Microgrid Stability

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Stability Definition

- **Power system stability**: The ability of the system for an initial operating condition to maintain the balance state or recover it after a disturbance such that all the variables of the system are limited to a certain value and practically the entire power system continues to work flawlessly.

- This stability definition is generic and can be used generally for **microgrids**.

Microgrid stability challenges: based on operation mode

- **In interconnection mode:**
  - Grid-synchronization
  - Fault ride-through, and voltage-ride through capabilities
  - GFO and GFL DER interconnections with stiff and weak grids

- **In islanded mode:**
  - frequency stability,
  - voltage stability,
  - Power sharing stability,
  - low inertia,
  - communication-related concerns and and cyber attacks

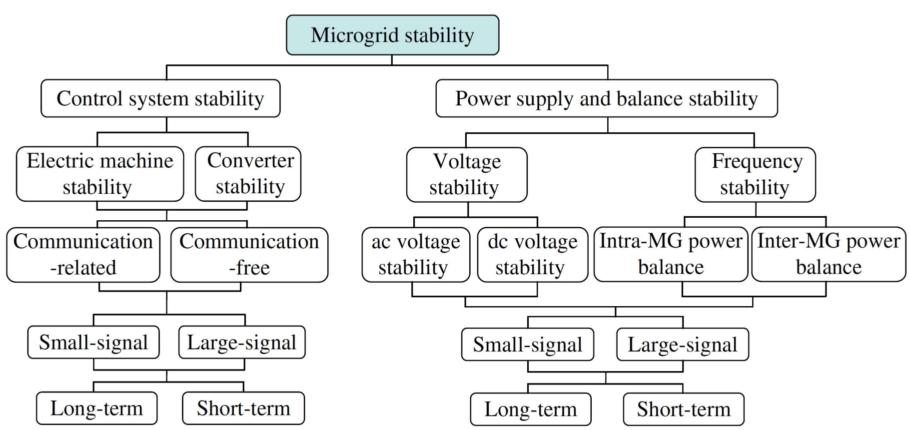
- Smooth transitions between islanding and grid-connected modes resulting in large-signal stability challenges.

Microgrid stability challenges: based on type of stability

- **Large-signal Stability:**
  - shows the ability of the system to maintain the synchronism due to the occurrence of a strong transient disturbance.
  - due to large disturbances including switching between **islanding/grid connected** modes, DER **plug-and-play**, **large sudden load** changes, and frequent **short-circuits**.
  - Time-domain waveforms

- **Small-signal Stability**
  - shows the system's ability to maintain synchronism due to small disturbances (small changes in load/generation).
  - focused on **control gains** and **system parameters**
  - MG topology, type of DERs, and control strategy cause some differences resulting in special considerations for each MG.

Microgrid Stability Classification



- **Power supply/balance stability:** the ability of the MG to maintain power balance and share power among DERs.
- **Control system stability:** deals with issues such as the inappropriateness of the control strategies and the poor adjustment of the parameters.

Stability Analysis Methods

Small-signal stability:

- **Eigenvalue analysis**
  - For small signal stability $$|\lambda I - A_{MG}| = 0,$$
  - only determine stability/instability for a specific operating point.

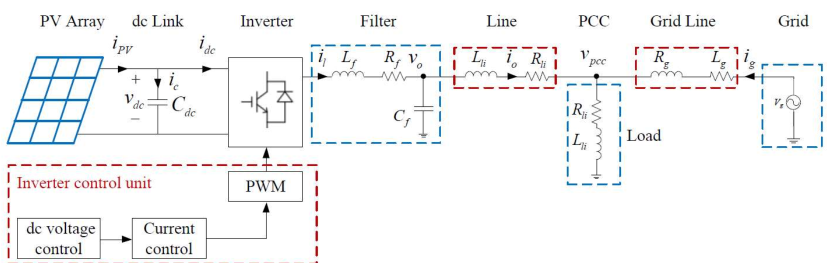
- **Participation factor/matrix**
  - determines the amount of being influenced for each eigenvalue and by each state variable

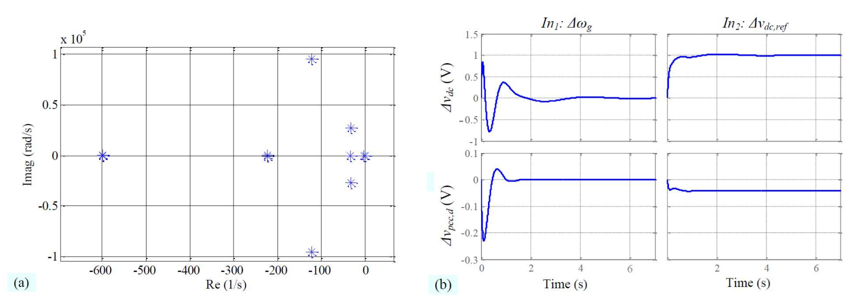
- **Sensitivity analysis**
  - Visualizes the impact of parameters or initial condition variations (loci of eigenvalues)

Large-signal stability:

- Nonlinear models, time-domain simulations, real-time simulations (RTSs) and experimental results
- Lyapunov theorem

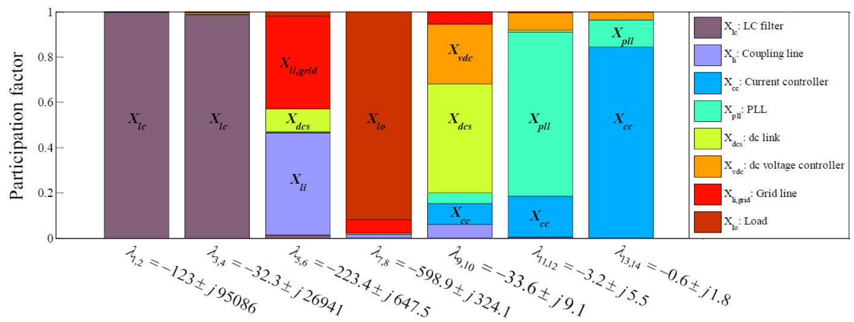
Example: Stability Analysis of Grid Connected PV





Example: Stability Analysis of Grid Connected PV

Participation matrix analysis results of the grid-connected PV system



$$M_{PF} = (\Phi^{-1}) \bullet \Phi,$$

Φ is the right eigenvector matrix of A_{MG}

$\bullet$ is the Hadamard product

$M_{PF}(i,j)$ shows the involvement of i'th state variable in j'th eigenvector

- The **current controller** and the **PLL** are the most important modules
- Participation matrix does not show the stability margin. It only works in a certain operation point.

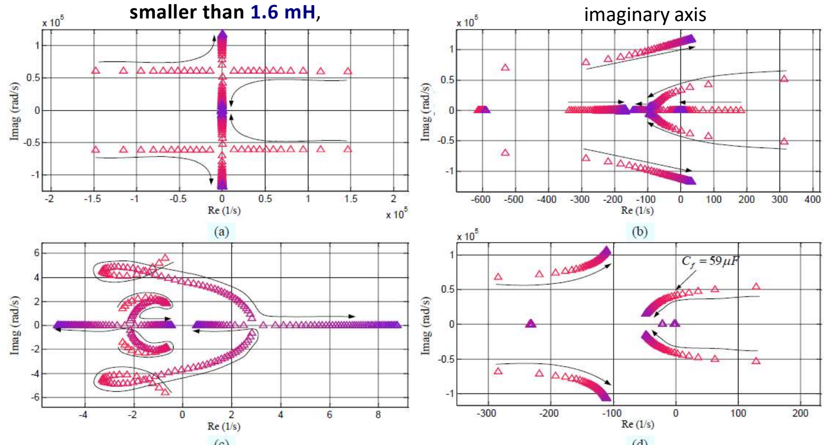
Example: Stability Analysis of Grid Connected PV

Sensitivity analysis of **LC filter parameters**

The **loci of the grid-connected PV eigenvalues** for changing the filter inductance from **0.2 mH to 10.2 mH (a, b, and c)**

variations of eigenvalues for values **smaller than 1.6 mH**,

Changes of eigenvalues close to the imaginary axis



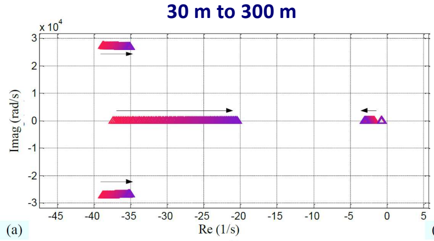
instability for values **greater than 3.4 mH**

changing the **filter capacitance from 30 µF to 120 µF**, instability for **values smaller than 59 µF**

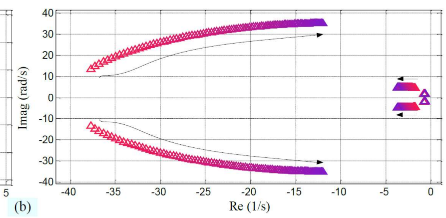
Example: Stability Analysis of Grid Connected PV

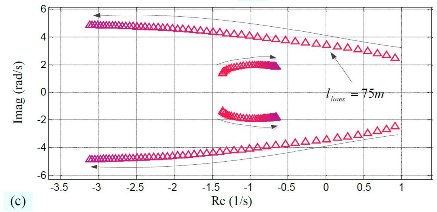
Sensitivity analysis of **Coupling/Grid Line Length**

changing the **coupling line** length **from 30 m to 300 m**



changing the **main grid line length from 30 m to 300 m**



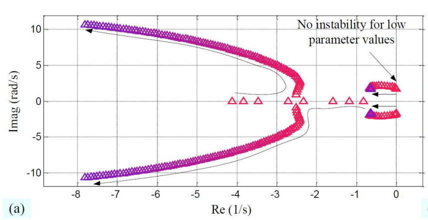


changing **both coupling line length and grid line length** from **30 m to 300 m,** instability for lines **shorter than 75 m.**

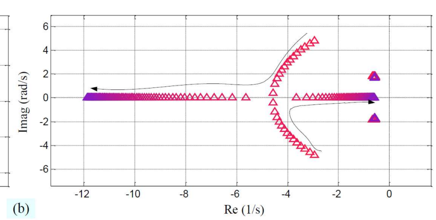
Example: Stability Analysis of Grid Connected PV

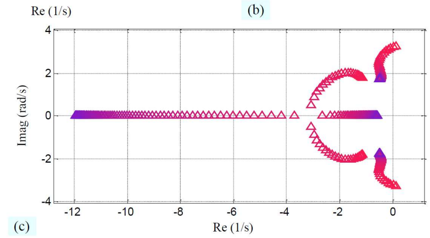
Sensitivity analysis of **PLL gains**

changes of the **integral gain** of the PLL controller from **1 to 50**



changes of the **proportional gain** of the PLL controller from **1 to 20**





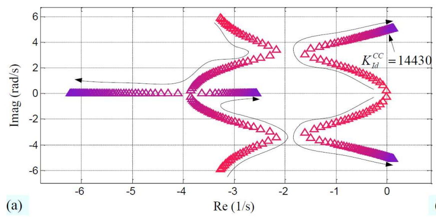
a similar scenario to (b) for the length of each coupling and grid lines as **60 m**.

Interactions among **PLL** state variables and lines state variables are a reason of instability.

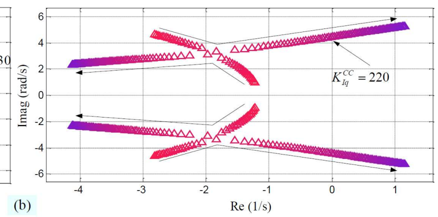
Example: Stability Analysis of Grid Connected PV

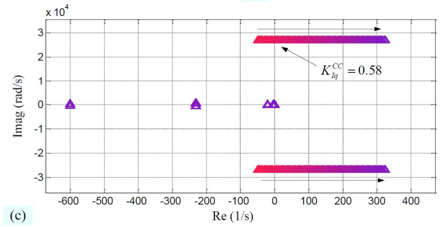
Sensitivity analysis of **current control gains**

changes of the **integral gain** of the **direct** component from **40 to 20000**



changes of the **integral gain** of the **quadrature** component from **40 to 430**



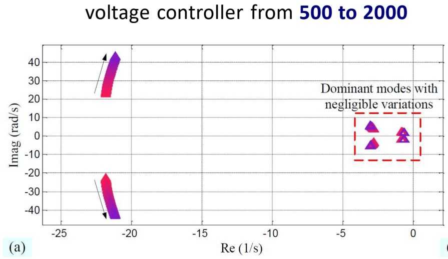


changes of the **proportional gain** of the direct/quadrature component from **0.04 to 4** (instability for bigger than **0.58**.)

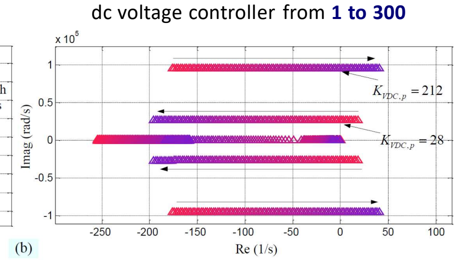
Example: Stability Analysis of Grid Connected PV

Sensitivity analysis of **DC voltage control gains**

changes of the **integral gain** of the dc voltage controller from **500 to 2000**

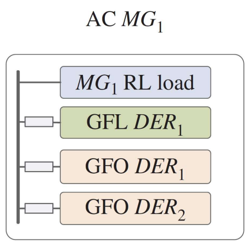


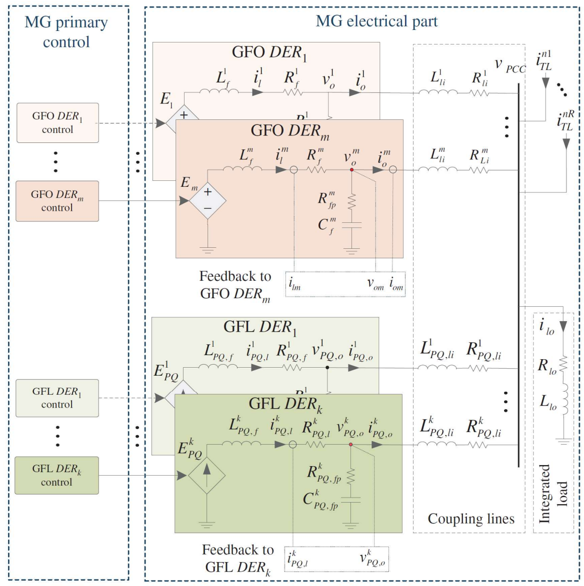
changes of the **proportional gain** of the dc voltage controller from **1 to 300**



Stability analysis of Islanded AC Microgrids

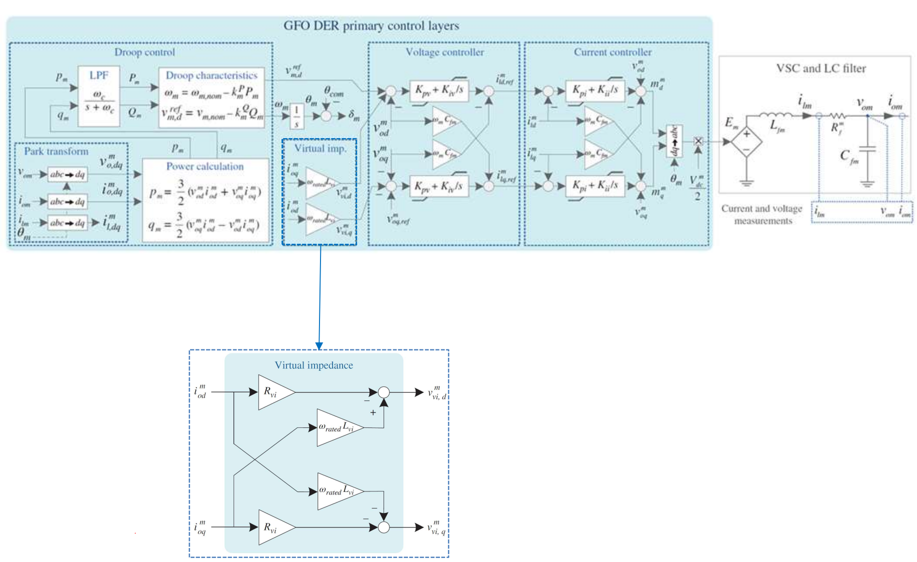
Example: Islanded AC Microgrids





Stability analysis of Islanded AC Microgrids

Primary Control Strategies of GFOs

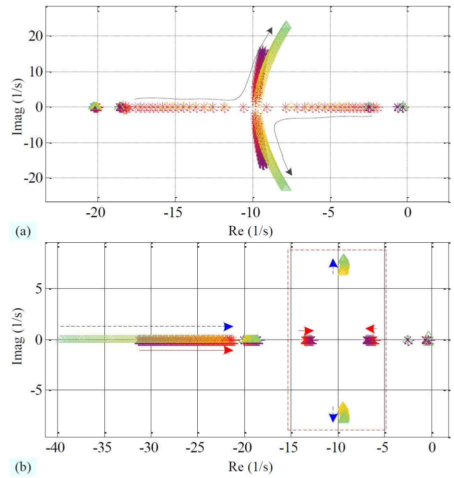


Stability analysis of Islanded AC Microgrids

Sensitivity analysis of **droop gains**

Changes of eigenvalues the ω − P droop gain, **0.2% < Δωmax/ωrated < 2%**

Changes of eigenvalues for v − Q droop gain, **1% < Δvmax/Vrated < 10%**



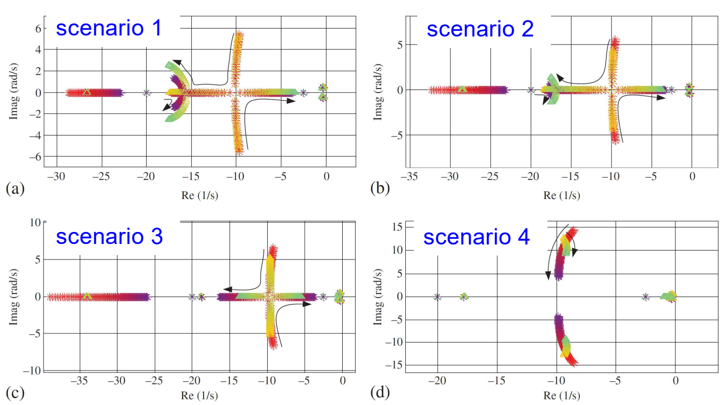
Droop characteristics have the most dominant parameters in small-signal stability.

Stability analysis of Islanded AC Microgrids

Sensitivity analysis of **virtual impedance**

The loci of dominant modes of the ac MG for 0 < Lvi < 12 mH,

DER1 (stars)
DER2 (triangles)

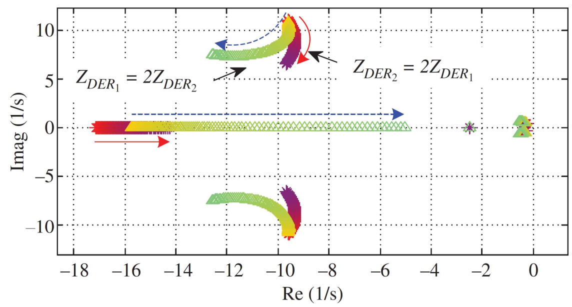


Scenario	Z_{DER_1}/Z_{DER_2}	S_{DER_1}/S_{DER}	$L_{li,1}$ (mH)	$R_{li,1}$ (Ω)	$P_{rated,1}$ (kW)	$Q_{rated,1}$ (kVAr)
1	2	2	3.8	0.8	40	20
2	0.5	2	1.9	0.4	40	20
3	2	0.5	3.8	0.8	20	10
4	2	0.5	3.8	0.8	10	5

Stability analysis of Islanded AC Microgrids

Sensitivity analysis of **virtual impedance**

The loci of dominant modes of the ac MG for $0 < R_{vi} < 1\Omega$, while L_{vi}=2mH

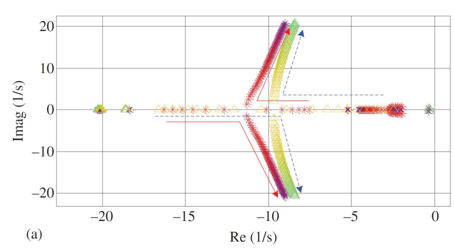


Stability analysis of Islanded AC Microgrids

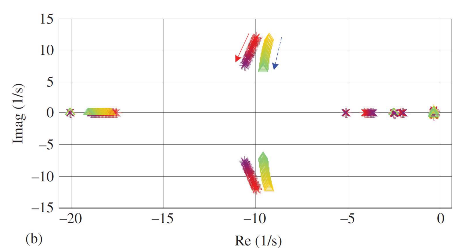
Sensitivity analysis of **secondary control**

The loci of dominant modes of the ac MG with (stars) and without (triangles) the secondary controller

Changes of eigenvalues the ω − P droop gain, **0.2% < Δωmax/ωrated < 2%**



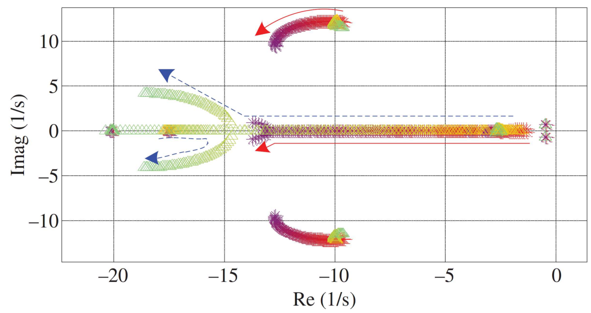
Changes of eigenvalues for 0.5 < ZDER2/ZDER1 < 2



Stability analysis of Islanded AC Microgrids

Sensitivity analysis of **secondary control**

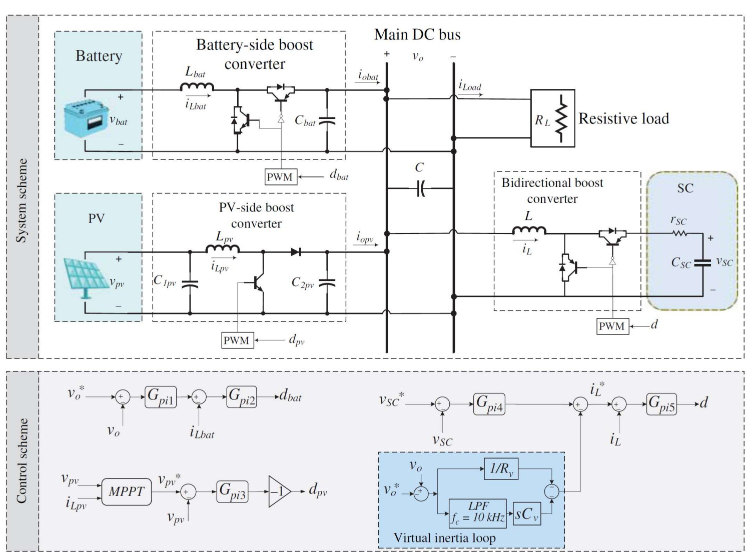
The loci of dominant modes of the ac MG for variations of DER1 secondary control gain (stars) and variation of DER2 secondary control gain (triangles) as $1 < \tau^{-1} < 10$



Decreasing the time constant of the secondary control loop (τ), results in a faster response and a larger stability margin related to the secondary control-affected dynamic modes.

Stability analysis of Islanded DC Microgrids

Islanded dc microgrid case study

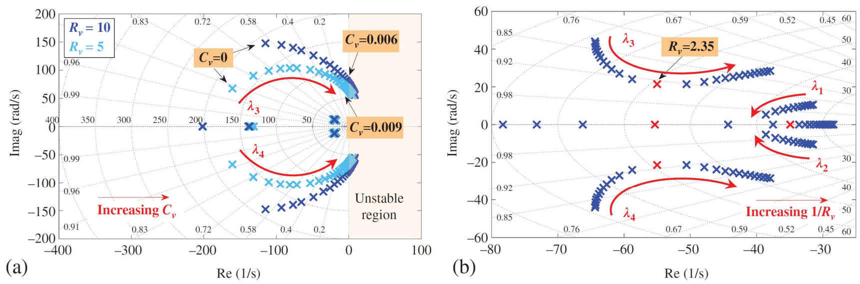


Stability analysis of Islanded AC Microgrids

Sensitivity analysis of **virtual inertia loop**

Trace of the dominant eigenvalues of the studied dc MG

varying Cv while Rv = 10 and Rv = 5 | varying Rv while Cv = 0.002



Transient Stability of Microgrids

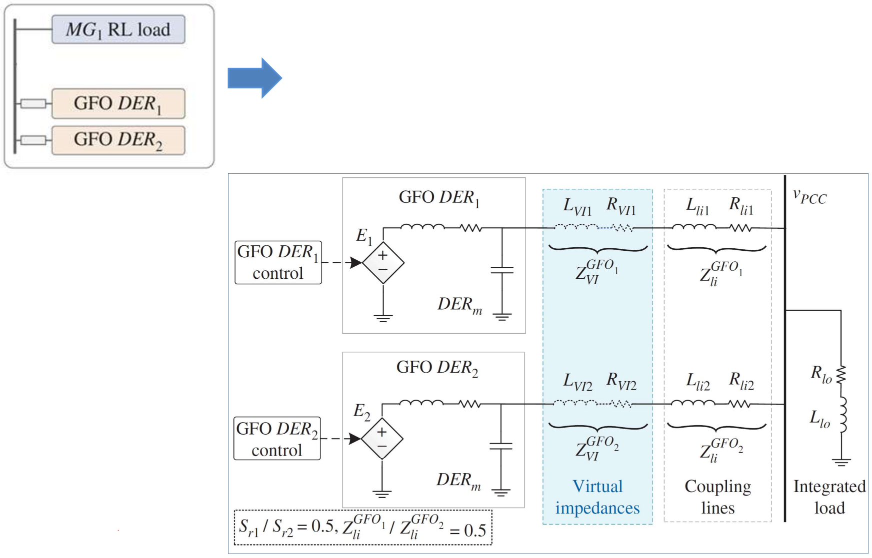
Transient stability of the power system:

- **Graphical methods**, mostly used in one-machine systems,
- **Direct methods**, employs Lyapunov functions, more applicable for low/reduced-order systems
- **Automatic learning methods**, benefit from intelligent algorithms such as genetic algorithm and artificial neural networks
- **Time-domain methods**.

Time-domain methods have been mostly used for MG transient stability analysis

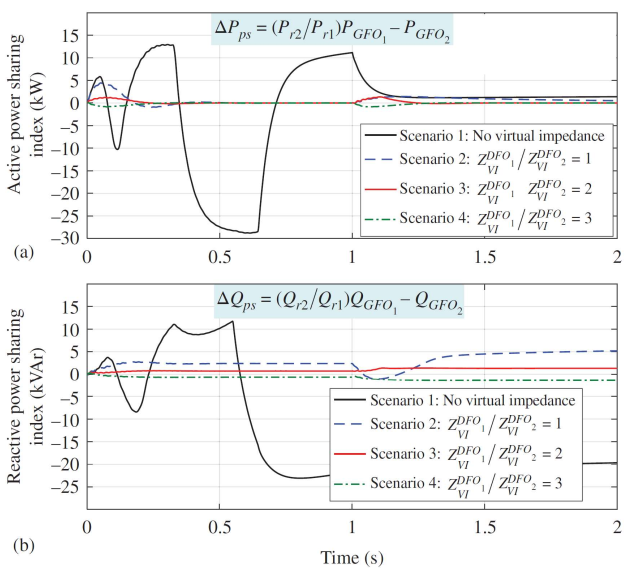
Transient Stability of Microgrids

Power Sharing Stability in AC Microgrids

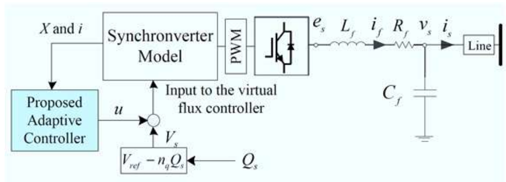


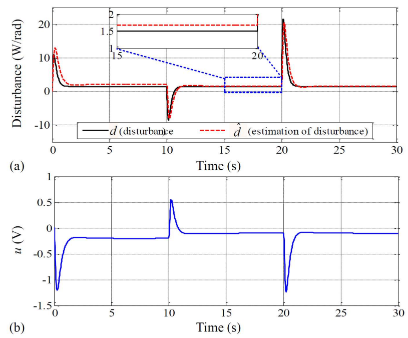
Transient Stability of Microgrids

Power Sharing Stability in AC Microgrids

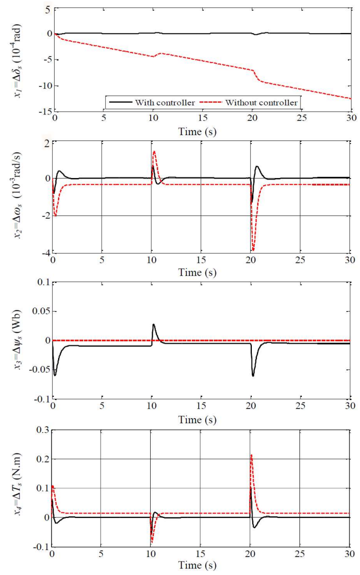


Transient Stability of a Synchronverter





The stabilizing adaptive backstepping controller features during a permanent disturbance



State variables of the synchronverter with and without the stabilizing controller

Thank you for your attention!

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