Distributed Generation & Microgrids: Is There a Limit to Decentralization?

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Traditional low voltage grid

- Limited number of loads
- Energy supplied top-down from central power station

- Increased loading
- Increased distortion: due to non-linear (power electronic) and sensitive loads power quality problems arise
Evolution in electrical energy

• **3 technological drivers**
  ▪ Power electronics (PE) becomes ubiquitous in loads, generators and grids
  ▪ More power produced (and stored) near consumers: Distributed Energy Resources (DER)
  ▪ Increased importance of Power Quality (PQ): more disturbances and more sensitive devices

• **3 socio-economic tendencies**
  ▪ Liberalization of energy markets
  ▪ More sustainable energy (renewable and ‘high-quality’)
  ▪ Non-guaranteed security of supply
DER technologies

- Distributed Generation:
  - Reciprocating engines
  - Gas turbines
  - Micro-turbines
  - Fuel cells
  - Photovoltaic panels
  - Wind turbines
  - CHP configuration

- Energy Storage
  - Batteries
  - Flywheels
  - Supercapacitors
  - Rev. fuel cells
  - Superconducting coils

Power electronic dominated grids

Source: KEMA
Grid of tomorrow?

- Local generation
- Local storage
- Controllable loads
- Power quality and reliability is a big issue

- System’s future size?
  - Growth:
    - Consumption rises annually 2-3%
    - Investments in production: very uncertain
      - What is accepted? What is possible in regulatory framework?
  - Short-term: make balance by introducing DG?
  - Long-term: more storage and/or ‘activate loads’?
Microgrid?

• Grids may even separate from central supply
  ▪ No net power exchange: total autonomy
  ▪ Important aspect, characterizing a Microgrid
    ○ “Ancillary Services” are all delivered internally
      ▪ Balancing the active and reactive power
      ▪ Stabilizing the grid: frequency, voltage
      ▪ Providing quality and reliability: unbalance, harmonics, ...

• Is a Microgrid new?
  ▪ It all started that way, before interconnection
  ▪ In fact, no: the grid behind certain UPS systems are driven like a microgrid with one generator
How much local sources can a distribution grid accept?

• Distribution grid was never built for local power injection, only top-down power delivery

• Electrical power balance, anytime, in any grid:
  \[ \text{Electricity produced} - \text{system losses} = \text{electricity consumed} - \text{storage} \]

• Barriers to overcome:
  - Power quality & reliability
  - Control, or the lack of
  - Safety
  - Societal issues
  - Economic aspects
• Problem:
  - Bidirectional power flows
  - Distorted voltage profile
  - Vanishing stabilizing inertia
  - More harmonic distortion
  - More unbalance

• Technological solution:
  - Power electronics may be configured to enhance PQ
  - DG units can be used as backup supply
Example: MV cable grid

Substation connecting to HV-grid

Location: Leuven-Haasrode, Brabanthal + SME-zone
Impact of wind turbine
• Problem:
  - Generators are NOT dispatched in principle
    - Weather-driven (many renewables)
    - Heat-demand driven (CHP)
    - Stabilising and balancing in cable-dominated distribution grids is not as easy as in HV grids

**active power** ↔ **frequency**

**reactive power** ↔ **voltage**
Networked system operations

- **Solutions:**
  - Higher level of control required to coordinate balancing, grid parameters?
  - Advanced control technologies

- **Future technologies, under investigation**
  - Distributed stability control
    - Contribution of power electronic front-ends (see example)
  - Market-based control
    - Scheduling local load and production, by setting up a micro-exchange (see example)
  - Management of power quality
    - Customize quality and reliability level
  - Alternative networks
    - E.g. stick to 50/60 Hz frequency? Go DC (again)?

- Rely heavily on intensified communication: interdependency
Example: fully decentralized control

- Standard method: “droop control”
- KUL method: Virtual Impedance method
  - Emulate a voltage source with internal tunable impedance in the time domain
  - Ref.: K.De Brabandere et al. @ PESC’04
- Advantage: seamless transition from grid-connected to island and reconnect

![Diagram showing control system components and interactions](image.png)
Experimental results: connection of two independent grids (islands)

voltage before

current before

voltage after

current after
Example: tertiary control on local market

- DG units locally share loads dynamically based on marginal cost functions, cleared on market.
Safety

• Problem:
  ▪ Power system is designed for top-down power flow
  ▪ Local source contributes to the short-circuit current in case of fault
    o Fault effects more severe
    o Difficult to isolate fault location
  ▪ Bidirectional flows
    o ‘Selectivity’ principle in danger: no backup ‘higher in the grid’ for failing protection device
  ▪ Conservative approach on unintentional islanding

• Solution:
  ▪ New active protection system necessary
Societal issues

• Problems:
  - Environmental effects
    - Global: more emissions due to non-optimal operation of traditional power plants
    - Local effects as power is produced on-the-spot, e.g. visual pollution
  - Making power locally often requires transport infrastructure for (more) primary energy
    - Problem is shifted from electrical distribution grid to, for instance, gas distribution grid!

• Solution:
  - Multi-energy vector approach
  - Open debate on security of supply
Economic issues

• Problems:
  ▪ Pay-back uncertain in liberalized market
    o ‘Chaotic’ green and efficient power production
    o Reliability or PQ enhancement difficult to quantify
  ▪ System costs
    o More complicated system operation
    o Local units offer ‘ancillary services’
  ▪ System losses generally increase
  ▪ Who pays for technological adaptations in the grid? Who will finance the backbone power system?
    o Too much socialization causes public resistance

• Solution:
  ▪ Interdisciplinary regulation, not only legal
  ▪ Need some real ‘deregulation’
System losses example

- DG introduction does not mean lowered losses.
- Optimum is 2/3 power at 2/3 distance.
- Other injections generally cause higher system losses.

Power flow along cable:

Before DG

After DG

DG (2.68 MW)

Zero point
Balancing question, again

- Fundamental electrical power balance, at all times is the boundary condition:

\[
Electricity \text{ produced} - \text{ system losses} = electricity \text{ consumed} - \text{ storage}
\]

- All sorts of reserves will decrease in the future
- Role of storage? Storage also means cycle losses!
- Next step in enabling technologies
  - *Usable* storage
  - Activated intelligent loads (demand response technology), also playing on a market?
  - Boundary condition: minimize losses
How far can we go?

• Large *optimization exercise*, considering the different technical barriers:
  - Optimal proliferation, taking into account local energetic opportunities, e.g. renewables options
  - Unit behavior towards grid: technology choice
  - Control paradigm
  - Is the same level of reliability still desired?
  - Level of introduction of new additional technologies (storage, activated loads)

• Optima are different, depending on stakeholder
  - E.g. grid operator vs. client
Optimization example

- Total problem yields a huge mixed discrete-continuous optimization problem
  - Optimization goals: voltage quality penalty, minimum losses, minimum costs
  - Complexity: sample grid yields $2^{40}$ siting options for simple domestic CHP and PV scenario → need advanced maths
  - Results are different hourly and vary with time of year,

  e.g. during day: PV opportunities → in peak hours: CHP helpful
Conclusion

• Current grid:
  ▪ Interconnection
  ▪ Higher PQ level required
  ▪ DER looking around the corner

• History repeats: after 100 years the idea of locally supplied, independent grids is back
  ▪ Microgrids, being responsible for own ancillary services

• Maximum (optimal?) level of penetration of DER = difficult optimization exercise

• Special (technological) measures are necessary
  ▪ E.g. in system control, mainly balancing
  ▪ Role of loads?

• Not only technology push, but also customer pull
more information: 
http://www.esat.kuleuven.be/electa 
check publications sections, e.g.: 


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Thank you!
(now, let’s discuss)