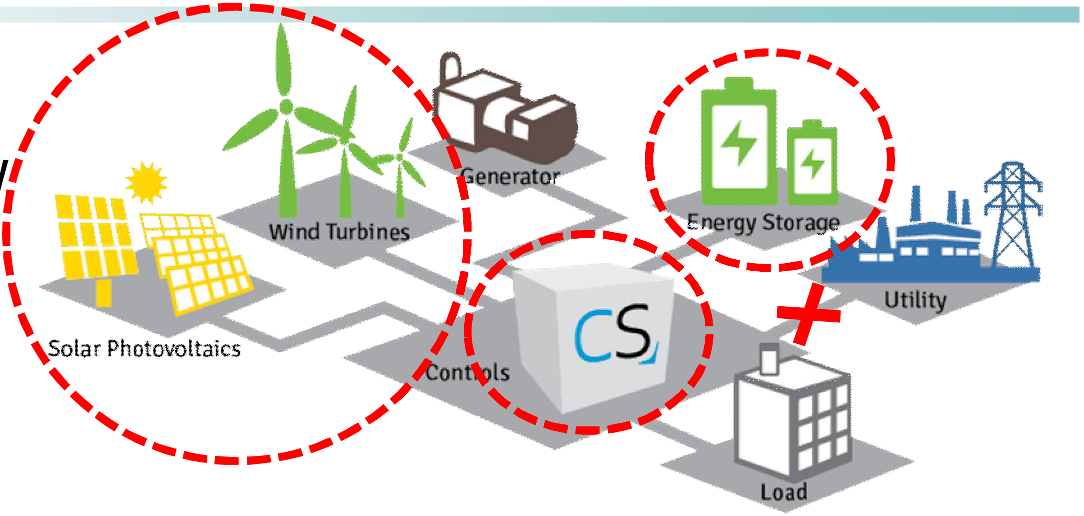
Microgrid 1 (loads, DG units, ESSs,...)

Microgrid 2 (loads, DG units, ESSs,...)

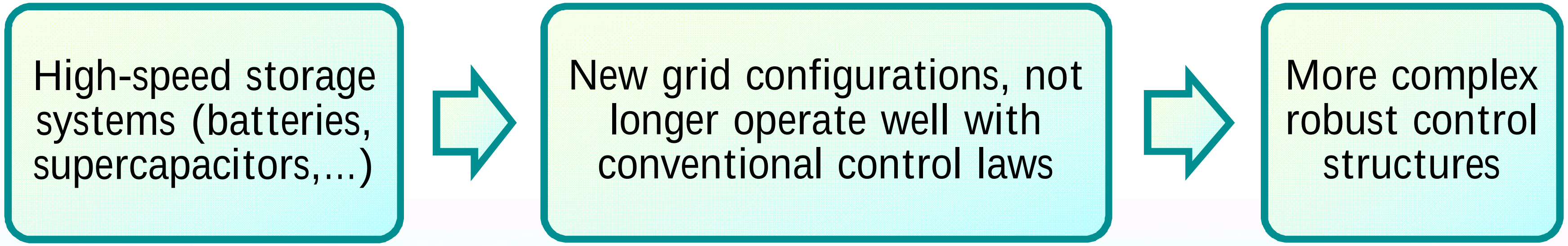
Microgrid n (loads, DG units, ESSs,...)

Main control challenges

- Stability issues
- Problems related to low inertia & uncertainties due to presence of RES
- Stand-alone mode of operation : frequency & voltage deviations within a small range are required



Microgrid. Source : http://www.cleanspark.com



High-speed storage systems (batteries, supercapacitors,...) ⇨ New grid configurations, not longer operate well with conventional control laws ⇨ More complex robust control structures

Control methods

- Proportional-integral-derivative (PID) control : limited possibility to ensure satisfactory trade-off among dynamic performances
- Fuzzy logic control : difficult to obtain a model serving for a systematic control design
- H_∞ control : able to handle multiple requirements in a systematic manner

Frequency stability problem of microgrids

- Frequency stability problem of microgrids with a high rate of decentralized, renewable and intermittent production
- Role of storage units
  - ➢ Fast dynamics, capacity to provide power peaks
  - ➢ Reducing frequency deviation
- Research work
  - ➢ Systematic design procedure for computing a multi-variable H_∞ robust controller for primary frequency regulation
  - ➢ How closed-loop operation demands must at their turn be taken into account in the initial microgrid setup & sizing

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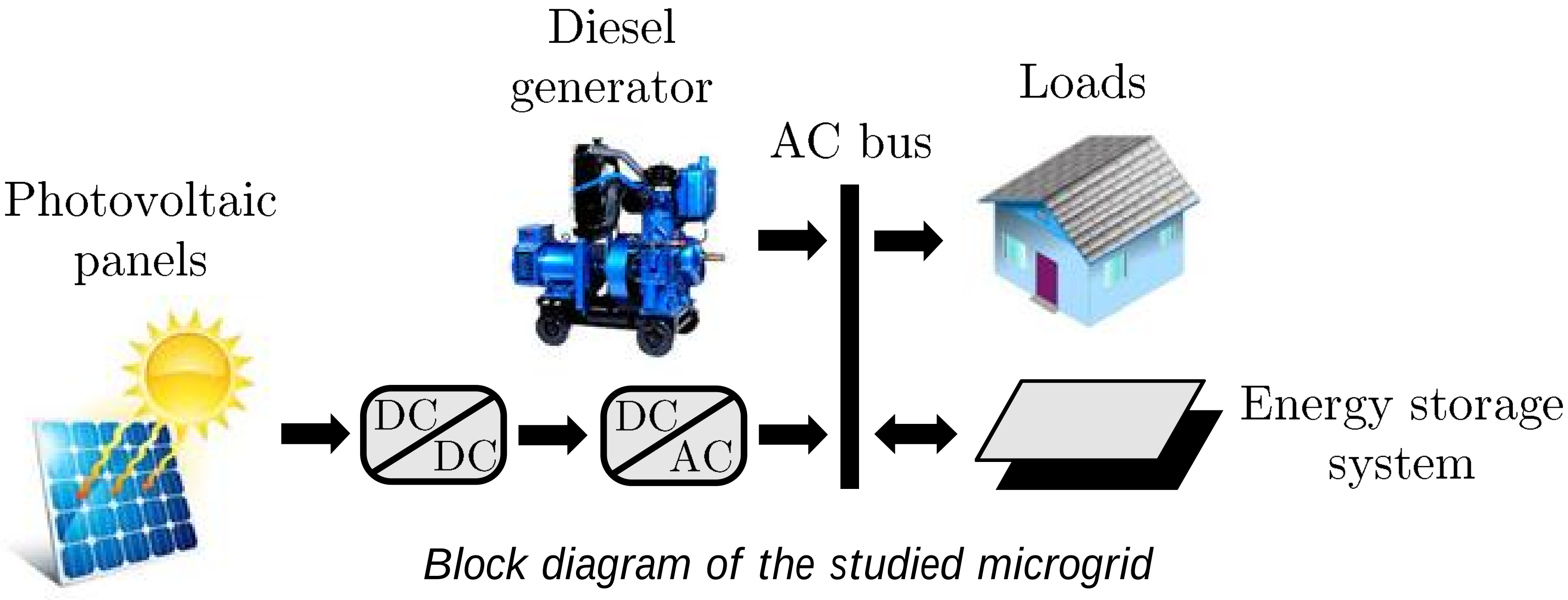
Microgrid description

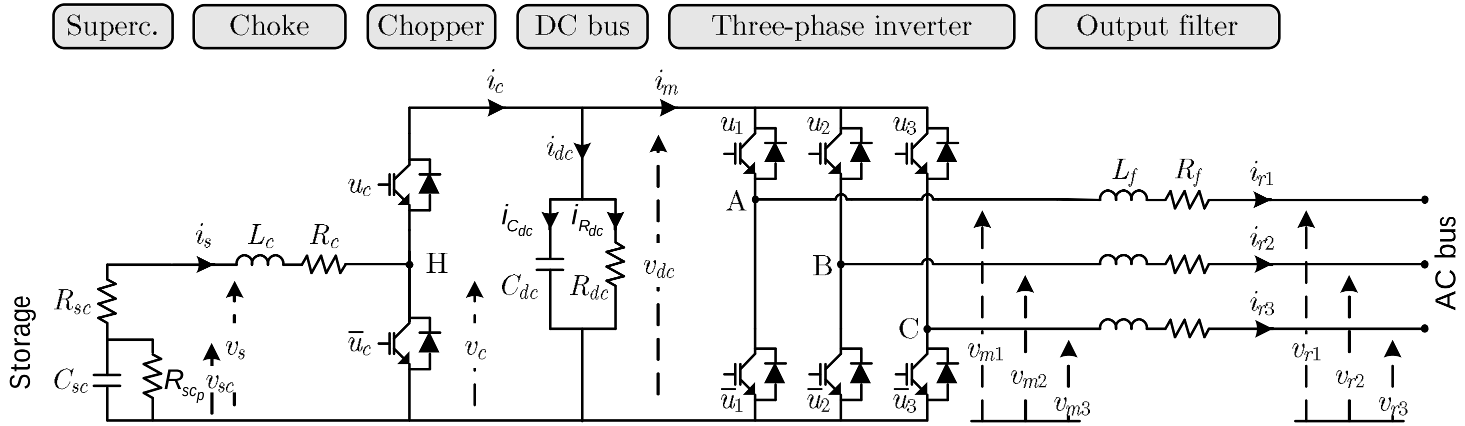
- Operating in stand-alone mode



Block diagram of the studied microgrid

Microgrid description

- Energy storage system



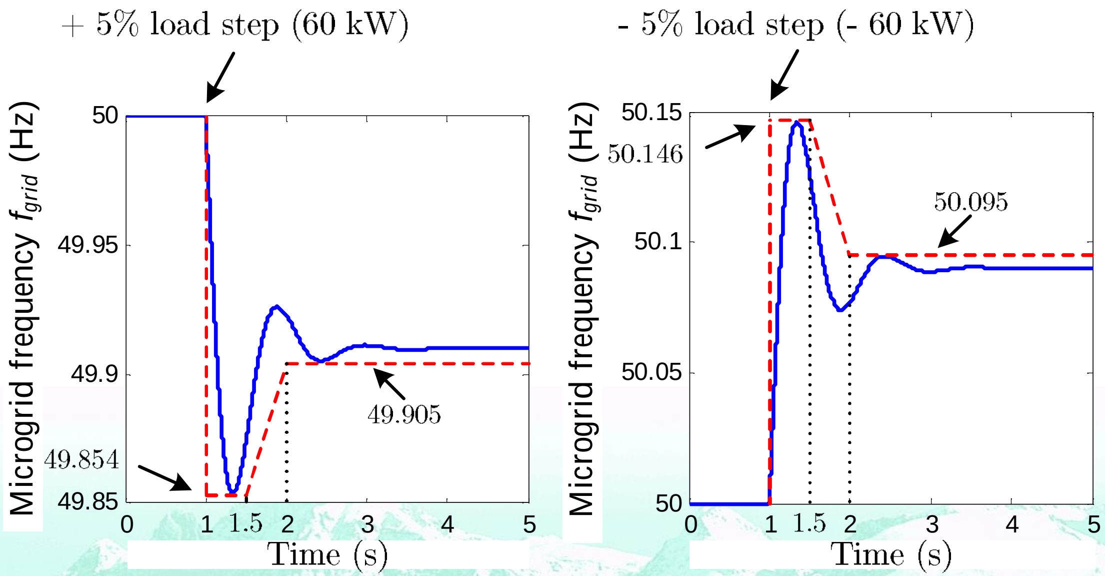
Full electrical scheme of the energy storage system

- Equation expressing the microgrid frequency deviation

$$\frac{\underline{d\Delta f_{grid}}}{dt} = \frac{1}{2\underline{H}}\left[\underline{i_{s_e}}\,\underline{\Delta v_{sc}} + \left(\underline{v_{sc_e}} - 2\underline{R_{sc}}\,\underline{i_{s_e}}\right)\underline{\Delta i_s} + \underline{\Delta P_{diesel}} - \underline{\Delta P_{load}}\right] - \frac{\underline{D_{load}}}{2\underline{H}}\underline{\Delta f_{grid}}(\Delta P_{PV} = 0)$$

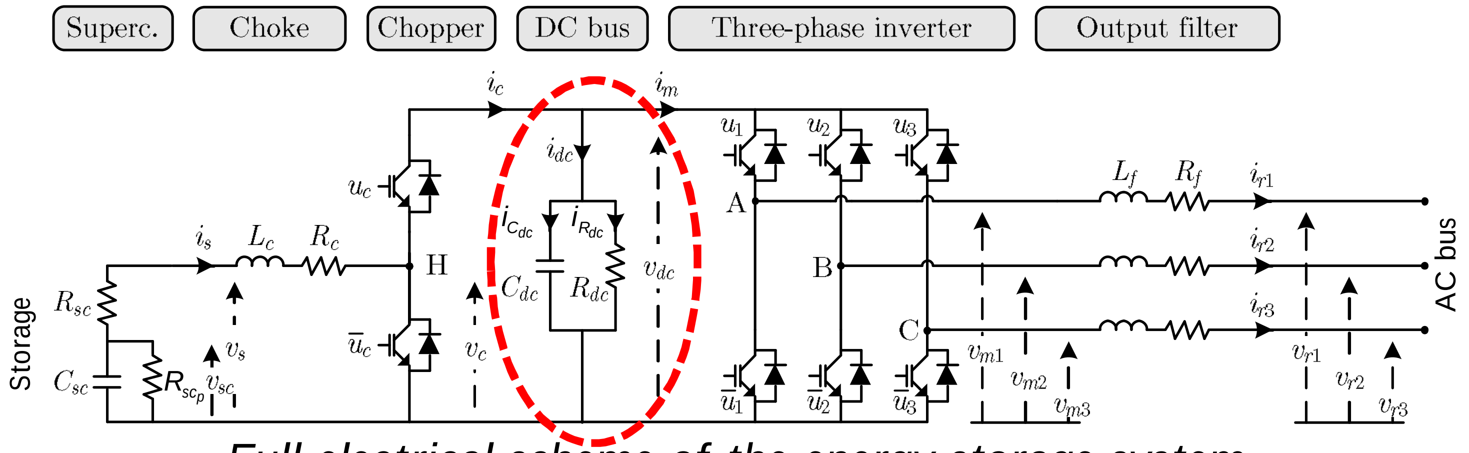
Coordinated strategy

- Proposed coordinated strategy : participation of both the storage system & the diesel generator in primary frequency control
- Role of the storage system : to improve dynamic performances in case of disturbances
- Template for the frequency variation



Performance specification on the microgrid frequency variation in response to a load step of ± 5% of the rated load power (± 60 kW) in the time domain

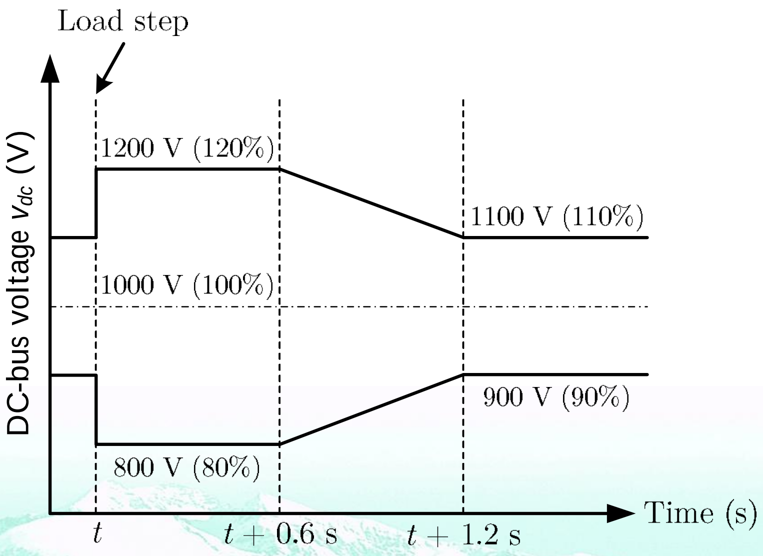
Coordinated strategy



Full electrical scheme of the energy storage system

- Another control objective : to regulate the DC-bus voltage v_{dc} at the desired value of 1000 V

Performance specification on the DC-bus voltage variation in response to a load step in the time domain



Choice of energy storage technology

- Diesel power variation in the frequency domain

$$\underline{\Delta P_{diesel}}(s) = -\underbrace{\frac{1}{T_{diesel}s + 1}}_{\text{Simplified dynamic modeling}} \underbrace{\left(\underline{K_p} + \frac{\underline{K_i}}{s}\right)}_{\text{PI controller for frequency control}} \underline{\Delta f_{grid}}(s), \qquad \underline{K_p} = \frac{1}{\underline{s_{diesel}}}$$

- Frequency deviation in the frequency domain without storage device

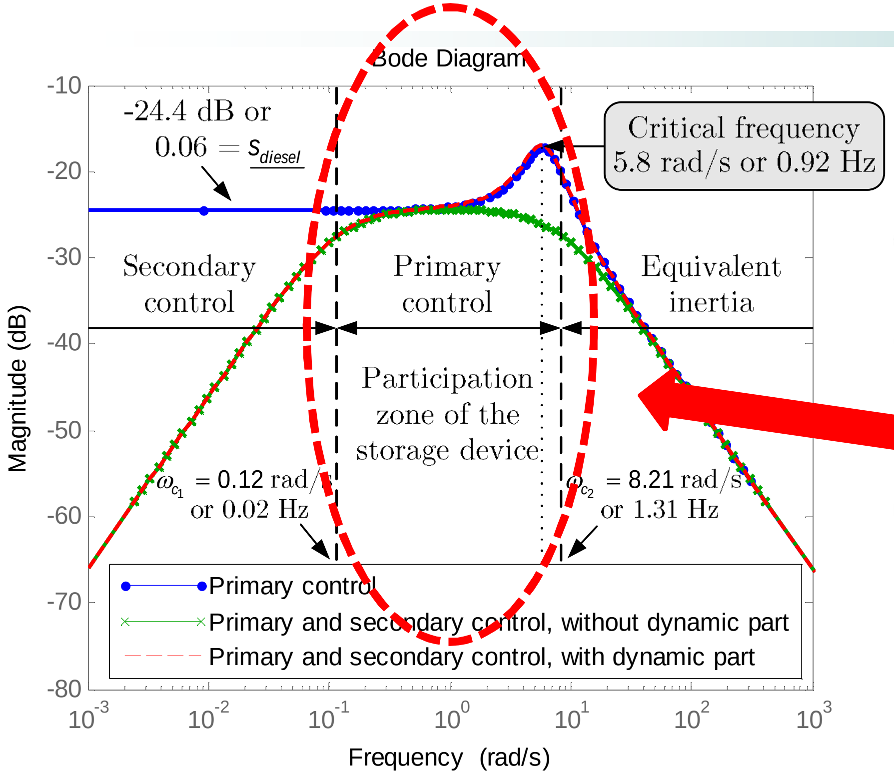
$$\underline{\Delta f_{grid}}(s) = \frac{1}{2\underline{H}s + \underline{D_{load}}}\left[\underline{\Delta P_{diesel}}(s) + \underline{\Delta P_{PV}}(s) - \underline{\Delta P_{load}}(s)\right]$$

$$\underline{\Delta P_{diff}}(s) = \underline{\Delta P_{PV}}(s) - \underline{\Delta P_{load}}(s)$$

- Transfer function between frequency deviation & power variation

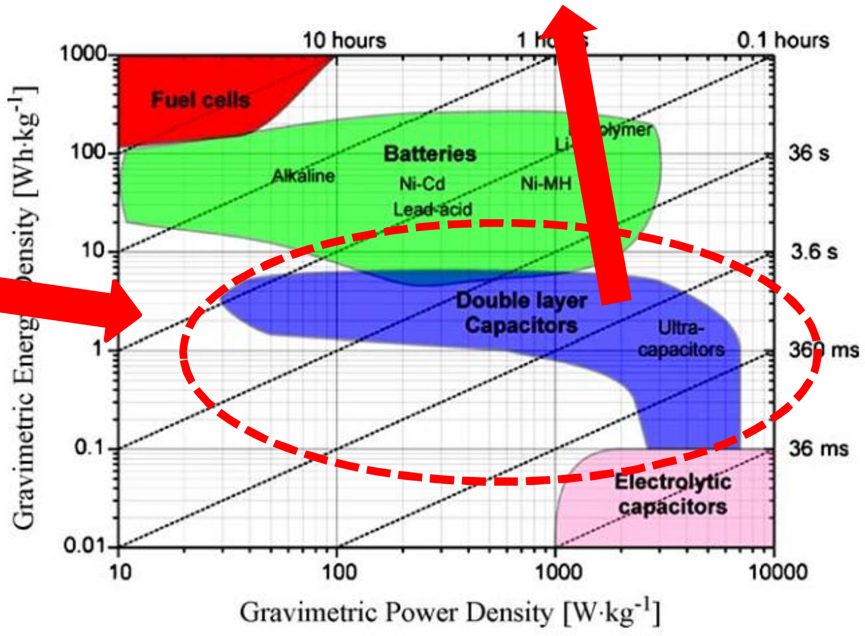
$$\boxed{\frac{\underline{\Delta f_{grid}}(s)}{\underline{\Delta P_{diff}}(s)} = \frac{(T_{diesel}s + 1)s}{(2\underline{H}T_{diesel})s^3 + \left(2\underline{H} + T_{diesel}\underline{D_{load}}\right)s^2 + \left(\underline{D_{load}} + \underline{K_p}\right)s + \underline{K_i}}}$$

Choice of energy storage technology



Bode diagram of the transfer function of the system

Supercapacitor



Ragone plot

- Selected frequency interval $f_c \in$ [0.02, 1.31] Hz for primary control participation of the storage device. Supercapacitor storage technology with its own frequency $f_p \in$ [0.00278, 27.78] Hz is the most appropriate

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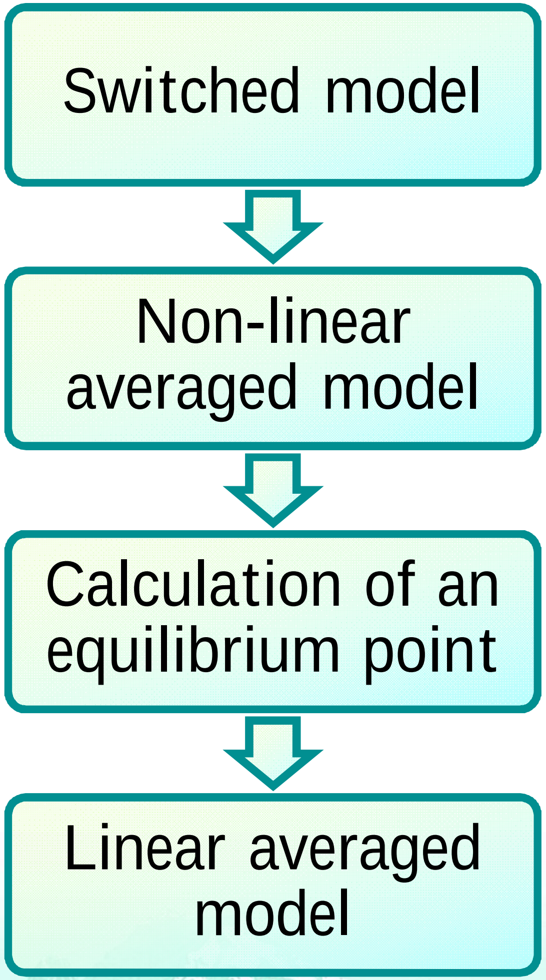
Modeling for H_∞ control

- Modeling methodology



Switched model

Non-linear averaged model

Calculation of an equilibrium point

Linear averaged model

- Per-unitization system
  - Base values for AC-side quantities

$$v_{d,b} = v_{q,b} = v_b = \sqrt{3}v_r = v_{rd}$$

$$i_{d,b} = i_{q,b} = i_b = \frac{S_b}{v_b}$$

$$Z_b = \frac{v_b}{i_b}, C_b = \frac{1}{Z_b\omega_b}, L_b = \frac{Z_b}{\omega_b}$$

$$\omega_b = \omega_0 = \omega_{grid_e}, f_b = f_0 = f_{grid_e}$$

  - Base values for DC-side quantities

$$v_{b-dc} = v_b, i_{b-dc} = \frac{S_b}{v_{b-dc}} = i_b$$

$$Z_{b-dc} = \frac{v_{b-dc}}{i_{b-dc}} = Z_b, C_{b-dc} = \frac{1}{Z_{b-dc}\omega_b} = C_b$$

$$L_{b-dc} = \frac{Z_{b-dc}}{\omega_b} = L_b$$

Modeling for H_∞ control

- Linear averaged model of the storage system in a per-unit term

~~$\frac{1}{\omega_b}\frac{d\underline{\Delta v_{sc}}}{dt} = \frac{1}{\underline{C_{sc}}}\underline{\Delta i_s} - \frac{1}{\underline{R_{sc_p}}\,\underline{C_{sc}}}\underline{\Delta v_{sc}}$~~

$$\frac{1}{\omega_b}\frac{d\underline{\Delta v_{dc}}}{dt} = \frac{1}{\underline{C_{dc}}}\alpha_{c_e}\underline{\Delta i_s} + \frac{1}{\underline{C_{dc}}}\underline{i_{s_e}}\Delta\alpha_c - \frac{1}{\underline{C_{dc}}}\left(\beta_{d_e}\underline{\Delta i_{rd}} + \underline{i_{rd_e}}\Delta\beta_d + \beta_{q_e}\underline{\Delta i_{rq}} + \underline{i_{rq_e}}\Delta\beta_q\right) - \frac{1}{\underline{R_{dc}C_{dc}}}\underline{\Delta v_{dc}}$$

$$\frac{1}{\omega_b}\frac{d\underline{\Delta i_s}}{dt} = \frac{1}{\underline{L_c}}\underline{\Delta v_{sc}} - \frac{\underline{R_{sc}} + \underline{R_c}}{\underline{L_c}}\underline{\Delta i_s} - \frac{1}{\underline{L_c}}\alpha_{c_e}\underline{\Delta v_{dc}} - \frac{1}{\underline{L_c}}\underline{v_{dc_e}}\Delta\alpha_c$$

$$\frac{1}{\omega_b}\frac{d\underline{\Delta i_{rd}}}{dt} = \frac{1}{\underline{L_f}}\beta_{d_e}\underline{\Delta v_{dc}} + \frac{1}{\underline{L_f}}\underline{v_{dc_e}}\Delta\beta_d - \frac{\underline{R_f}}{\underline{L_f}}\underline{\Delta i_{rd}} + \underline{\omega_{grid_e}}\underline{\Delta i_{rq}} + \underline{i_{rq_e}}\underline{\Delta\omega_{grid}}$$

$$\frac{1}{\omega_b}\frac{d\underline{\Delta i_{rq}}}{dt} = \frac{1}{\underline{L_f}}\beta_{q_e}\underline{\Delta v_{dc}} + \frac{1}{\underline{L_f}}\underline{v_{dc_e}}\Delta\beta_q - \frac{\underline{R_f}}{\underline{L_f}}\underline{\Delta i_{rq}} - \underline{\omega_{grid_e}}\underline{\Delta i_{rd}} - \underline{i_{rd_e}}\underline{\Delta\omega_{grid}}$$

Modeling for H_∞ control

- Power variation of diesel generation in the time domain for only primary control participation

$$\frac{d\underline{\Delta P_{diesel}}}{dt} = -\frac{1}{T_{diesel}}\underline{\Delta P_{diesel}} - \frac{1}{T_{diesel}\underline{S_{diesel}}}\underline{\Delta f_{grid}}$$

- Linear averaged model in the state-space form for H_∞ control

$$\boxed{\begin{cases} \underline{\Delta \dot{\mathbf{x}}} = \mathbf{A}\underline{\Delta \mathbf{x}} + \mathbf{B_1}\underline{\Delta \mathbf{u}} + \mathbf{B_2}\underline{\Delta \mathbf{w}} \\ \underline{\Delta \mathbf{y}} = \mathbf{C}\underline{\Delta \mathbf{x}} + \mathbf{D_1}\underline{\Delta \mathbf{u}} + \mathbf{D_2}\underline{\Delta \mathbf{w}} \end{cases}}$$

$\underline{\Delta \mathbf{x}} = \left[\cancel{\underline{\Delta i_{dc}}}\ \ \underline{\Delta v_{dc}}\ \ \underline{\Delta P_{diesel}}\ \ \underline{\Delta f_{grid}}\right]^T$: state vector

$\underline{\Delta \mathbf{u}} = \left[\underline{\Delta i_s^{ref}}\ \ \underline{\Delta i_{rd}^{ref}}\right]^T$: control input vector ($\Delta i_{rq}^{ref} = 0$)

$\underline{\Delta \mathbf{w}} = \underline{\Delta P_{load}}$: disturbance input

$\underline{\Delta \mathbf{y}} = \left[\cancel{\underline{\Delta i_{dc}}}\ \ \underline{\Delta v_{dc}}\ \ \underline{\Delta f_{grid}}\right]^T$: measured output vector

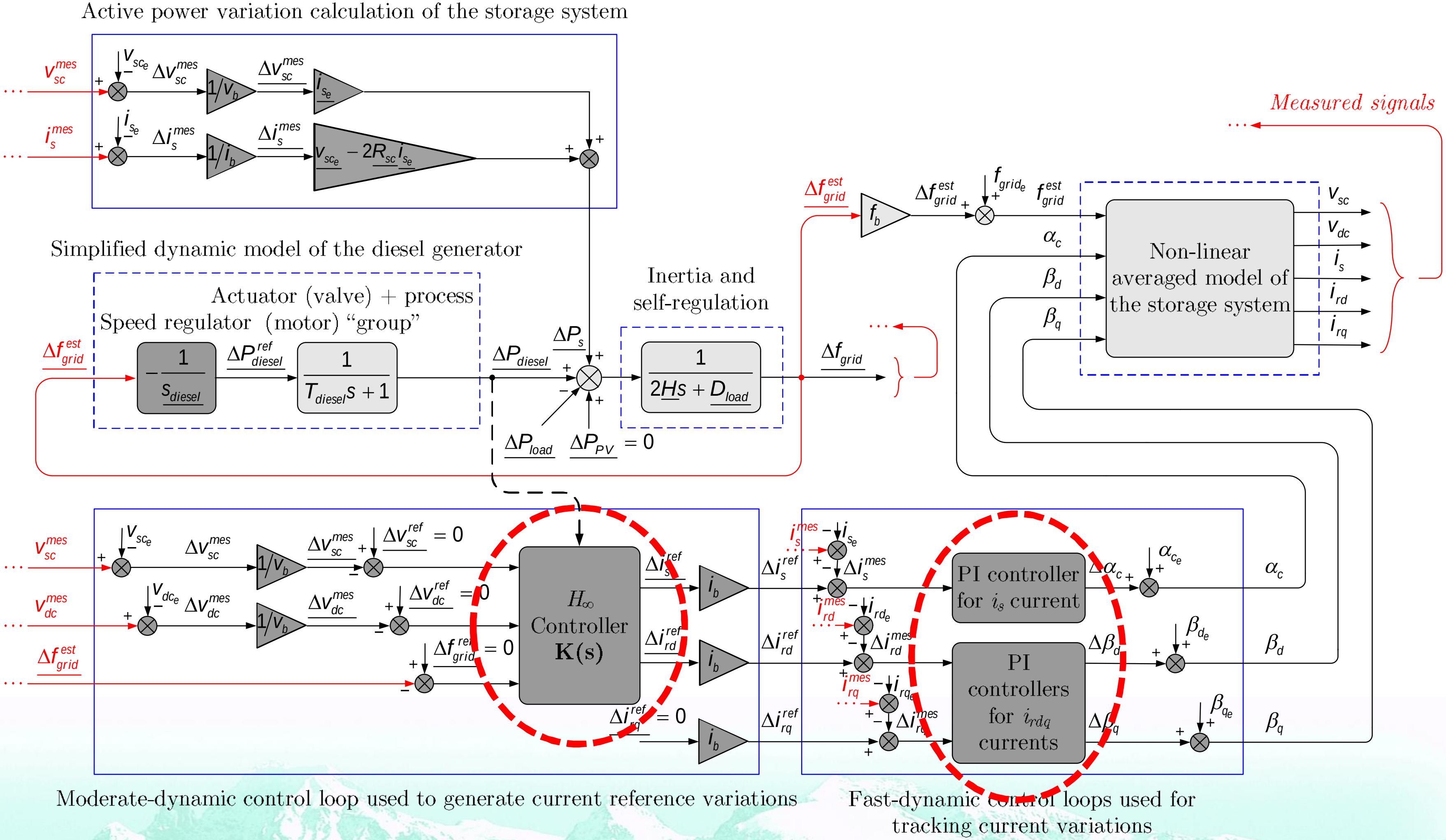
Modeling for H_∞ control

$$\mathbf{A} = \begin{bmatrix} \cancel{\frac{\omega_b}{R_{sc_p}C_{sc}}} & \cancel{0} & \cancel{0} & \cancel{0} \\ \cancel{0} & -\frac{\omega_b}{R_{dc}C_{dc}} & 0 & 0 \\ \cancel{0} & 0 & -\frac{1}{T_{diesel}} & -\frac{1}{T_{diesel}s_{diesel}} \\ \cancel{\frac{1}{2H}i_{s_e}} & 0 & \frac{1}{2H} & -\frac{D_{load}}{2H} \end{bmatrix} \qquad \mathbf{B_1} = \begin{bmatrix} \cancel{\frac{\omega_b}{C_{sc}}} & \cancel{0} \\ \frac{\omega_b}{C_{dc}}\alpha_{c_e} & -\frac{\omega_b}{C_{dc}}\beta_{d_e} \\ 0 & 0 \\ \frac{1}{2H}\left(v_{sc_e} - 2R_{sc}i_{s_e}\right) & 0 \end{bmatrix}$$

$$\mathbf{B_2} = \begin{bmatrix} \cancel{0} \\ 0 \\ 0 \\ -\frac{1}{2H} \end{bmatrix} \qquad \mathbf{C} = \begin{bmatrix} \cancel{1} & \cancel{0} & \cancel{0} & \cancel{0} \\ \cancel{0} & 1 & 0 & 0 \\ \cancel{0} & 0 & 0 & 1 \end{bmatrix} \qquad \mathbf{D_1} = \begin{bmatrix} \cancel{0} & \cancel{0} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \qquad \mathbf{D_2} = \begin{bmatrix} \cancel{0} \\ 0 \\ 0 \end{bmatrix}$$

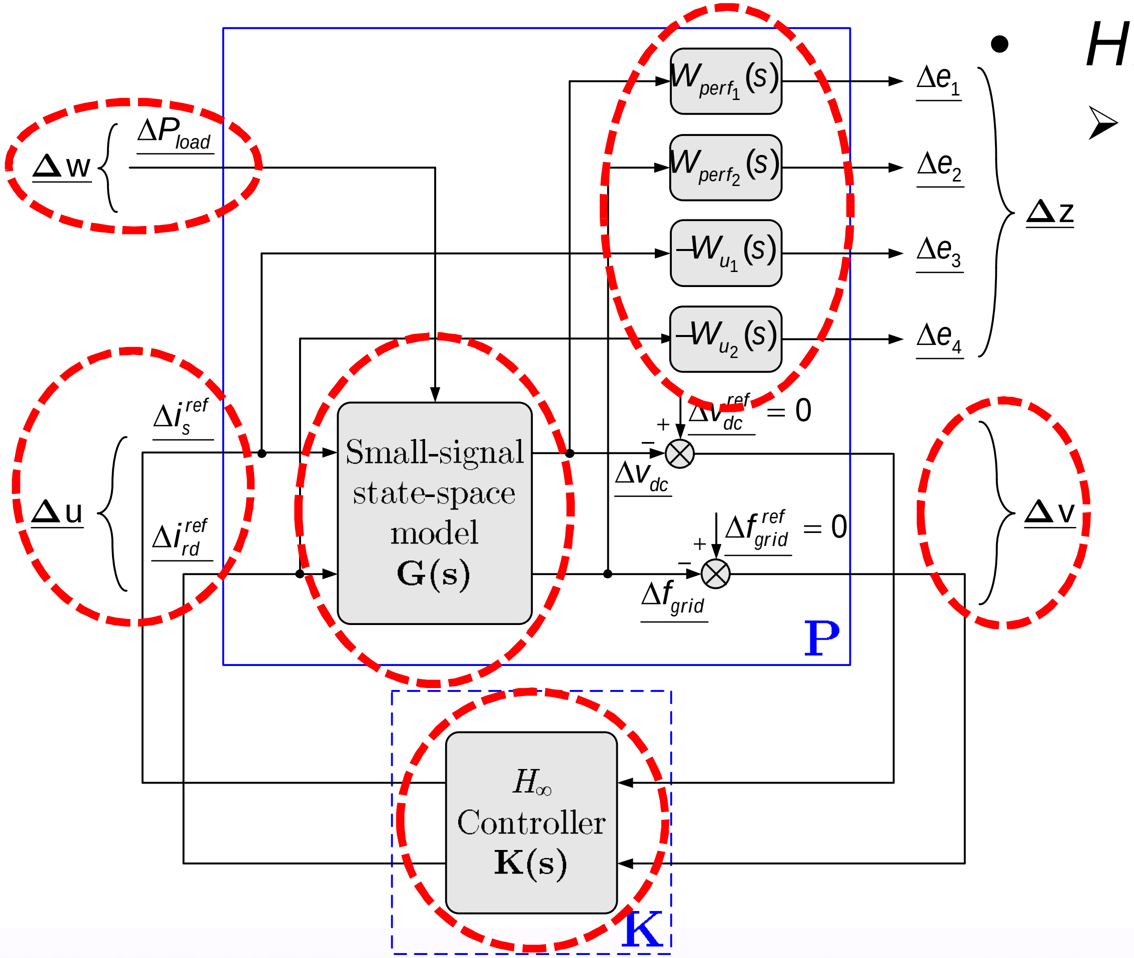
H_∞ control design

- Proposed global control structure



Block diagram of the proposed global control structure

H_∞ control design



- H_∞ control level
  - Model associated with H_∞ control
    - ✓ Plant "$\mathbf{P}$"
      - Linear state-space model $\mathbf{G}(s)$
      - Weighting functions
    - ✓ H_∞ controller $\mathbf{K}(s)$
    - ✓ Control inputs

      $$\underline{\Delta\mathbf{u}} = \left[\underline{\Delta i_s^{ref}} \;\; \underline{\Delta i_{rd}^{ref}}\right]^T$$

    - ✓ Disturbance input

      $$\underline{\Delta\mathbf{w}} = \underline{\Delta P_{load}}$$

    - ✓ Measured outputs

      $$\underline{\Delta\mathbf{y}} = \left[\underline{\Delta v_{dc}} \;\; \underline{\Delta f_{grid}}\right]^T$$

Control configuration in the so-called $\mathbf{P}-\mathbf{K}$ *form*

H_∞ control design

- Weighting function selection
  - ✓ DC-bus voltage variation $\underline{\Delta v_{dc}}$ & frequency variation $\underline{\Delta f_{grid}}$ are bounded by first-order weighting functions

$$\boxed{\frac{1}{W_{perf}(s)} = \frac{s+\omega_b A_\varepsilon}{s/M_s+\omega_b}}$$

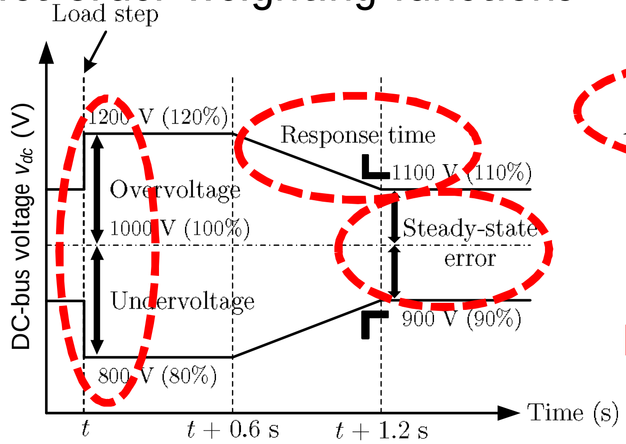
M_s : limitation of the overshoot
ω_b : the desired response time
A_ε : limitation of the steady-state error

$$M_{s_1} = \frac{\Delta v_{dc_{max}}}{\underline{\Delta P_{load}}}, A_{\varepsilon_1} = \frac{\Delta v_{dc_{min}}}{\underline{\Delta P_{load}}}$$

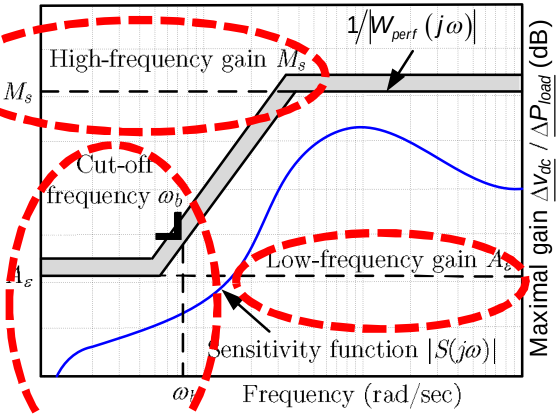
$$\omega_{b_1} = 1/\left(40T_{0_{rdq}}\right)\left(t_{r_1} \approx 1.2\ \text{s}\right)$$

$$M_{s_2} = \frac{\Delta f_{grid_{max}}}{\underline{\Delta P_{load}}}, A_{\varepsilon_2} = \frac{\Delta f_{grid_{min}}}{\underline{\Delta P_{load}}}$$

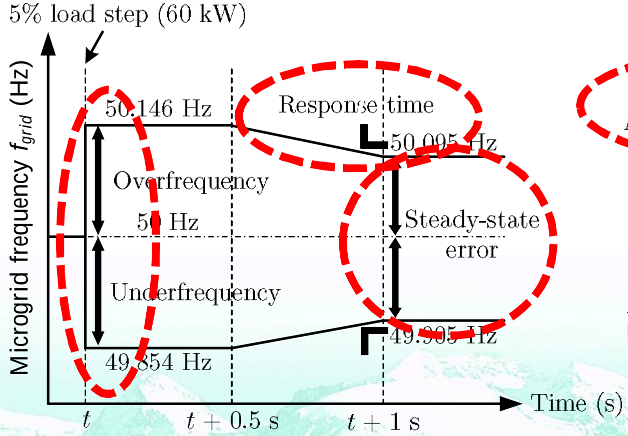
$$\omega_{b_2} = 1/\left(20T_{0_{rdq}}\right)\left(t_{r_2} \approx 0.6\ \text{s}\right)$$



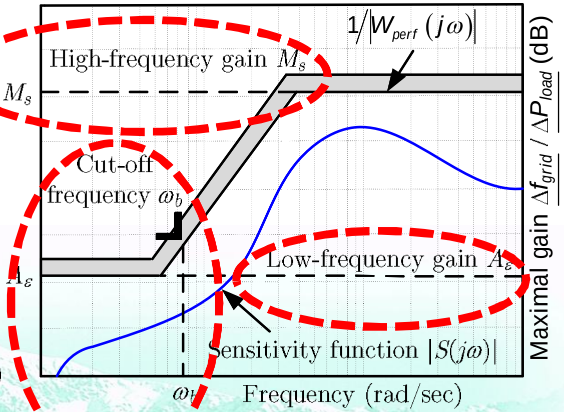
Performance specification on the DC-bus voltage variation



Performance template $1/W_{perf}(s)$



Performance specification on the microgrid frequency variation



Performance template $1/W_{perf}(s)$

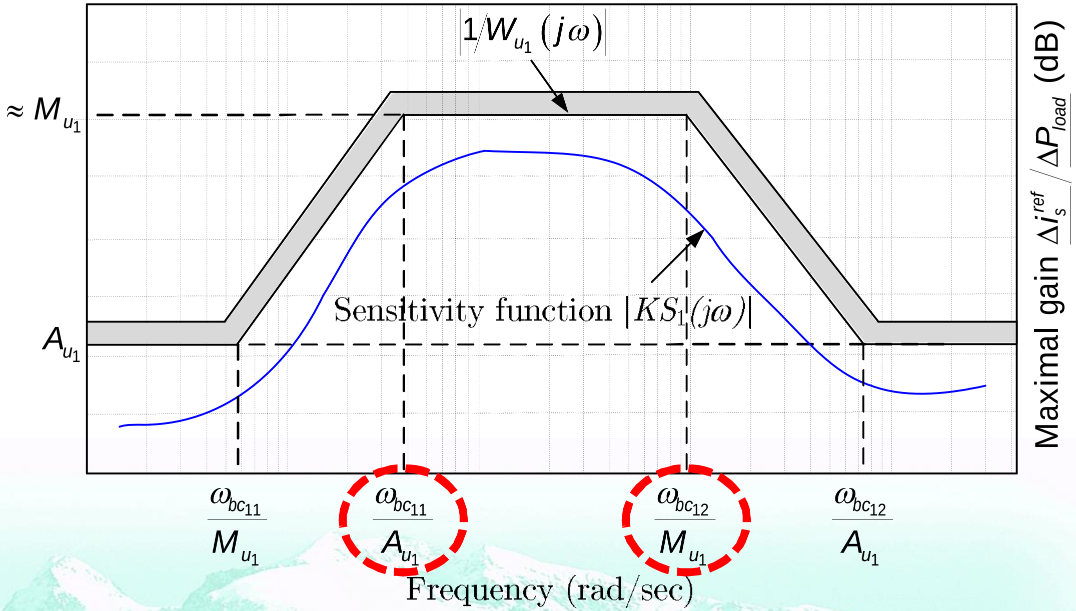
H_∞ control design

✓ Active power injection or absorption of the storage system is controlled via i_s. Storage device current reference variation $\underline{\Delta i_s^{ref}}$ is bounded by a band-pass weighting function

$$\frac{1}{W_{u_1}(s)} = A_{u_1}\frac{\left(\frac{M_{u_1}}{\omega_{bc_{11}}}s+1\right)\left(\frac{A_{u_1}}{\omega_{bc_{12}}}s+1\right)}{\left(\frac{A_{u_1}}{\omega_{bc_{11}}}s+1\right)\left(\frac{M_{u_1}}{\omega_{bc_{12}}}s+1\right)},\ \frac{\omega_{bc_{11}}}{A_{u_1}} < \frac{\omega_{bc_{12}}}{M_{u_1}}$$

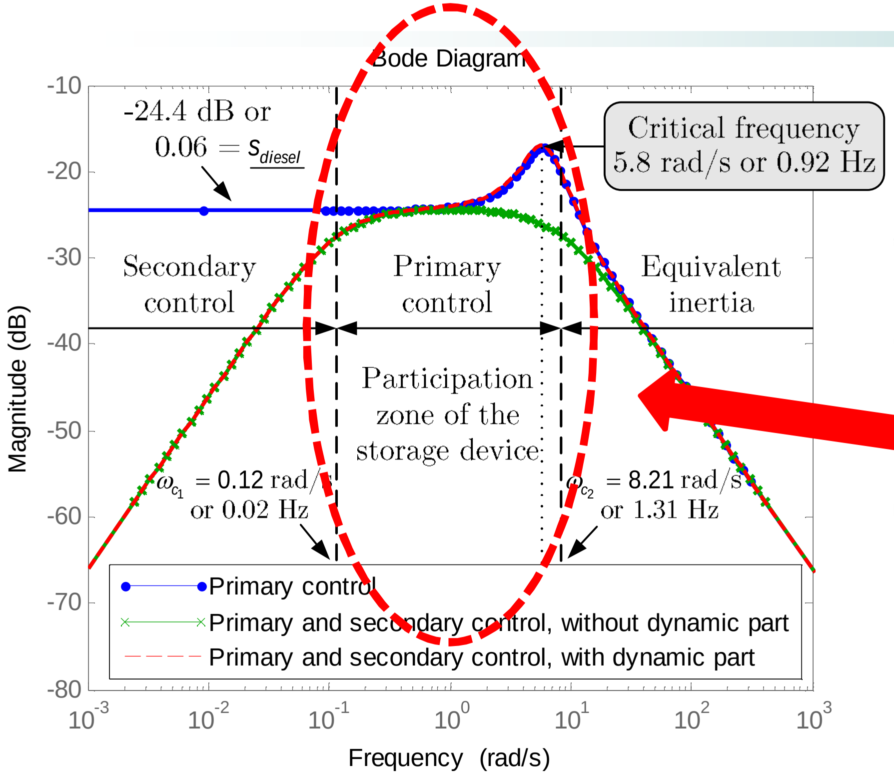
$$M_{u_1} = \frac{\Delta i_{s_{max}}}{\Delta P_{load}} = \frac{i_{s_{max}} - i_{s_e}}{\Delta P_{load}},\ A_{u_1} = 0.1 M_{u_1}$$

Choice of $\frac{\omega_{bc_{11}}}{A_{u_1}}$ & $\frac{\omega_{bc_{12}}}{M_{u_1}}$: based on the own frequency of the selected supercapacitor technology & participation zone of the storage device in primary frequency control

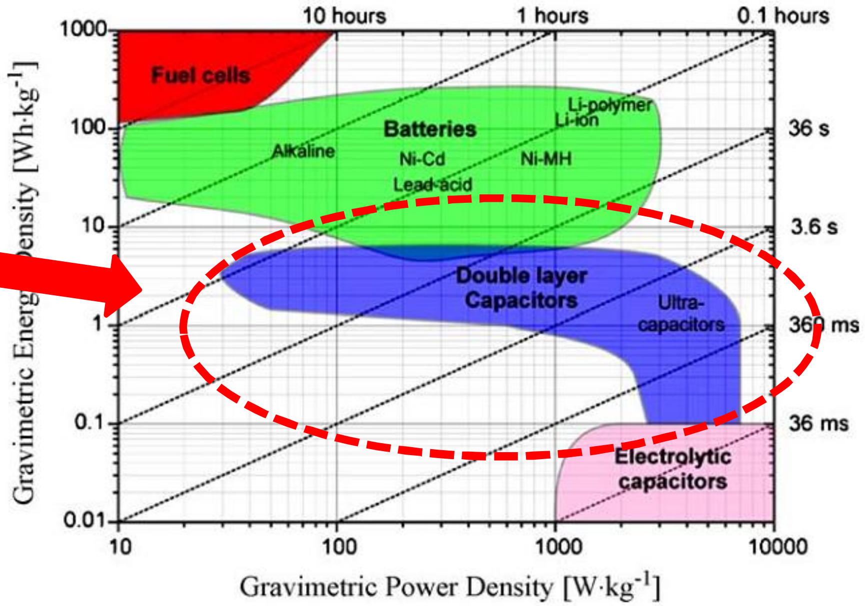


Performance template $1/W_{u_1}(s)$

H_∞ control design



Bode diagram of the transfer function of the system



Ragone plot

Selected frequency interval for primary control participation : $f_c \in [0.02, 1.31]$ Hz (or $\omega_c \in [0.12, 8.21]$ rad/s)

$$\frac{\omega_{bc_{11}}}{A_{u_1}} = 0.12 \div 174.55, \qquad \frac{\omega_{bc_{12}}}{M_{u_1}} = 0.12 \div 174.55$$

Own frequency of supercapacitor technology : $f_p \in [0.00278, 27.78]$ Hz (or $\omega_p \in [0.0175, 174.55]$ rad/s)

Own frequency of the selected supercapacitor technology : $f_p = 0.48$ Hz (or $\omega_p = 3.04$ rad/s)

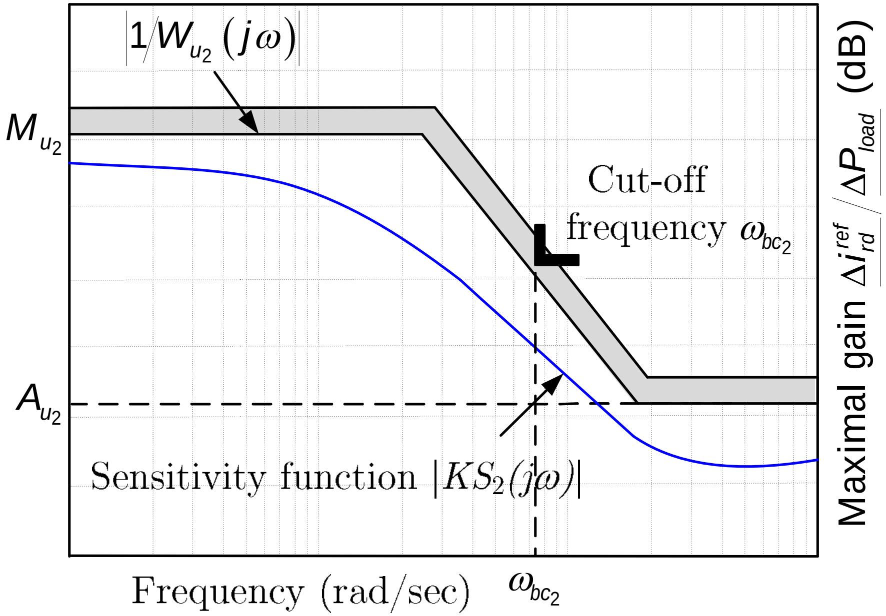
H_∞ control design

- ✓ DC-bus voltage is regulated via i_{rd}. The inverter output current reference variation in d-axis $\underline{\Delta i_{rd}^{ref}}$ is bounded by the first-order weighting function

$$\boxed{\frac{1}{W_{u_2}(s)} = \frac{A_{u_2}s + \omega_{bc_2}}{s + \omega_{bc_2}/M_{u_2}}}$$

$$M_{u_2} = \frac{\underline{\underline{\Delta i_{rd_{max}}}}}{\underline{\Delta P_{load}}} = \frac{\underline{\underline{i_{rd_{max}} - i_{rd_e}}}}{\underline{\Delta P_{load}}}, A_{u_2} = 0.1M_{u_2}$$

$\omega_{bc_2} = 1/(100T_{s_i})$, where $T_{s_i} = 1/f_{s_i}$, f_{s_i} is the inverter switching frequency



Performance template $1/W_{u_2}(s)$

H_∞ control design

- H_∞ controller synthesis
  - ✓ "hinfsyn" function
  - ✓ Minimization of the norm

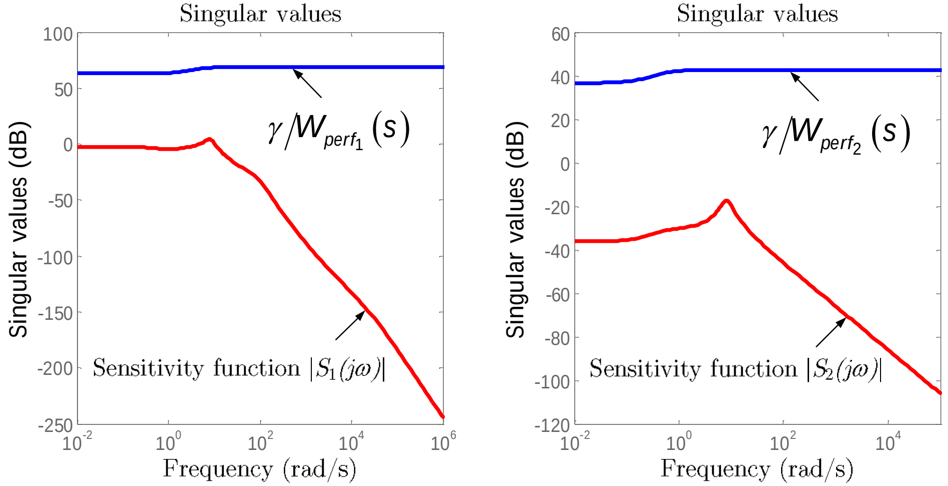
$$\left\| \begin{matrix} W_{perf} S \\ W_u KS \end{matrix} \right\|_\infty < \boxed{\gamma}$$

S/*KS* mixed-sensitivity optimization must typically be solved

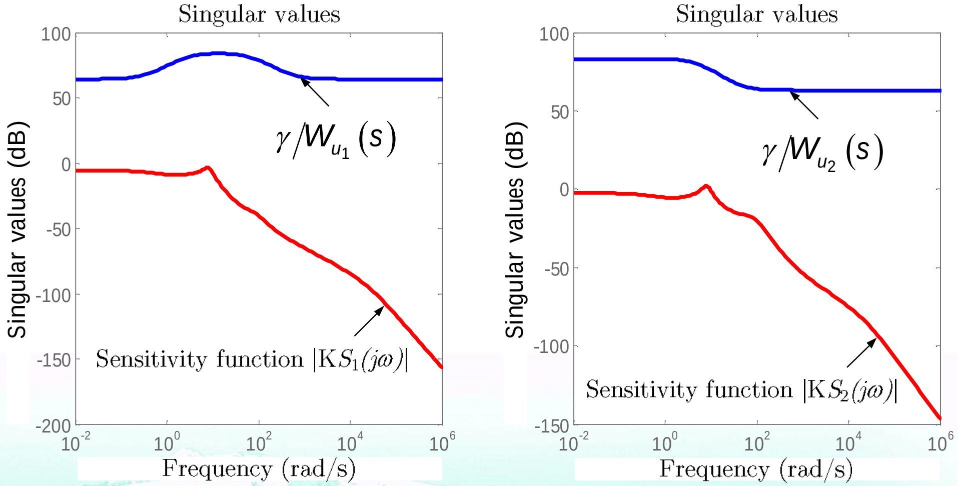
  - ✓ Sensitivity functions

$$S_1 = \frac{\Delta v_{dc}}{\Delta P_{load}}, S_2 = \frac{\Delta f_{grid}}{\Delta P_{load}}$$

$$KS_1 = \frac{\Delta i_s^{ref}}{\Delta P_{load}}, KS_2 = \frac{\Delta i_{rd}^{ref}}{\Delta P_{load}}$$



Sensitivity functions S and corresponding templates



Sensitivity functions KS and corresponding templates

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Configuration for robustness analysis

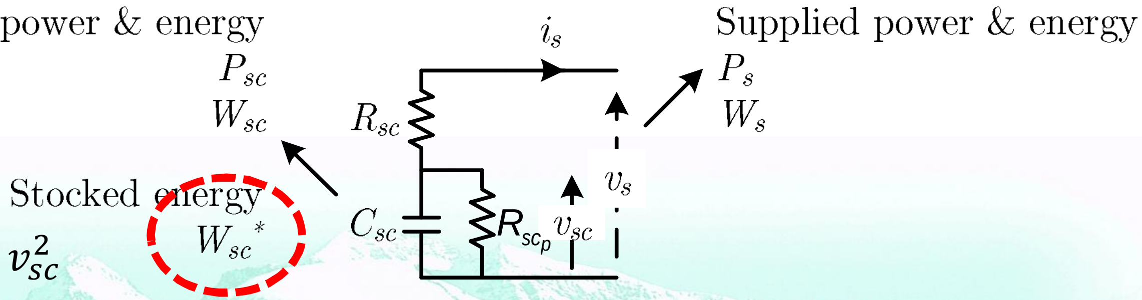
$$\mathbf{A} = \begin{bmatrix} \cancel{\frac{\omega_b}{R_{sc_p} C_{sc}}} & \cancel{0} & \cancel{0} & \cancel{0} \\ \cancel{0} & -\frac{\omega_b}{R_{dc} C_{dc}} & 0 & 0 \\ \cancel{0} & 0 & -\frac{1}{T_{diesel}} & -\frac{1}{T_{diesel} s_{diesel}} \\ \cancel{\frac{1}{2H} i_{s_e}} & 0 & \frac{1}{2H} & -\frac{D_{load}}{2H} \end{bmatrix} \qquad \mathbf{B_1} = \begin{bmatrix} \cancel{\frac{\omega_b}{C_{sc}}} & \cancel{0} \\ \frac{\omega_b}{C_{dc}} \alpha_{c_e} & -\frac{\omega_b}{C_{dc}} \beta_{d_e} \\ 0 & 0 \\ \frac{1}{2H} \left(v_{sc_e} - 2 R_{sc} i_{s_e} \right) & 0 \end{bmatrix}$$

Parametric uncertainty

$$\mathbf{B_2} = \begin{bmatrix} \cancel{0} \\ 0 \\ 0 \\ -\frac{1}{2H} \end{bmatrix} \quad \mathbf{C} = \begin{bmatrix} \cancel{1} & \cancel{0} & \cancel{0} & \cancel{0} \\ \cancel{0} & 1 & 0 & 0 \\ \cancel{0} & 0 & 0 & 1 \end{bmatrix} \quad \mathbf{D_1} = \begin{bmatrix} \cancel{0} & \cancel{0} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \quad \mathbf{D_2} = \begin{bmatrix} \cancel{0} \\ 0 \\ 0 \end{bmatrix}$$

$$W_{sc}^* = \frac{1}{2} C_{sc} v_{sc}^2, W_{sc_{max}}^* = \frac{1}{2} C_{sc} v_{sc_{max}}^2$$

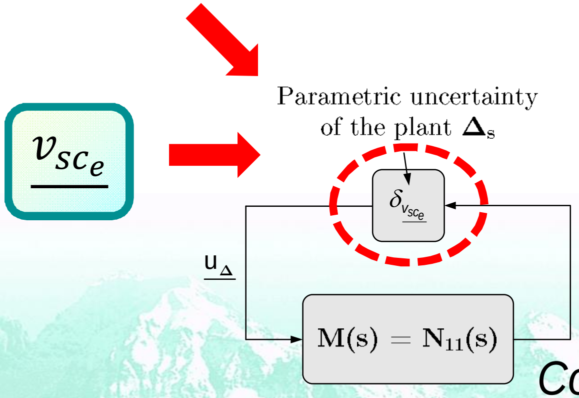
$$SoC = \frac{W_{sc}^*}{W_{sc_{max}}^*} = \frac{\frac{1}{2} C_{sc} v_{sc}^2}{\frac{1}{2} C_{sc} v_{sc_{max}}^2} = \frac{1}{v_{sc_{max}}^2} v_{sc}^2$$

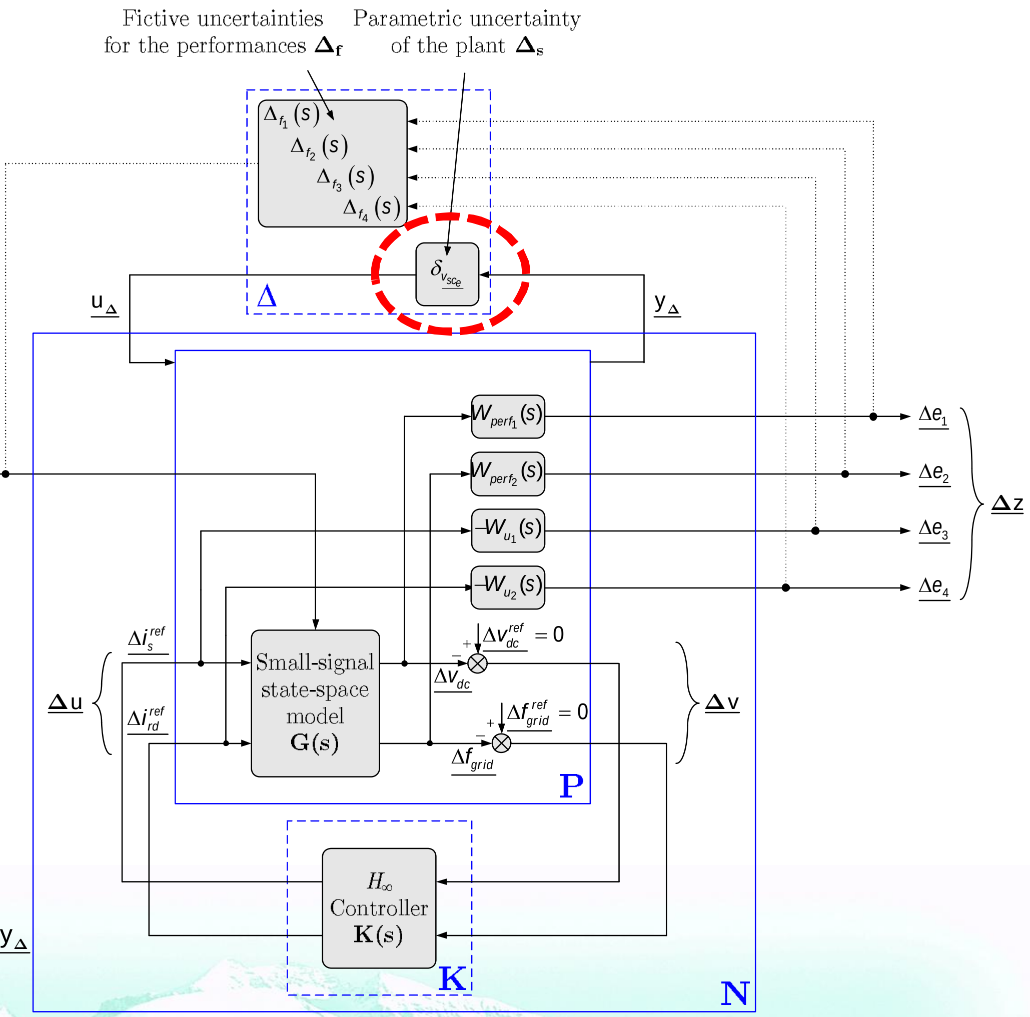


Schematic diagram of the supercapacitor

Configuration for robustness analysis

- Structured singular value (μ-analysis)
- RS & RP : the closed-loop system remains stable and well-performing for a given uncertainty level ?
- Parametric uncertainties taken into account





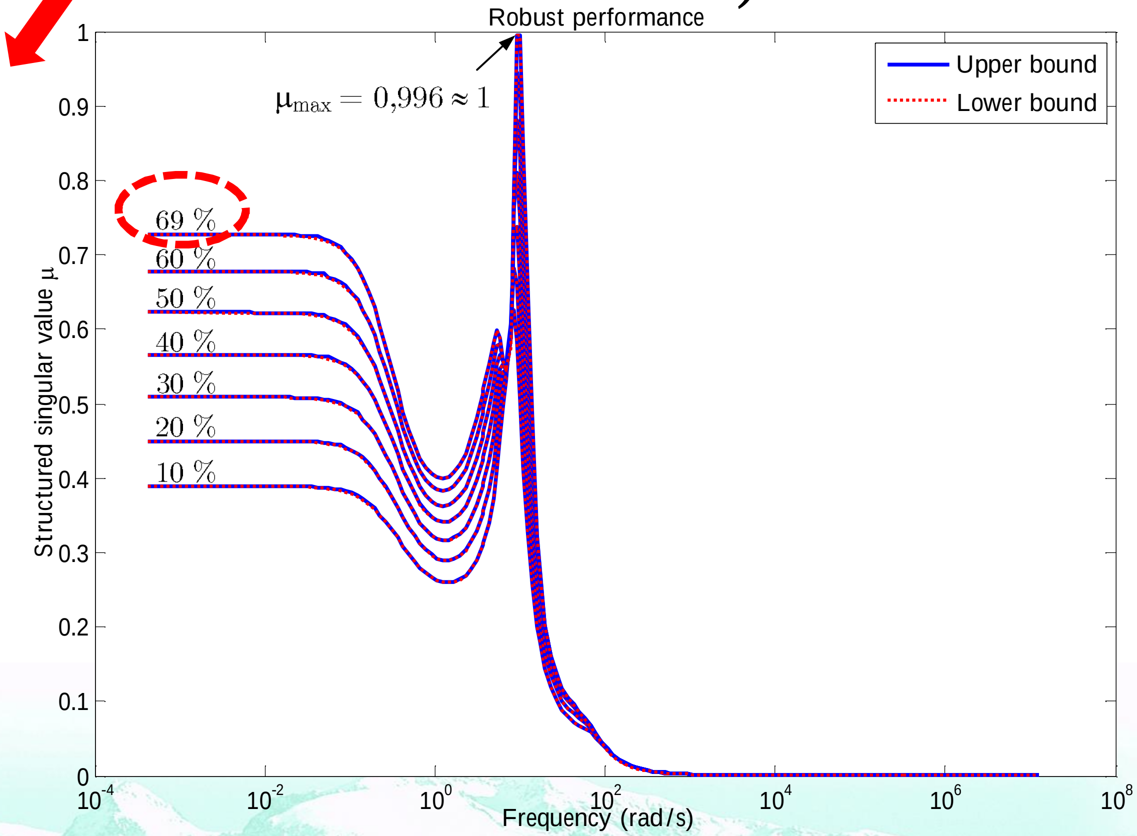
Configuration for robustness analysis

μ-analysis results

- Condition for robust performance $\mu \leq 1$ is verified for the uncertainty of up to ± 69% of the rated value of v_{sc_e} $\left(v_{sc_{e_{rated}}} = 585\ V, or\ SoC_{e_{rated}} = 0.5625\right)$

$v_{sc_e} \in [181.35\ V, 988.65\ V]$

$(SoC_e \in [0.0541, 1.6066])$



Robust performance analysis

Outline

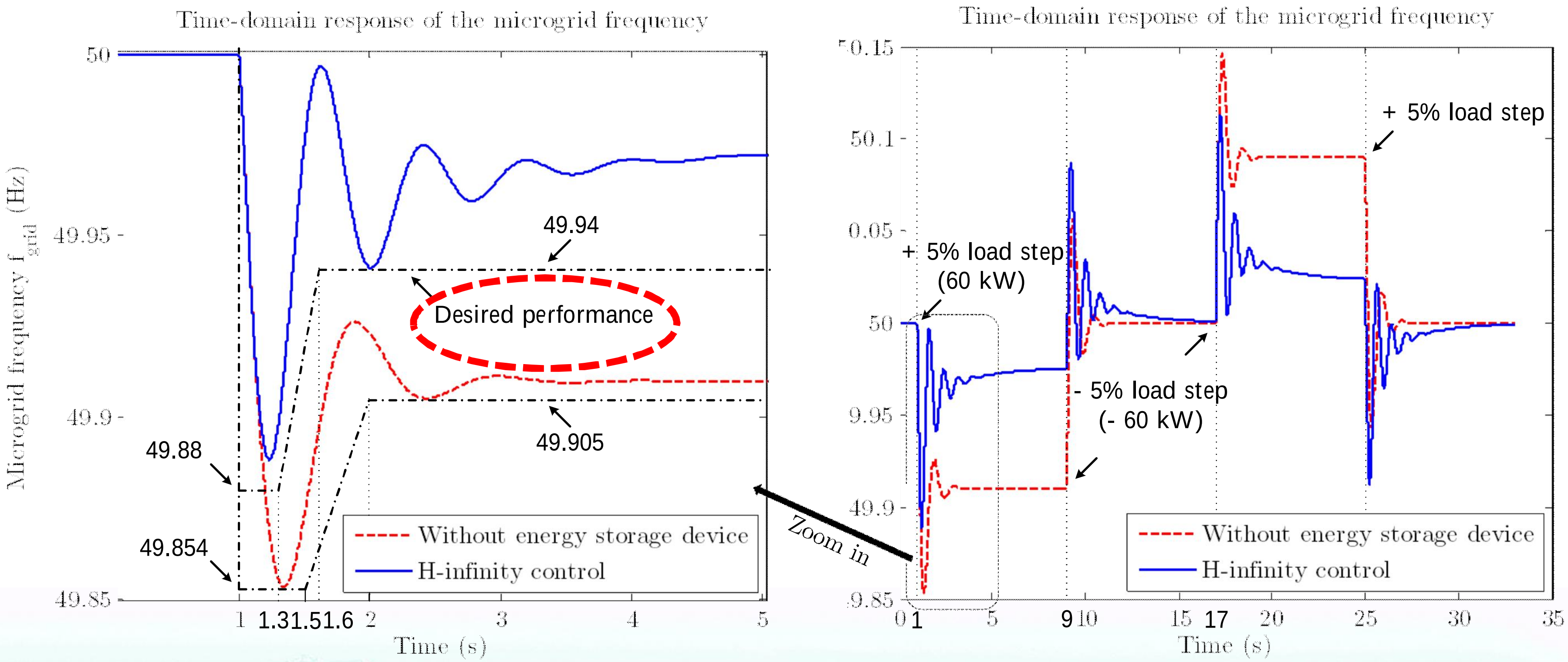
- Context of the study
- Microgrid description, coordinated strategy & choice of energy storage technology
- Modeling & design for H_∞ control
- Robustness analysis
- Numerical simulation results
- Conclusions & future work

Numerical simulation results

- Non-linear averaged model is used for the time-domain simulations
- Taking into account SoC of the supercapacitor (v_{sc} is considered as a state variable) in simulation
- Load profile is varied in step of $+ 5\%$ of the rated load power (60 kW) at $t = 1$ s, $- 5\%$ at $t = 9$ s, $- 5\%$ at $t = 17$ s and $+ 5\%$ at $t = 25$ s

Numerical simulation results

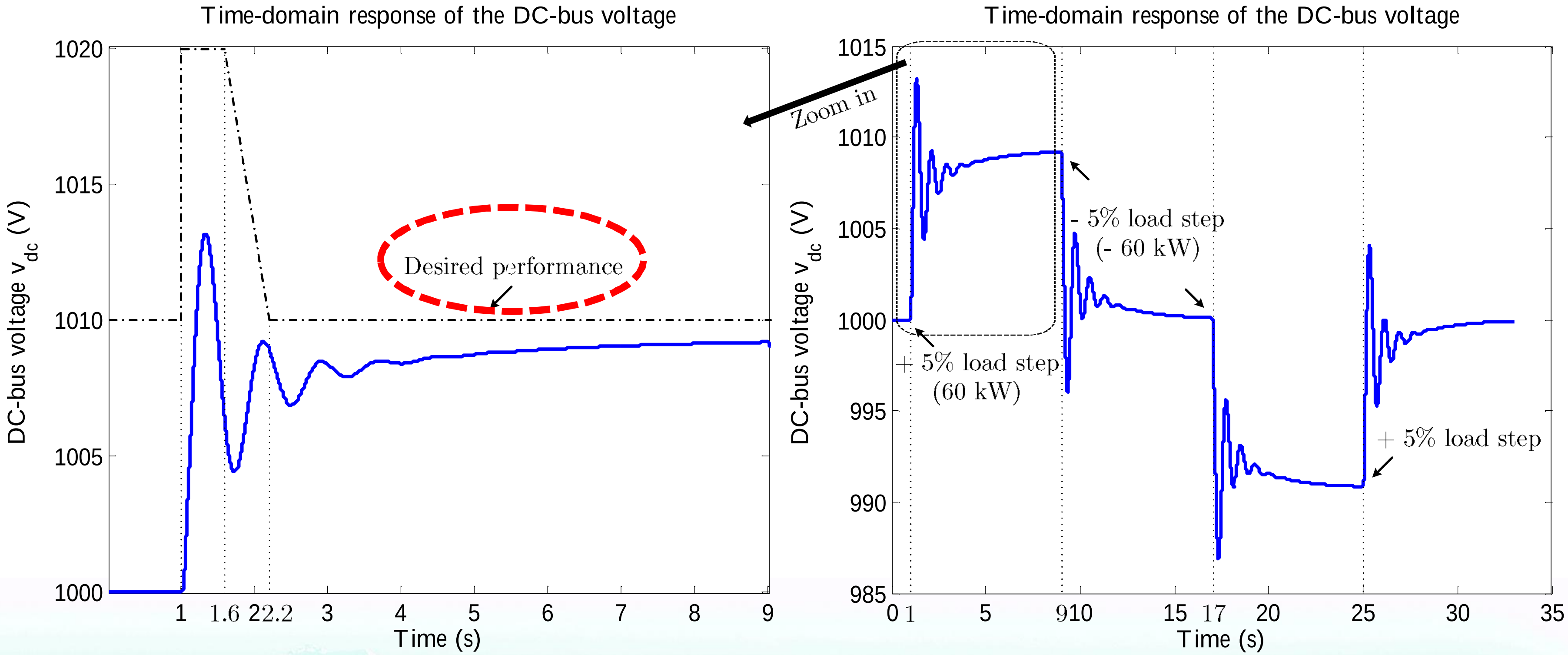
- Desired time-domain performance corresponding to the parameter choice of the weighting function $W_{perf_2}(s)$ is well-respected



Time-domain response of the microgrid frequency f_{grid} under small step load disturbances of ± 5% of the rated load power (± 60 kW) from the rated parameters

Numerical simulation results

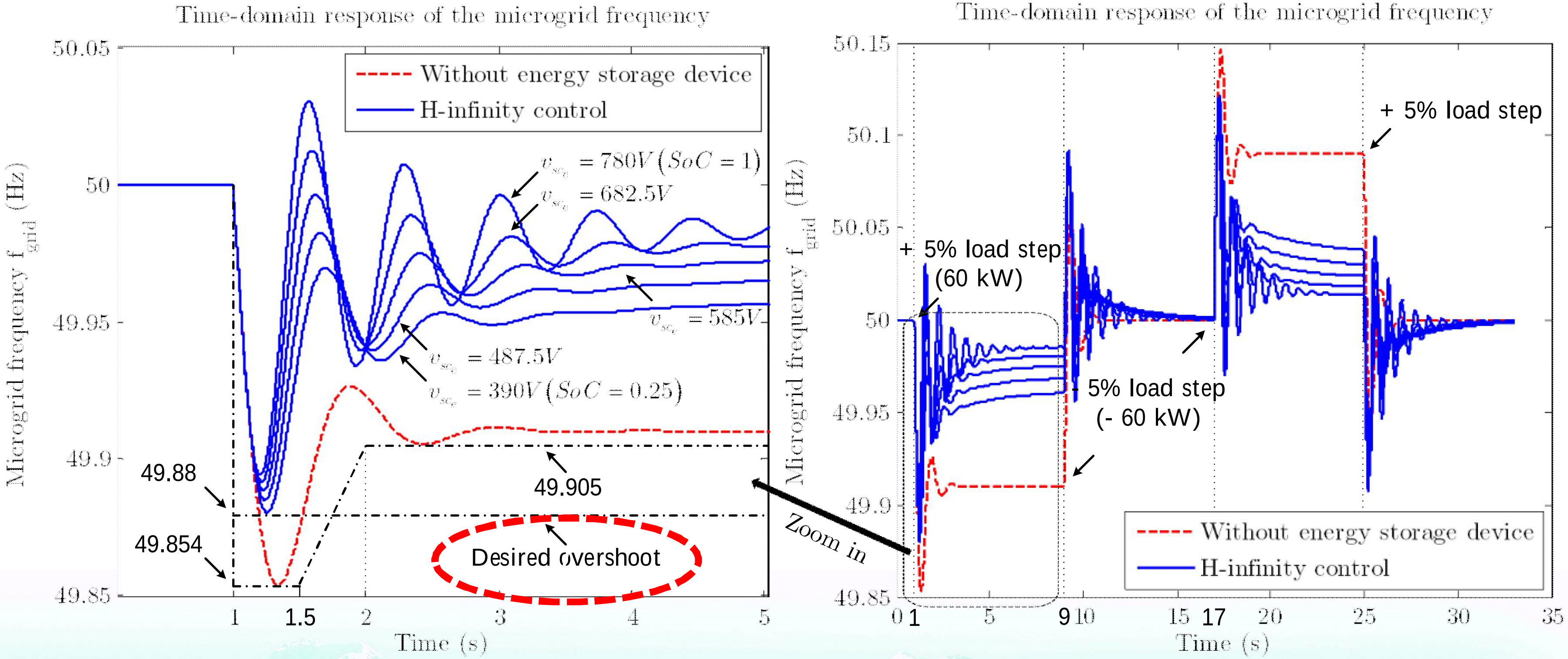
- DC-bus voltage control objective is satisfied with respect to the parameter selection of the weighting function $W_{perf_1}(s)$ ➡ H_∞ controller ensures desired performances



Time-domain response of the DC-bus voltage v_{dc} under small step load disturbances of ± 5% of the rated load power (± 60 kW) from the rated parameters

Numerical simulation results

- $SoC_e \in [0.25, 1]\left(v_{sc_e} \in [390\,V, 780\,V]\right)$
- Desired overshoot is well-respected irrespective of the initial value of SoC

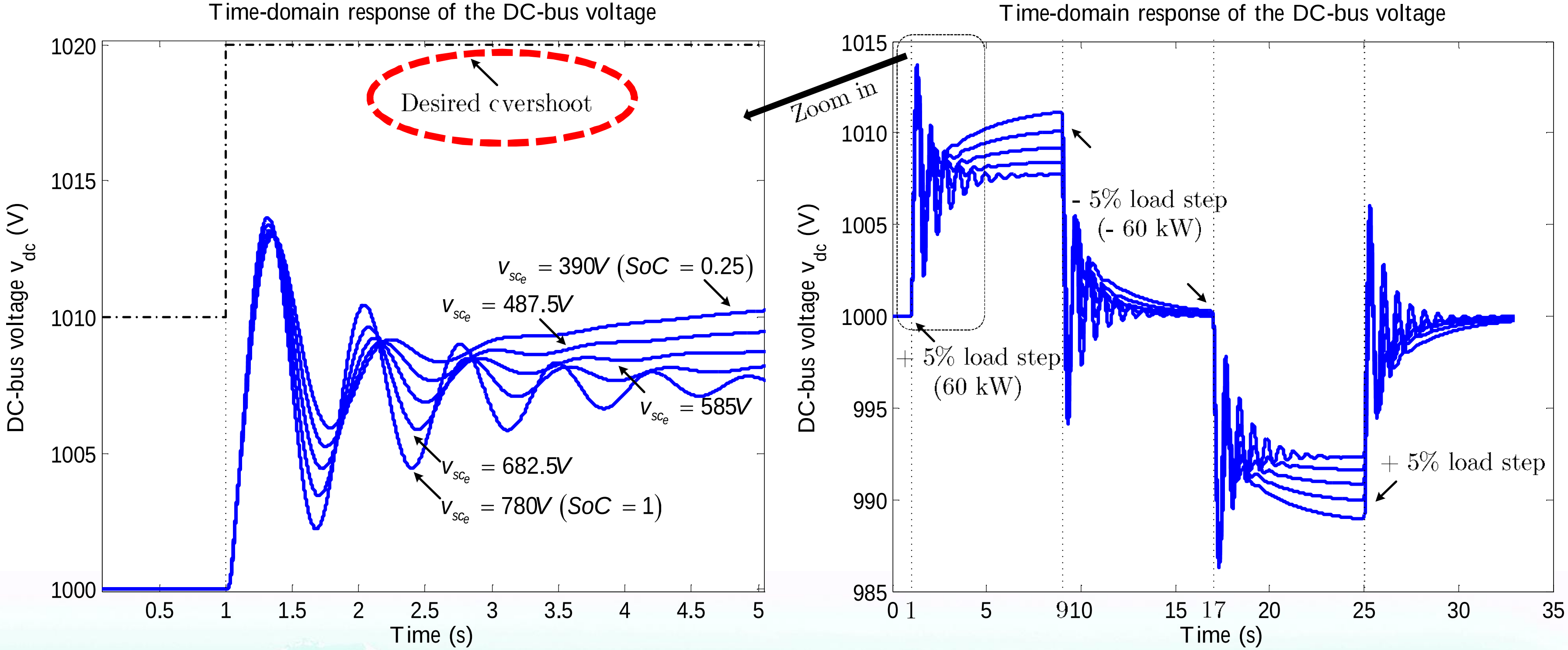


Time-domain response of the microgrid frequency f_{grid} under small step load disturbances of ± 5% of the rated load power (± 60 kW) taking into account the uncertainty on SoC_e(or v_{sc_e})

Numerical simulation results

- Overshoot of the DC-bus voltage is satisfied irrespective of the initial value of SoC

➡ H_∞ controller is robust in performance to $SoC_e \in [0.25, 1]$



Time-domain response of the DC-bus voltage v_{dc} under small step load disturbances of ± 5% of the rated load power (± 60 kW) taking into account the uncertainty on SoC_e(or v_{sc_e})

Outline

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Conclusions & future work

- Conclusions
  - Systematic design procedure for computing a multi-variable H_∞ robust controller for primary frequency regulation in stand-alone microgrids highly penetrated by renewable energy sources
  - Effectiveness of the proposed H_∞ robust control strategy has been validated via numerical simulation results
  - Robustness analysis of the synthesized H_∞ controller taking into account the uncertainty on SoC_e of the supercapacitor
- Future work
  - Design of a robust control strategy for PCC voltage regulation
  - Practical implementation of the proposed control algorithms on a real-time test bench

Thank you !

Questions ???

Meeting of Group MOSAR - GdR MACS
Nantes, March 16th 2016