
Converter-Interfaced Distributed Generation Grid Interconnection Issues

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Presentation outline

- Definition and motivation
- DG controller features
- Voltage dips ride through capability
- Voltage compensation capability
- Island operation capability
- Conclusions and future work

Definition

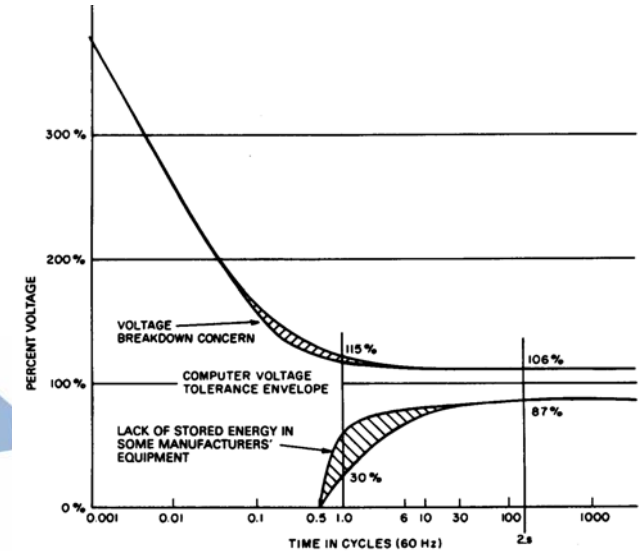
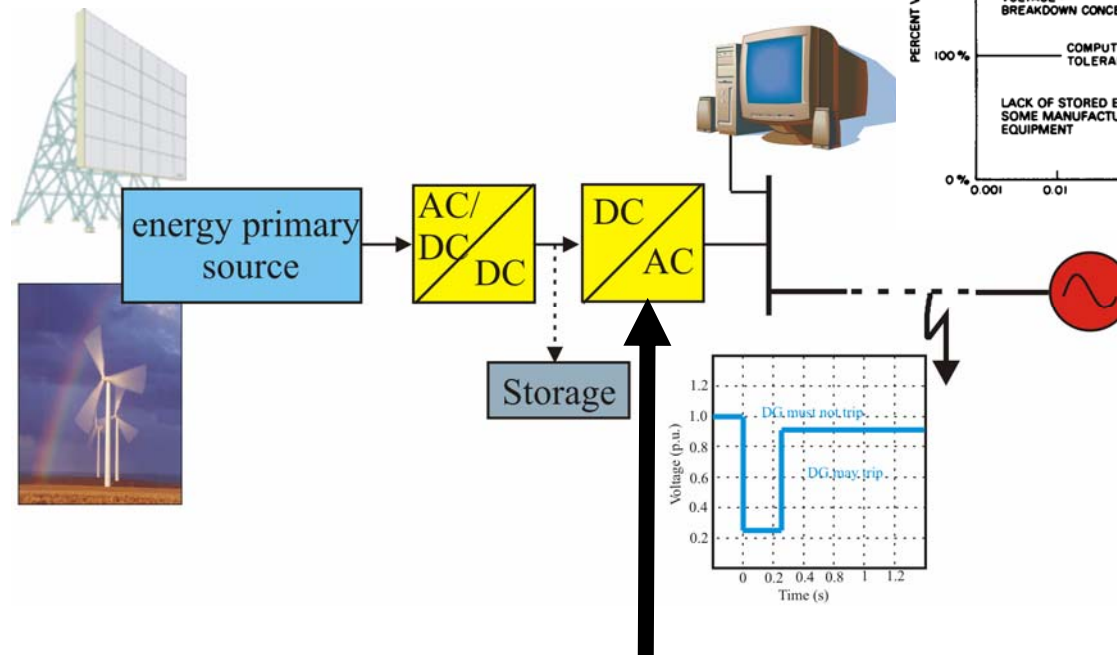
Definition (IEEE Std 1547.1-2005)

Distributed generation (DG): Electric generation facilities connected to an area in the electric power system (EPS) through a point of common coupling (PCC); a subset of distributed resources (DR).

Distributed resources (DR): Sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies.

DG Technology

System under focus



Possible control functions

- Voltage dips ride through
- Voltage compensation
- Intentional islanding



Driving forces of the integration of DGs

Environmental

- limiting green house gas emissions
- avoidance of construction of large generating plants

Customers (commercial)

- increasing reliability as seen by customers (that are in the DG vicinity)
- providing local ancillary services (improve power quality)

National

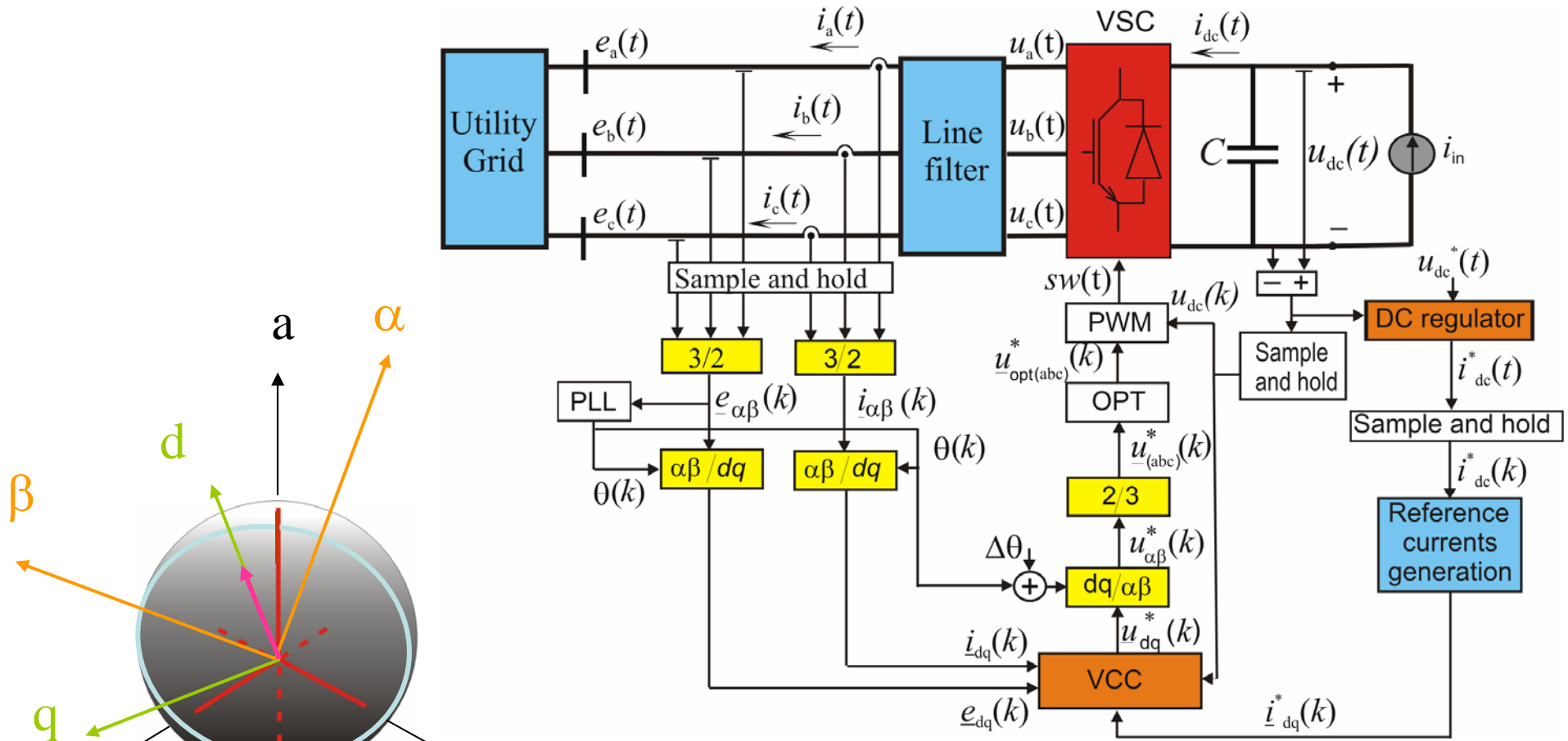
- provide energy security (diversification of energy sources)
- support for competitive policy (provide competitive energy costs and better service quality)

Main contributions

A front end converter interface of a DG is considered

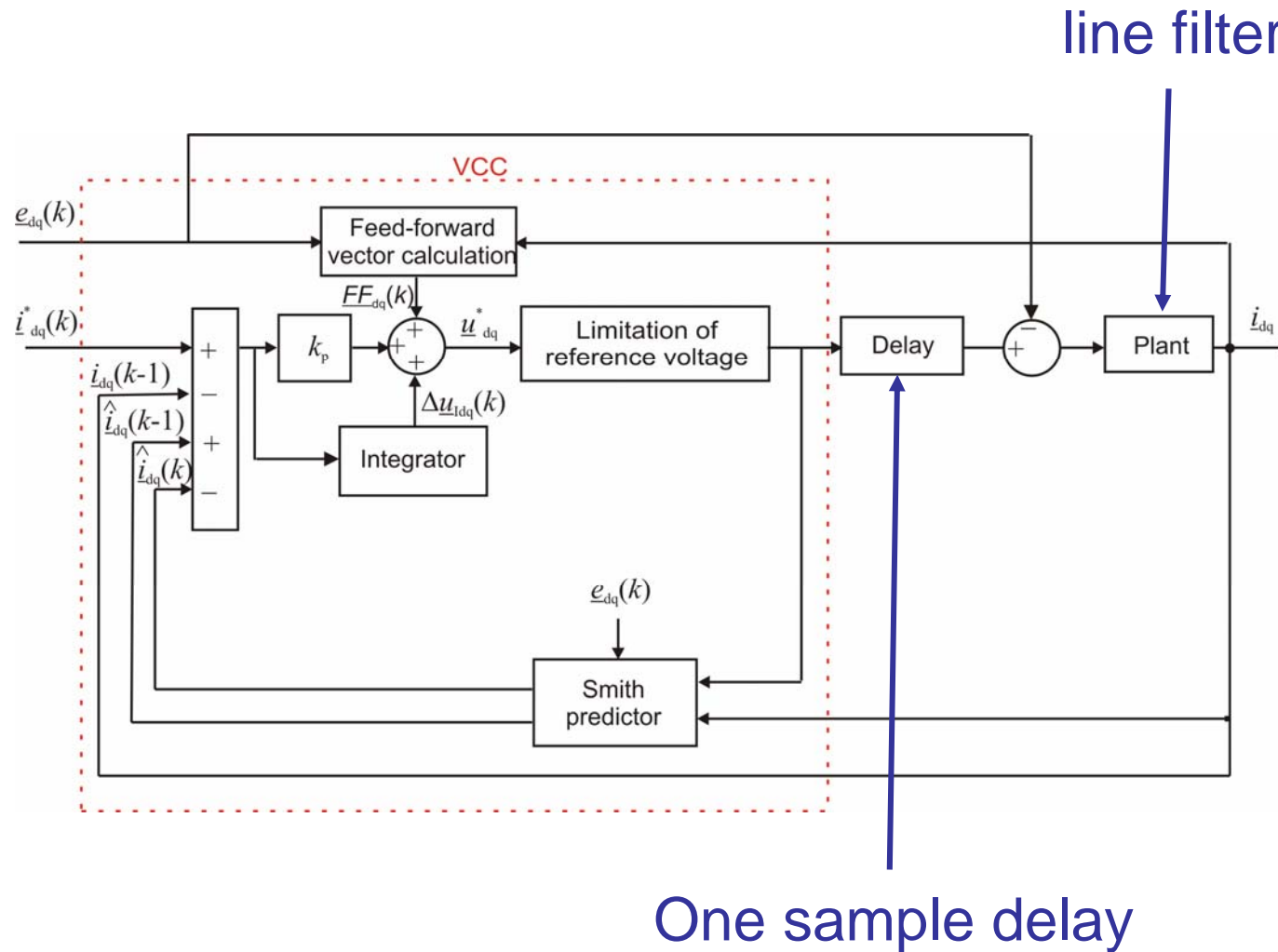
- The main **controller** has been **developed** in two cases - **L** line filter and **LCL** line filter.
- Study the possible **voltage dips** at the DG terminal and derivation of the **maximum currents** that flow in case of various dip types.
- Investigation of the effect of the estimated phase error on the **voltage compensation**.
- Investigation of the DG **intentional islanding** in a weak grid.

Basic controller features for the DG interface



Control the injected current into the grid
 Control the active and reactive currents separately
 Control the DC-link voltage

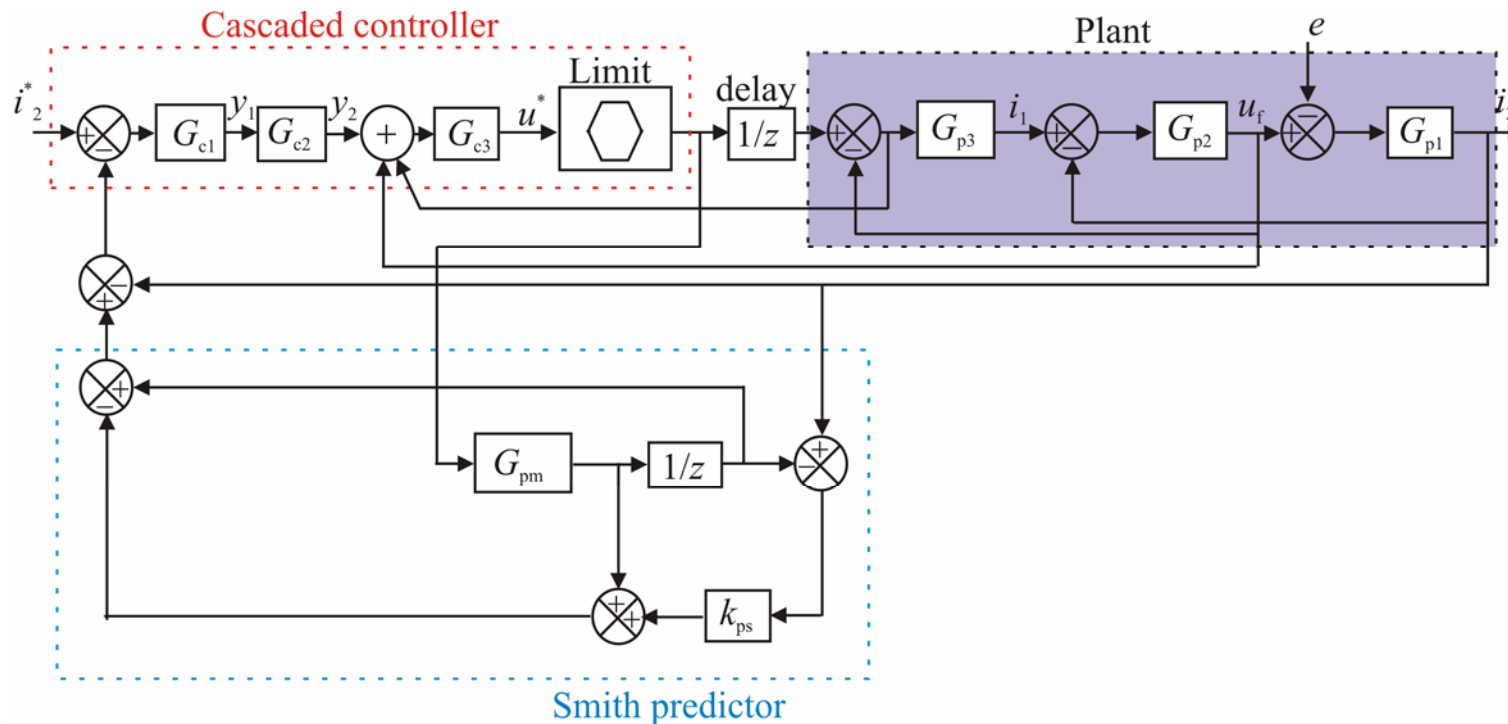
Basic current controller features for the DG interface



line filter

One sample delay

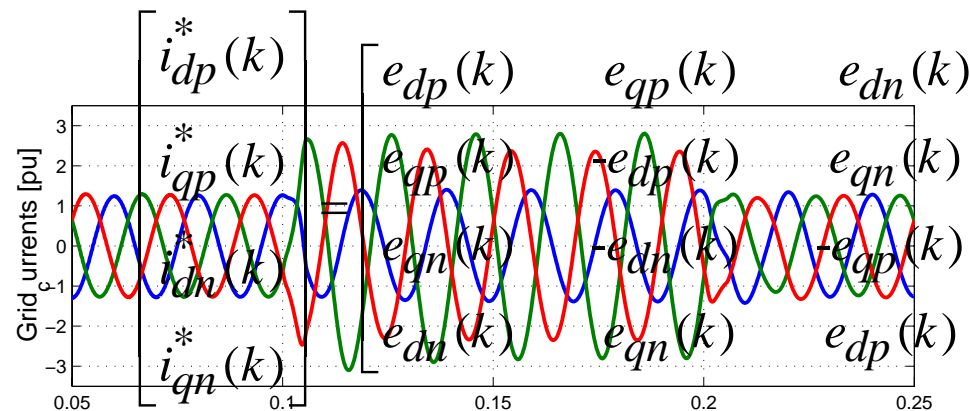
Basic current controller – LCL line filter



In case of unbalanced grid voltage, the VCC is described in a +ve seq and -ve seq frames (DVCC)

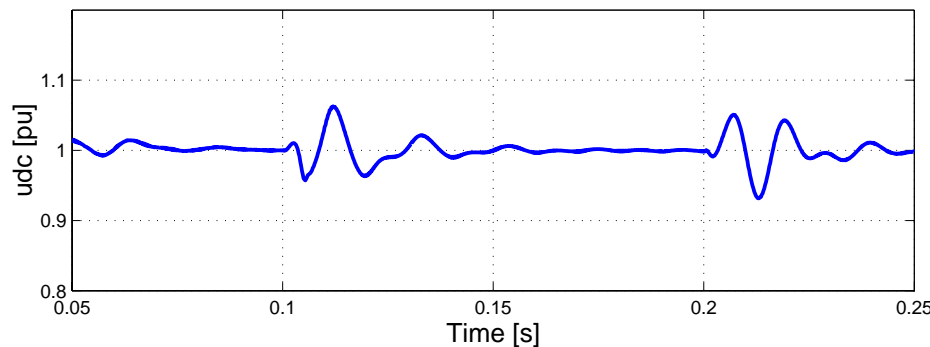
Reference current generation for the DG controller

Based on the instantaneous power theory where the power is expressed in the rotating dq -frame, and the resulting components can be controlled independently.



$$\begin{bmatrix} e_{qn}(k) \\ -e_{dn}(k) \\ e_{dp}(k) \\ e_{qp}(k) \end{bmatrix}^{-1} \begin{bmatrix} P_{dc} - \Delta P(k-1) \\ 0 \\ -\Delta P_{s2}(k-1) \\ -\Delta P_{c2}(k-1) \end{bmatrix}$$

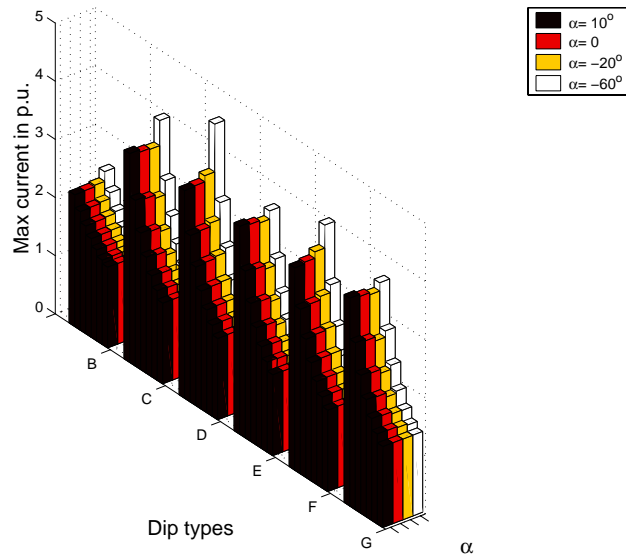
Double phase fault, from 0.1 s to 0.2 s, with 40% remaining voltage



The effect of voltage dips on the DG interface

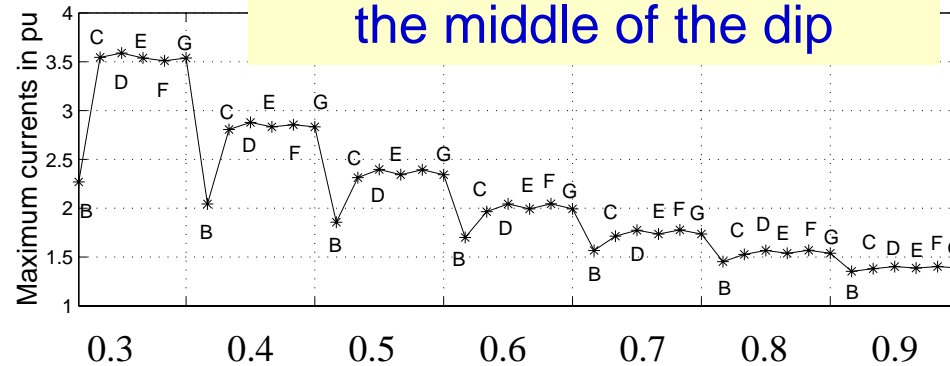
Voltage dips definition (IEEE std 1159 1995)

A decrease to between 0.1 to 0.9 p.u. in the RMS value of the voltage at the power frequency for durations of 0.5 cycle to 1 min, as experienced by the end user.

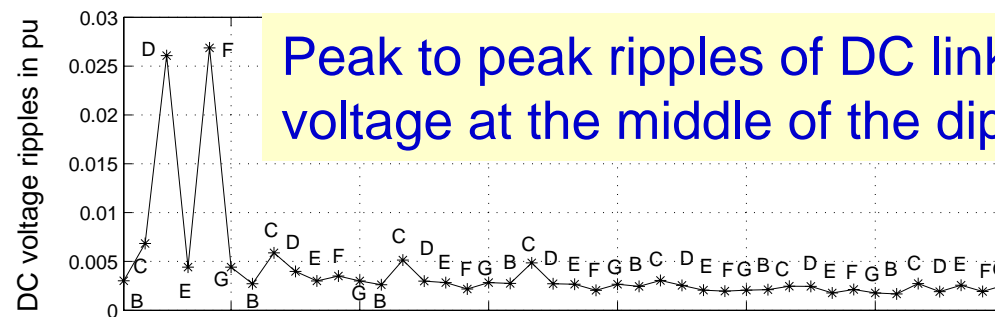


p.s. Voltage dips classification and α definition from ref [52] in the thesis.

Maximum grid current at the middle of the dip



Peak to peak ripples of DC link voltage at the middle of the dip



Unbalanced voltage dips magnitudes in pu

Maximum currents during voltage dips

Dips due to single phase faults (dip types “B” and “D”)

$$I_{\max} = \sqrt{\frac{2}{3}} \cdot \frac{K P_{\text{dc}}}{e_{\text{dp}} + e_{\text{dn}}}$$

Input power from primary source

Dips due to two phase faults (dip types “C”, “E”, “F”, “G”)

$$I_{\max} = \sqrt{\frac{2}{3}} \cdot \frac{K P_{\text{dc}}}{e_{\text{dp}}^2 - e_{\text{dn}}^2} \sqrt{\frac{1}{4} (e_{\text{dp}} - e_{\text{dn}})^2 + \frac{3}{4} (e_{\text{dp}} + e_{\text{dn}})^2}$$

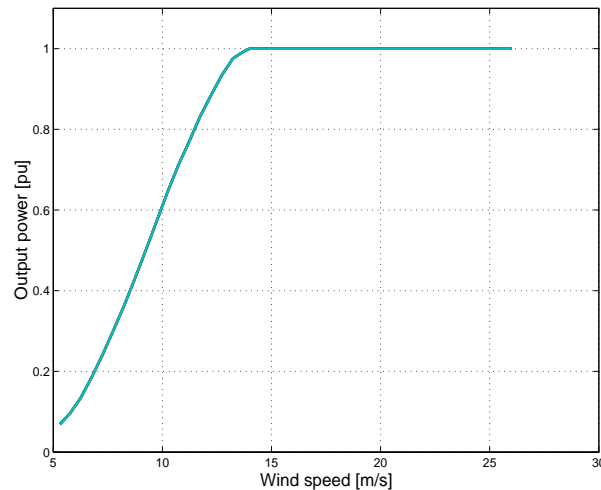
Dip due to three phase faults (dip type “A”)

$$I_{\max} = \sqrt{\frac{2}{3}} \cdot \frac{K P_{\text{dc}}}{E \times V_{\text{dip}}}$$

Case study

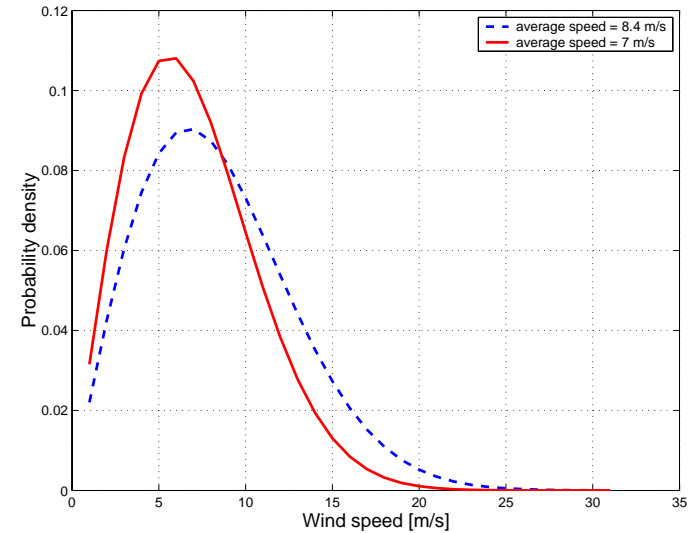
1

For a specific turbine the wind speed-power curve is given



2

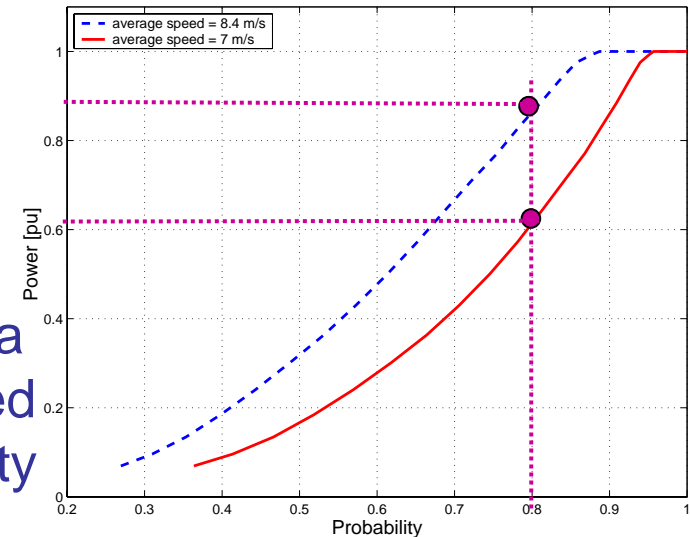
For a certain site we have the probability density of wind speed (Weibull distribution)



3

The probability of the power is then obtained

Maximum power for a site is then determined for a certain probability (say 80%)



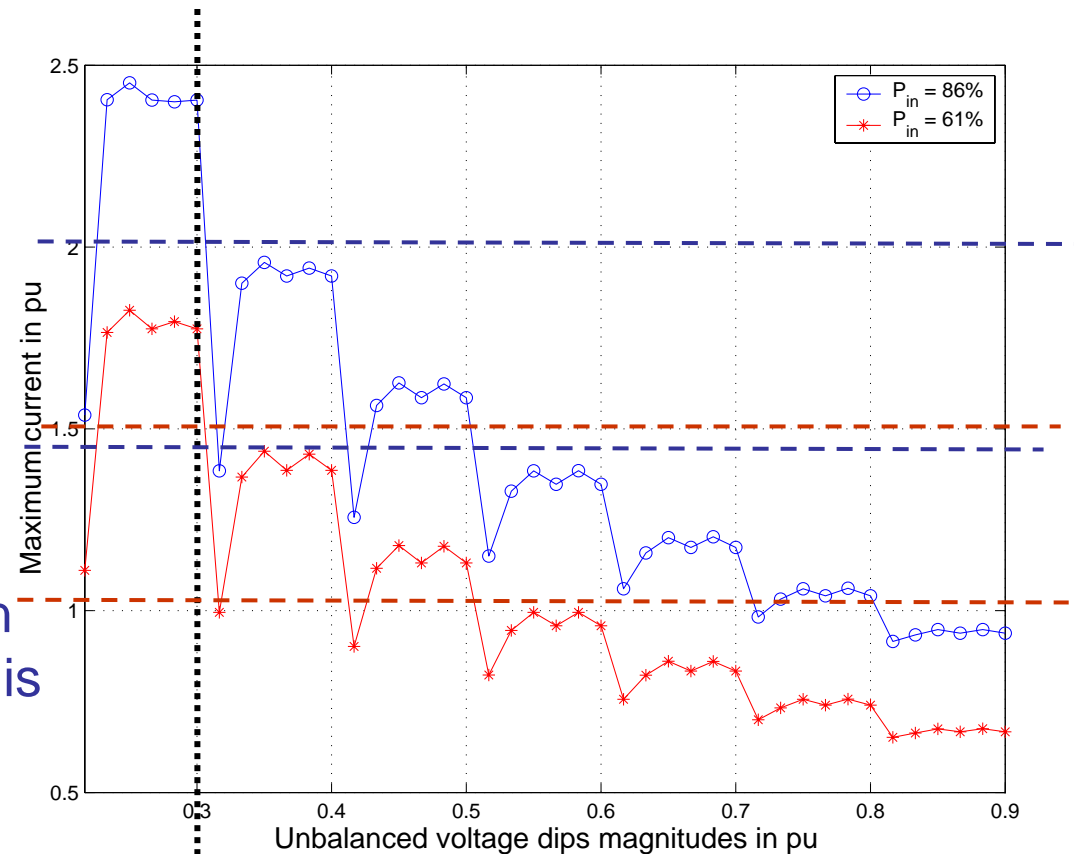
Case study – cont.

4

The rating of the converter is decreased with increased input power and decreased dip magnitudes

Example: if ride through is required for all dips higher than 30% magnitude, the converter is designed for:

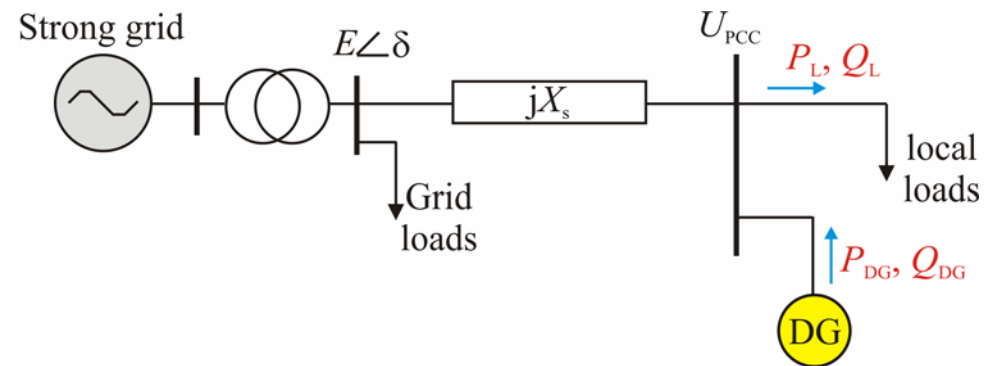
- 2 pu for a site with 8.4 m/s average speed
- 1.5 pu for a site with 7 m/s average speed



Voltage compensation capability

The reactive power transfer to the grid (local loads off)

$$Q_{DG} = \frac{U_{PCC}^2}{X_s} - \sqrt{\left(\frac{U_{PCC}E}{X_s}\right)^2 - P_{DG}^2}$$



The instantaneous reactive power to the grid (in dq -frame)

$$q_{DG} = -u_{d(PCC)}i_{2q}$$

Controller

$$i_{2q}^*(k) = k_{pr}\varepsilon_e(k) + \frac{k_{pr}T_s}{T_{ir}} \sum_{n=1}^k \varepsilon_e(n-1)$$

$$\varepsilon_e(k) = u_{d(PCC)}(k) - u_{d(PCC)}^*(k)$$

Islanding

Definition:

A condition in which a portion of the utility system that contains both load and distributed resources remains energized while isolated from the remainder of the utility system.

- IEEE std 929-2000 → **detection methods** should be developed to prevent islanding
- IEEE std 1547-2003 → **intentional islanding** maybe considered in the future

Islanding detection methods

Passive methods:

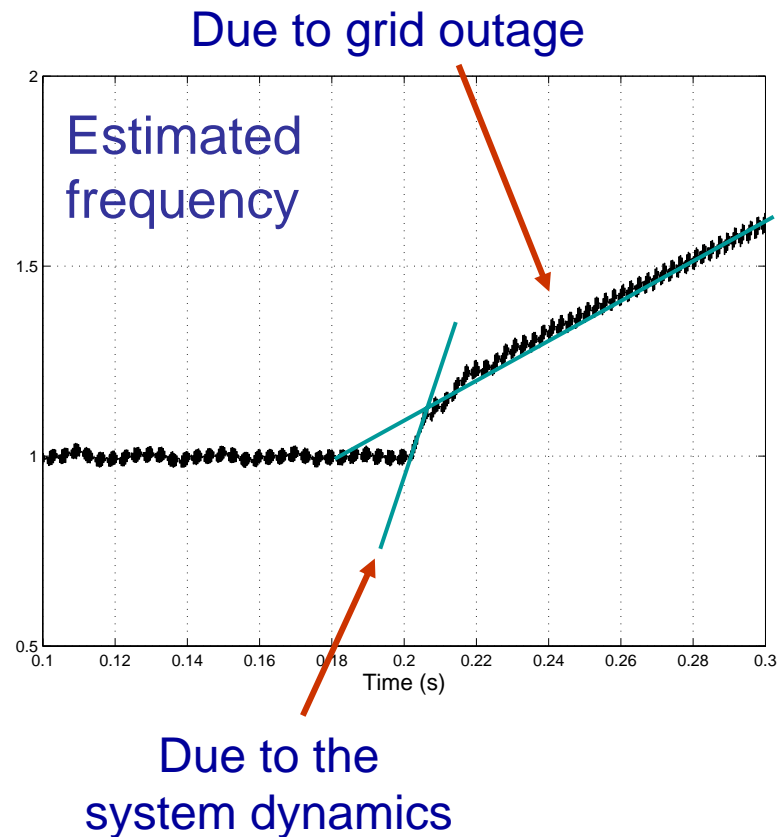
Depend on monitoring the grid states and specifying an islanding window.

A condition could appear, where the **DG** output **and** the **island loads** are closely **matched**, at which the PCC voltage and frequency will not change during islanding.

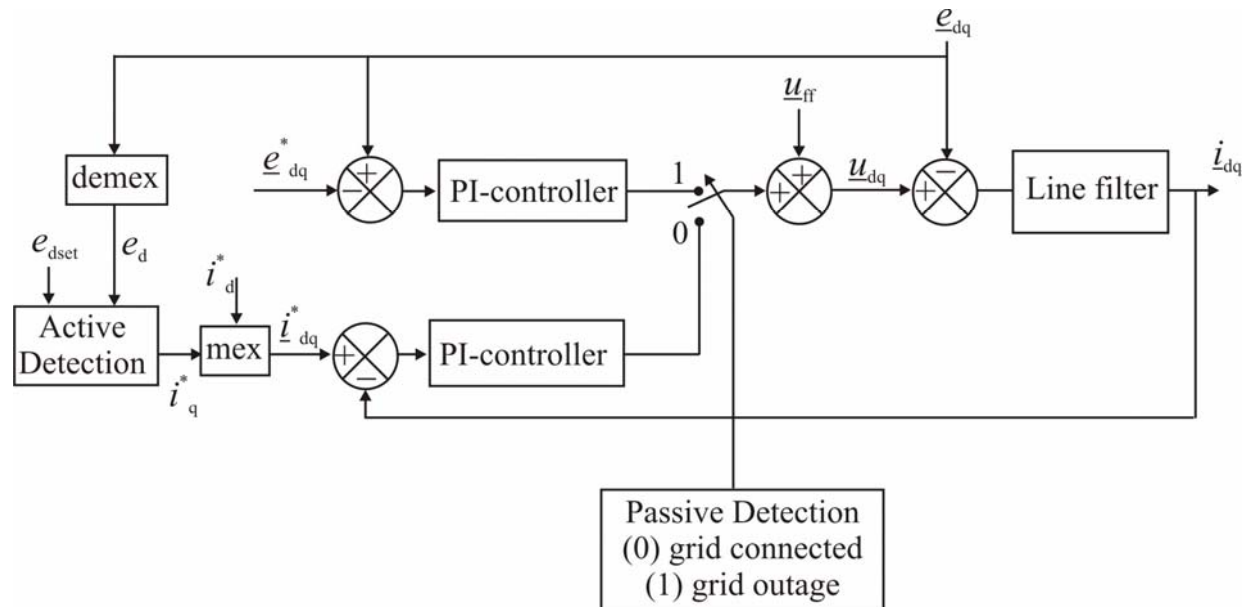
Active methods: (islanding detection using the DG controller)

Depend on the assumption of a strong grid. The controller tries to disturb the grid by injecting a distorted current, frequency, or varying the output power. If disturbed, islanding is detected.

Passive detection algorithm



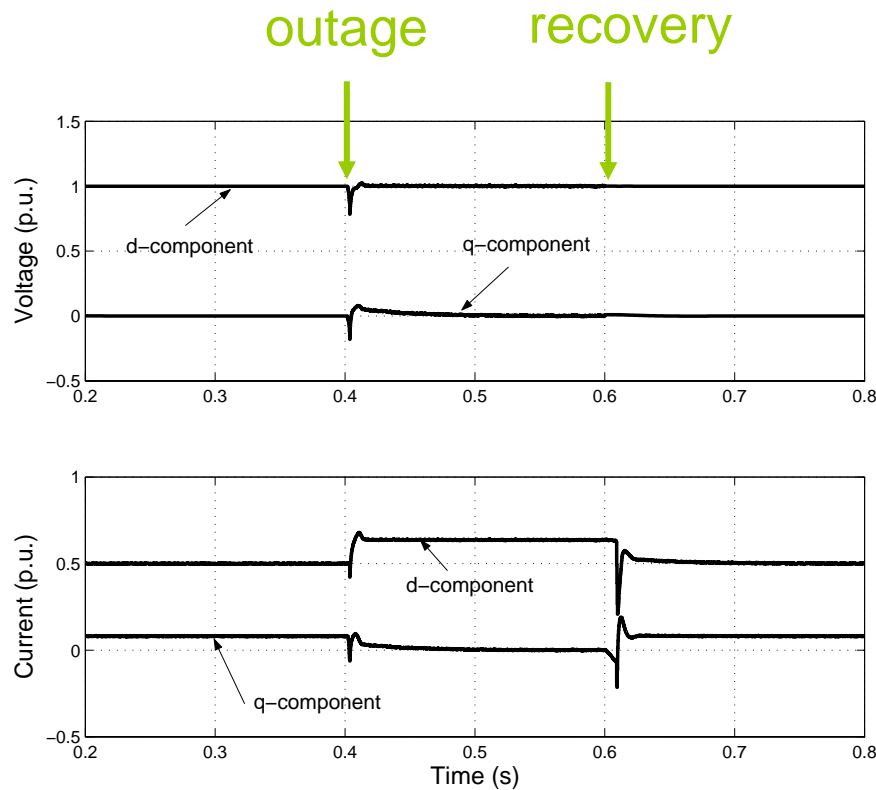
Active islanding detection – strong grid



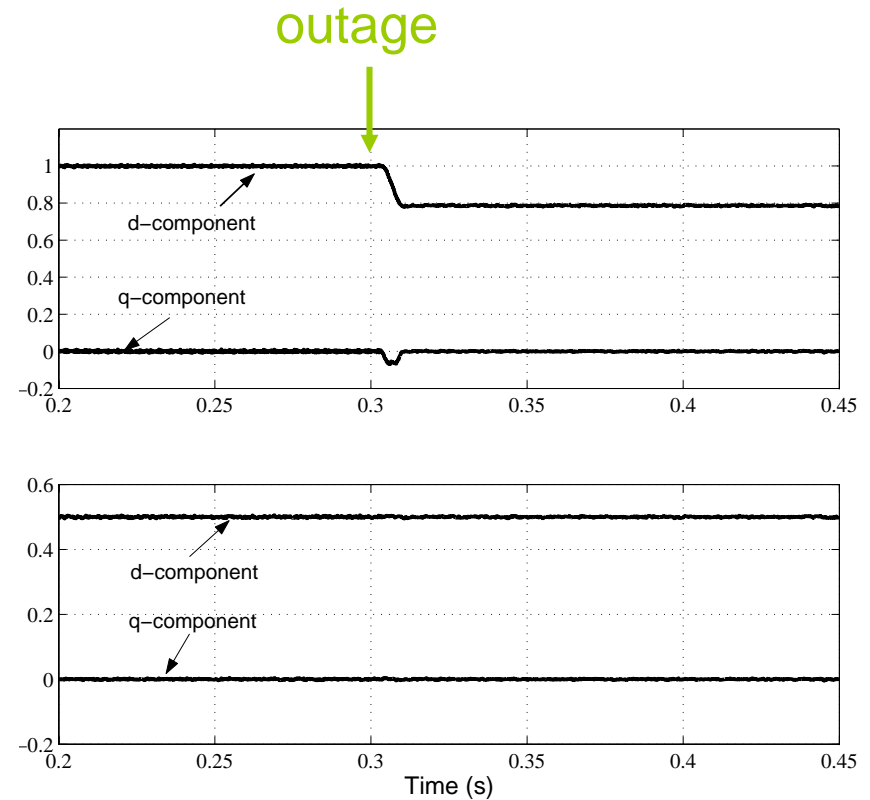
Advantage: Less NDZ

Injected DG currents – matching load

With active islanding detection

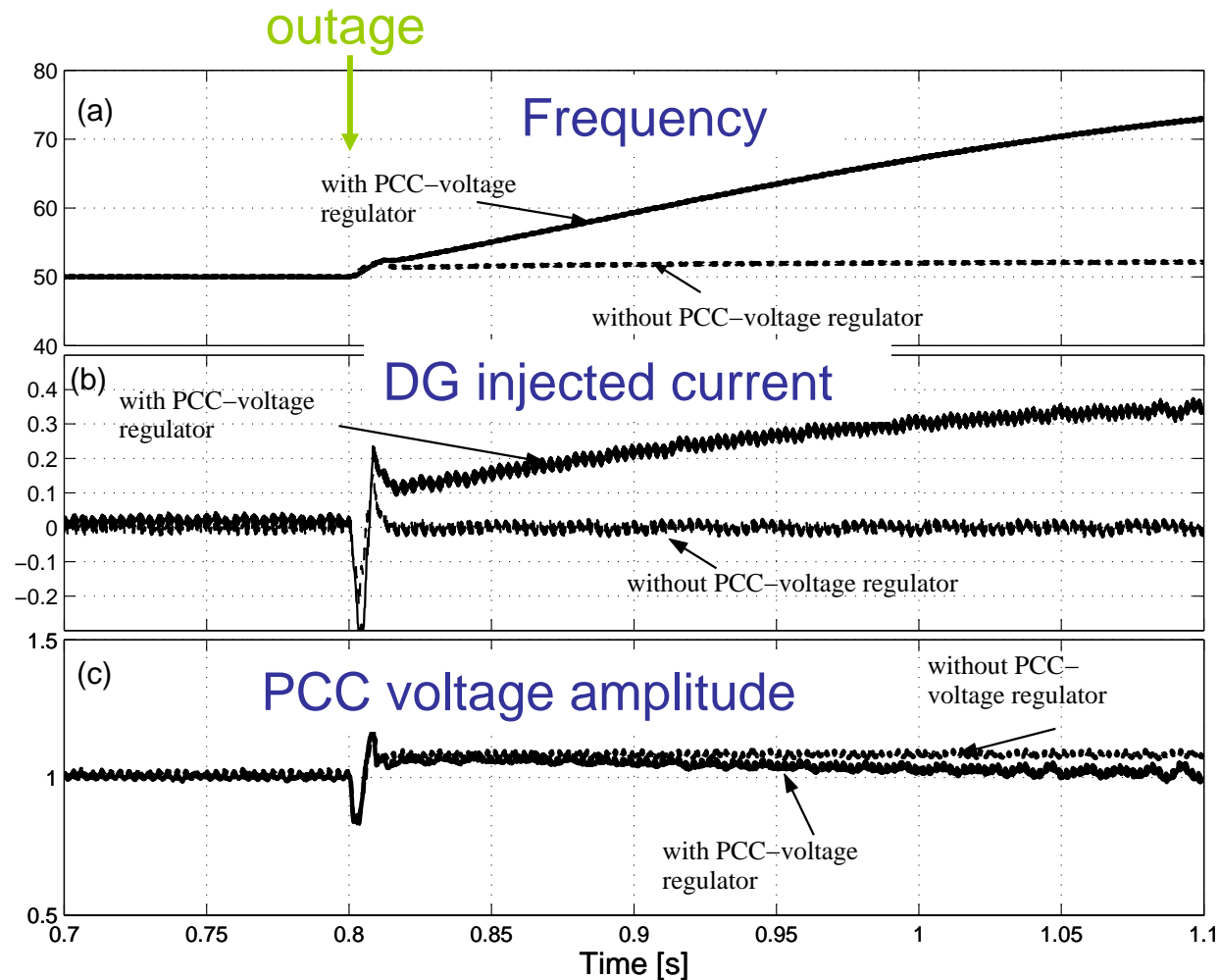


Without active islanding detection



Island load: quadratic voltage dependent $\Delta P = -0.07$ pu, $\Delta Q = 0$

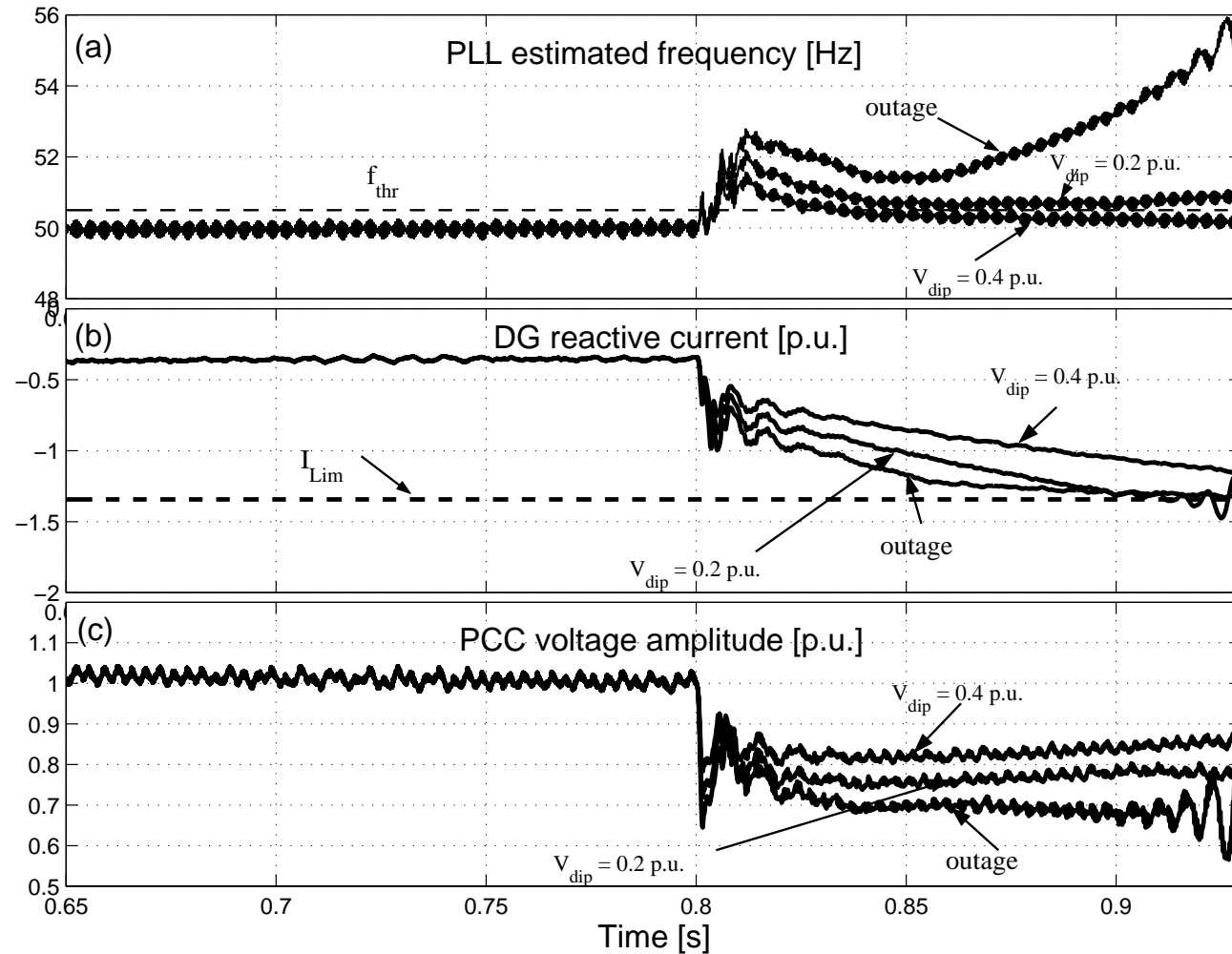
Active islanding detection - weak grid



Island load: quadratic voltage dependent $\Delta P = 0.15$ pu, $\Delta Q = 0$

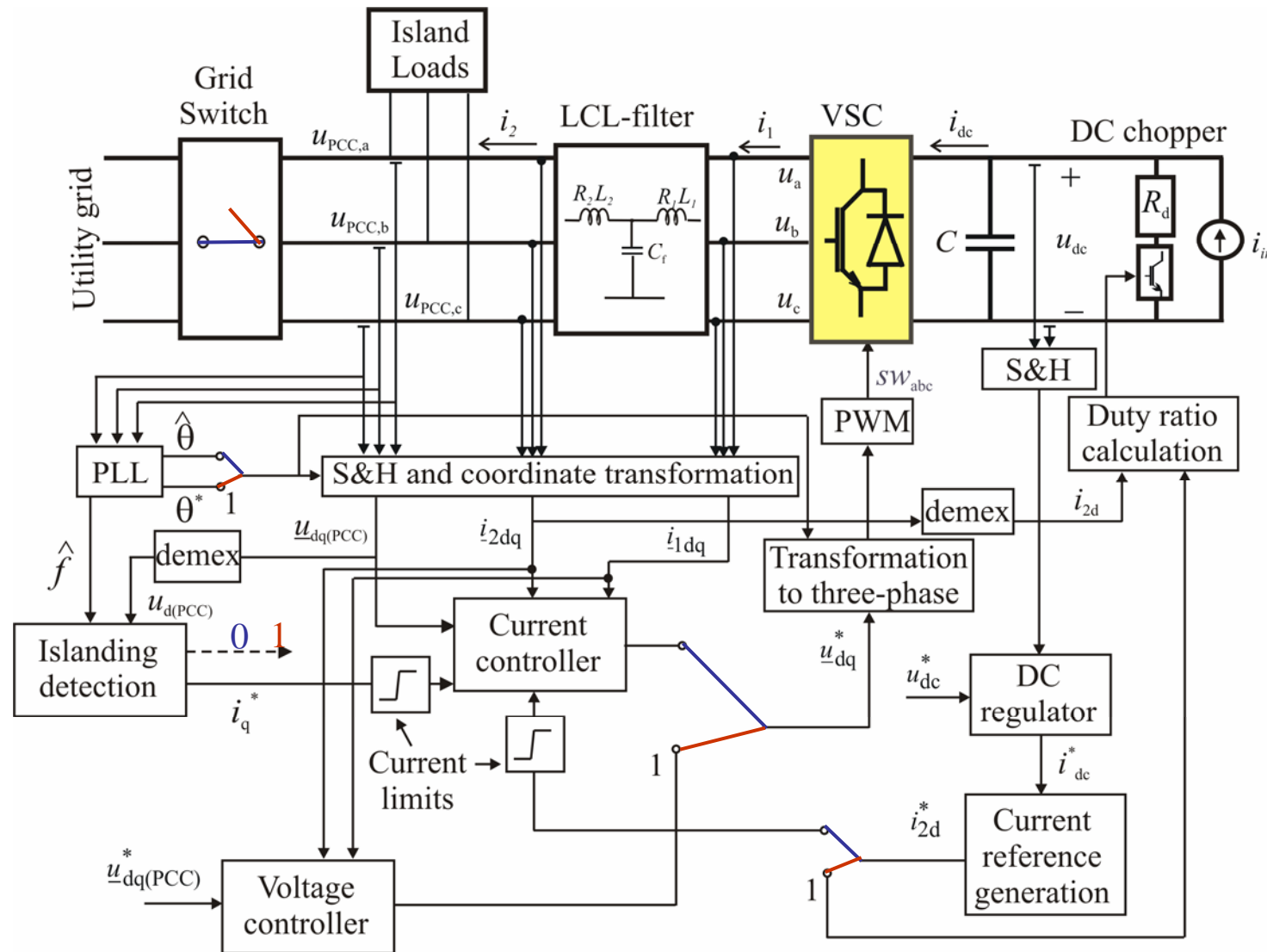
Setting the reactive current limit

I_{Lim} is set to ride-through dips of 0.3 p.u. amplitude



Island load: IM, load inertia = 0.6 kg.m², $\Delta P = 0.4$ pu

Transition from parallel operation to island operation



Operation from grid connected to island to grid connected

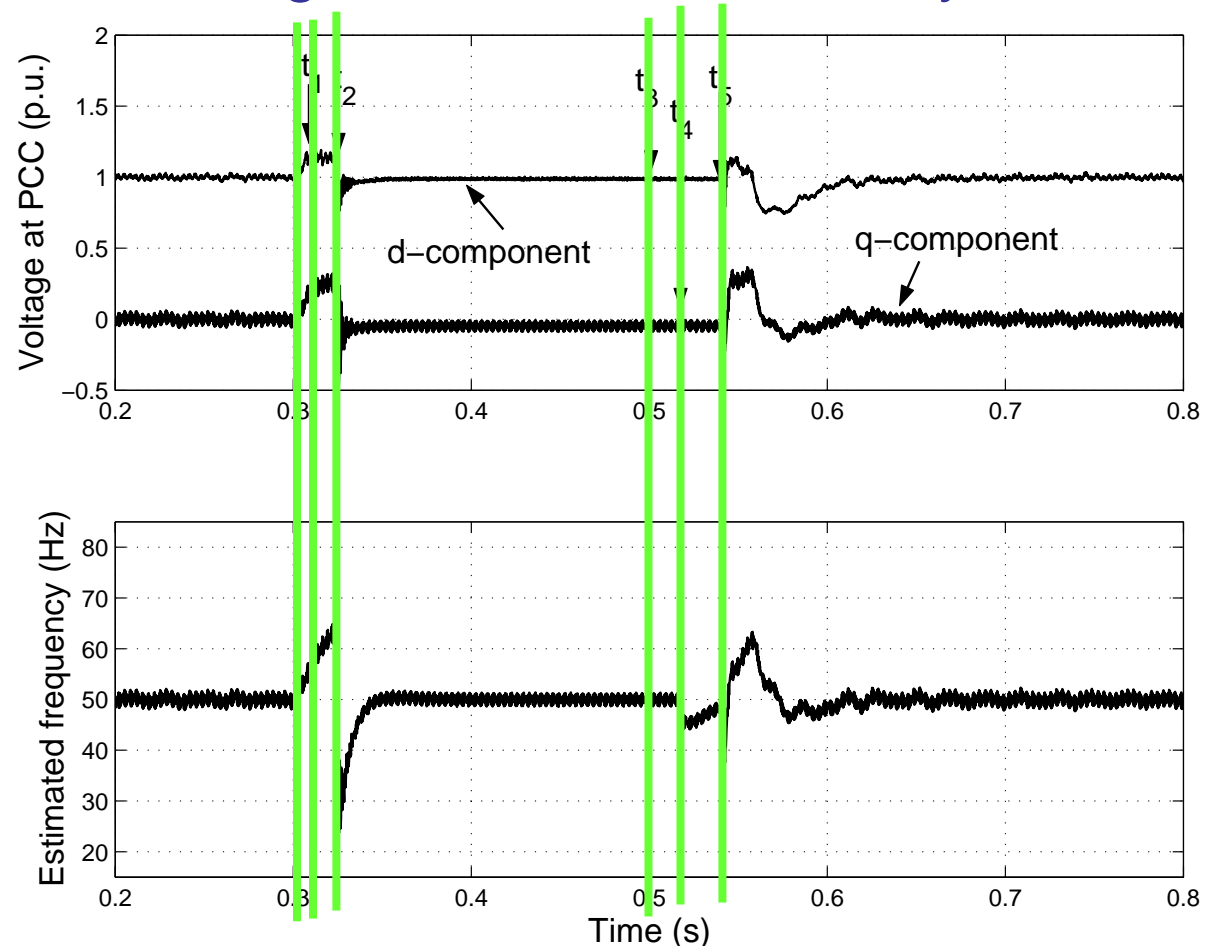
Grid outage at 0.3 s and recovery at 0.5 s

t_1 detection starts

$t_1 \rightarrow t_2$ time threshold

$t_2 \rightarrow t_5$ island operation

t_4 synchronization starts



Island load: quadratic voltage dependent $\Delta P = 0.55$ pu, $\Delta Q = 0.2$

Conclusions

Voltage dips ride-through capability

- A ride-through capability is possible by over-sizing the VSC.
- Using the statistics of the most frequent dips in a specific network or decreasing the input power from the primary source could be beneficial for the economical (optimal) sizing.

Voltage compensation capability

- The voltage compensation limit should be regarded according to a specific grid and DG site.

Conclusions

Intentional Islanding Capability

- Active islanding detection methods are preferred over the passive methods owing to less NDZ.
- Using the voltage regulator and setting a current limit are required to provide active islanding in weak grids.

Future work

- controllers in the $\alpha\beta$ -frame
- whole DR system with possible physical modification.
- parallel DGs that work within a micro-grid, with the possibility to assign different jobs for each unit or changing the structure of the grid according to the required functions (priority func).
- study of the interaction between the DG controller and the protection system.

*Thank you for
your attention*

