

Power Quality Control in Hybrid AC/DC Microgris

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Introduction



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Donadeo Innovation Centre of Engineering

Location: Edmonton Alberta, Canada Founded in 1908 18 Faculties 400 programs



ECE research building

Faculty of Engineering: 4000 undergraduate 1600 graduate students

Introduction



Topics

1. Hybrid AC/DC Microgrids

- Hybrid AC/DC microgrids structure
- Power quality in hybrid AC/DC microgrid
- Interfacing converters and control

2. Power Quality Control Through Interfacing Converters

- AC and DC grids support
- Unbalance compensation
- Harmonics control



Future Power Systems



Source: www.clean-coalition.org



AC Coupled Microgrid



- AC-coupled microgrid is the dominant structure now due to its simple structure and simple control and power management scheme.
- ➤ High frequency AC bus/link is possible.



DC Coupled Microgrid Hybrid Microgrid Interlinking AC Bus DC Bus **Converters** (ILCs) DC Utility \boxtimes DC/DC Distributed Grid DC/AC Generation/ DC/AC AC Distributed AC/DC Generation AC Load DC/AC Storage Bidirectional **Element** (if Converter necessary) **DC Load** AC Load

- Interlinking converters (ILCs) are used to link the DC and AC buses.
- Variable frequency AC load can be connected to DC bus.
- The DC-coupled microgrid features simple structure and does not need any synchronization when integrating different DGs.
- Some SEs can be connected to DC bus directly without converters



Hybrid AC/DC Coupled Microgrid



- Both DC and AC buses have DGs and SEs, and these buses are linked by interlinking converters (ILC).
- > Probably the most promising microgrid structures in the near future.
- Requires more coordination between the DC and AC subsystems.

1.2 Power Quality





General residential distribution feeder in North America

Distribution system loads:

- Distributed loads
- Single phase loads
- Nonlinear loads energy efficient loads.

1.2 Power Quality





Household CFLs growth prediction

Data: Lawrence Berkeley National Lab

	Appliance	Harmonic Load Current (%)						
		1 st	3 rd	5 th	7 th	9 th	11 th	13 th
	CFL	100	87	60	47	47	40	26
	LED	100	73	26	27	58	15	16
	PC	100	78	49	19	12	14	14

Harmonics of some nonlinear loads (typically THD > 100%)

Salles et al, "Assessing the Collective Harmonic Impact of Modern Residential Loads", *IEEE Trans. Power Delivr.* vol. 27, no. 4, pp. 1937-1946, Oct. 2012.

Nonlinear loads are rapidly increasing in distribution systems

- More efficient loads (CFL, LED, ASD fridge, LED, high efficiency washer, etc.) are increasingly adopted
- Many of them produce high harmonics
- Residential system voltage THD in North America will reach 5% soon



The power quality issues are becoming urgent for future distribution systems:

- DC subgrid voltage variations and harmonics
- AC subgrid voltage variations:
 - Frequency deviation
 - Voltage magnitude change (particularly with DG)
- AC subgrid voltage unbalance:
 - Utilities in Canada already experienced tripping of loads due to severe unbalance
- AC subgrid voltage harmonics.
 - Distribution system voltage THD is deteriorating
 - PFC capacitors further complicate the situation
- Traditional centralized power quality compensation does not work well

1.3 Interfacing Converters



DC/AC interfacing converters



Single stage DC-AC



Double stage (DC-DC and DC-AC)

AC/AC interfacing converters



Two stage (AC-DC-AC)



Multiple stage conversion





Control of Interfacing Converters - Manly for Real and Reactive Power Flow

- The DC-AC interfacing converters (including DC-AC bus interlinking converter) can work on:
- Bi-directional power control mode:
 - Current control method (CCM) mostly used for grid-tied converters
 - Voltage control method (VCM) droop control, virtual synchronous generator.
- DC link voltage control mode (for DC-AC bus interlinking converter): balancing the power generation and consumption on DC bus.
- AC link voltage control mode: mainly for stand-alone microgrid operation.

Topic 2



Power Quality Control using Interfacing Converters

- Renewable energy based DG systems, energy storage system, and DC-AC interlinking converter usually have available rating for ancillary services such as:
 - Grid support
 - Unbalance compensation
 - Harmonics compensation



- Ancillary services for DG/SE and microgrid systems are becoming an important issue that can further improve the system cost effectiveness
- Distributed compensation is more effective than centralized compensation due to the distributed loads



AC Grid Support Functions

The grid-supporting power converter can be controlled as a current source (CCM) or voltage source (VCM).



Grid voltage amplitude and frequency support control: CCM

- The frequency variation is controlled by the active power while the reactive power controls the amplitude of voltage.
- ▶ The frequency and voltage controllers are proportional controllers (K_p and K_q) for realizing the inverse P f and Q V droop control.

2.1 Grid Support



AC Grid Support Functions



Grid voltage amplitude and frequency support control: VCM

- When the power converter works as a controllable voltage source, a linking impedance (physical or virtual) is necessary between the converter and grid.
- > The active and reactive power controllers are proportional controllers (k_P and k_q) for realizing P f and Q V droop control.



AC/DC Grid Support Example on ILC control for AC/DC grid support



Loh et al, "Autonomous Operation of Hybrid Microgrid With AC and DC Subgrids", IEEE Trans. Power Electron. vol. 28, no. 5, pp. 2214-2223, May. 2013

Equalizing the AC side normalized frequency and DC side normalized voltage and determine the ILC power reference

A possible improvement is to consider AC & DC grid stiffness

PCC

ILC works in power control mode

Grid

2.2 Unbalance Compensation

- Unbalance voltage affects power equipment, introduces double-frequency oscillations on DC bus, increase converter AC current peak/harmonics
- Negative sequence current can be generated through interfacing converter to reduce negative sequence voltage at PCC



Equivalent circuit for unbalance compensation



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Reference power and positive and negative sequence voltages generate the reference currents of inverter:

$$I_{\alpha}^{*} = P^{*} \left(\frac{\mathbf{k}_{1}}{|\mathbf{v}^{+}|^{2}} V_{\alpha}^{+} + \frac{(1-\mathbf{k}_{1})}{|\mathbf{v}^{-}|^{2}} V_{\alpha}^{-} \right) + Q^{*} \left(\frac{\mathbf{k}_{2}}{|\mathbf{v}^{+}|^{2}} V_{\beta}^{+} + \frac{(1-\mathbf{k}_{2})}{|\mathbf{v}^{-}|^{2}} V_{\beta}^{-} \right)$$
$$I_{\beta}^{*} = P^{*} \left(\frac{\mathbf{k}_{1}}{|\mathbf{v}^{+}|^{2}} V_{\beta}^{+} + \frac{(1-\mathbf{k}_{1})}{|\mathbf{v}^{-}|^{2}} V_{\beta}^{-} \right) - Q^{*} \left(\frac{\mathbf{k}_{2}}{|\mathbf{v}^{+}|^{2}} V_{\alpha}^{+} + \frac{(1-\mathbf{k}_{2})}{|\mathbf{v}^{-}|^{2}} V_{\alpha}^{-} \right)$$

k₁ and k₂ provide flexible control of positive and negative sequences while adjusting power oscillation, max current, etc..

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Unbalance Voltage Compensation Control

Control scheme switched from **positive-sequence current injection** to **unbalance compensation** (k_1 and k_2 adjusted to reduce real power oscillation)





Parallel Interfacing Converters under Unbalanced Voltage:



The active-reactive powers oscillations of ith-ILC can be controlled using scalar coefficients k_{pi} and k_{qi}:

$$i_{i}^{*} = i_{pi}^{*} + i_{qi}^{*} = \left(\frac{P_{i}}{|v^{+}|^{2} + k_{pi}|v^{-}|^{2}}v^{+} + \frac{P_{i}k_{pi}}{|v^{+}|^{2} + k_{pi}|v^{-}|^{2}}v^{-}\right) + \left(\frac{Q_{i}}{|v^{+}|^{2} + k_{qi}|v^{-}|^{2}}v^{+}_{\perp} + \frac{Q_{i}k_{qi}}{|v^{+}|^{2} + k_{qi}|v^{-}|^{2}}v^{-}_{\perp}\right)$$

- For n-parallel ILCs, the power (DC bus) oscillations caused by the converters can be properly utilized to cancel each other
 - ✤ A redundant ILC to cancel the effects of other ILCs
 - All ILCs participate according to their available ratings

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Parallel Interfacing Converters under Unbalanced Voltage

Three ILCs with rated power: S1=9kVA, S2=4kVA, S3=10kVA From positive-seq current injection to unbalance comp with peak current sharing





Harmonics Compensation

- Nonlinear loads cause PCC voltage distortions, especially in a weak grid.
- Interlinking converter (or DG interfacing converter) can absorbed the nonlinear load current and improve the PCC voltage quality.
- The converter side impedance should be controlled



Equivalent Circuit

2.3 Harmonics Compensation

Harmonics Compensation - CCM based control



- Harmonic compensation achieved by controlling the converter as a shunt active power filter (APF)
- Fundamental current reference is generated by the output power control
- Reference harmonic current produced by grid side voltage harmonics (V_{PCC_h}) and a virtual resistance R_h.
- The DG acts as a small resistance at the harmonic frequency (R-APF).
- R_h can be adaptively controlled according to the available converter rating (to avoid interference with primary function of real power generation)

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2.3 Harmonics Compensation SALBE

Harmonics Compensation - VCM based control



- > Converter harmonic voltage is controlled as $V_{h_ref} = -G \cdot V_{PCC_h}$
- > Then the equivalent harmonic impedance at converter side: $Z_{ILC_{eq}} = Z_{ILC} / (1+G)$
- Harmonic impedance at converter side can be controlled substantially lower than that at grid side – nonlinear load currents flow to converter

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2.3 Harmonics Compensation



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Conclusions



- With more controllability and flexibility in a microgrid system, valuable ancillary functions can be provided for better grid operation and better power quality.
- Voltage support is the most widely implemented ancillary functions now.
- Unbalance and harmonics compensation is becoming more important with the increasing single phase and nonlinear loads virtual impedance control can facilitate the unbalance and harmonics compensation.
- Coordinated virtual impedance control is important in multiple converters for optimal task sharing (considering PFC and harmonics resonance) and void circulation current.
- To encourage more ancillary functions, relevant grid codes, polices and markets are required.



Future research direction on hybrid AC/DC microgrid power quality control:

- Parallel operation of DC-AC interlinking converters (ILCs) between DC and AC subgrids.
- Harmonics compensation and control with low switching frequency new converter topologies, new PWM techniques.
- Multiple converter interactions resonances, impedance variations, damping.
- System level coordination through supervisory control (SCADA).

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