Microgrids

Introduction & course organization

ELEN0445-1
Versions

• Version 1: 18/09/2017
• Version 2: 26/09/2017
Content of this lecture

• Introduction and motivation
• Organization and plan of the course
Introduction
A bit about my background

I apply optimization and machine learning to power systems

PhD: EDF’s generation assets scheduling

Management and design of European Day-Ahead market algorithm (Euphemia)

Active management of distribution networks and hosting capacity computation (GREDOOR project coordination)

Microgrids control
The current power system in “developed” countries

- It has been working seamlessly for users for decades
- at a relatively affordable price
- with a high service level
The current power system in “developed” countries

• Still relies heavily on hydrocarbons that will inevitably vanish

• Nuclear power is losing more and more public support, and becomes more expensive than other sources

• Is centralized and sometimes transmits energy on very long distances, which is not always good for reliability and efficiency

• Transmission grid extension faces public adoption issues

• Governments strive to organize smarter distribution grids because of the huge investments needed, the difficulty of coordination between the actors, the difficulty to leverage the demand-side flexibility, and the difficulty to make regulation evolve

• It is very hard to reproduce in some parts of the world
Can microgrids solve some of the cons while keeping the pros?
A bit of history: Edison vs. Tesla

• First grids followed Edison’s view, were DC and localized

• Tesla imposed the bulk/centralized view in AC
  ✦ More adapted to motors
  ✦ Easier to raise/decrease voltage level, thus reduce losses

• Now Edison view can be implemented because technically feasible:
  ✦ power electronics, energy storage, advanced load control, intelligent control, and communication
  ✦ (not necessarily through DC grids, although this could be an option).
First definition of a microgrid

A microgrid (MG) is a “complete” but small power system. It is a network of consumer, generation and storage devices that can be optimized *jointly* to satisfy goals*. It makes more sense when those devices are within clearly defined electrical boundaries. It is on the “*customer side*”, although it can be operated by a third party.

*We will see later on what are the goals, or functions of a microgrid
Components of a microgrid

• People (Yes, I think we should put them first)
• Consumption devices
• Generation devices
• Storage devices
• Inverters
• A network
• Sensors and actuators
Schematic example

POI: Point of interconnection, also called point of common coupling (PCC)

Microgrid

Source image taken from Typhoon HIL website
Copper plate assumption

In this course, unless stated otherwise, we neglect the network connecting the components of the microgrid.

This means mainly that we neglects losses, and other electrical phenomena that can be caused by the impedance of the cables connecting the devices.
Schematically

POI: Point of interconnection, also called point of common coupling (PCC)
Main goals of a microgrid

<table>
<thead>
<tr>
<th>Satisfy the demand with maximum reliability and power quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximize the renewable energy harvested locally</td>
</tr>
<tr>
<td>Minimise the total cost of electricity: local electricity may be cheaper than from the grid, at least periodically</td>
</tr>
<tr>
<td>Help the public grid</td>
</tr>
<tr>
<td>Local jobs, energy belongs to the people</td>
</tr>
<tr>
<td>May increase security of supply, through (long-term) storage</td>
</tr>
</tbody>
</table>
Why building/studying microgrids?

The development of distributed generation, the decreasing costs of storage means, and the evolution of communication and sensing technologies open new options to the conventional distribution of electric energy, and new options for integrating distributed generation smoothly in constantly evolving energy and ancillary services markets.

Energy markets and ancillary services markets defined on the next slides.
Energy markets

- Energy markets organize the sales and purchases of the electricity commodity
- They are organized by time frame (futures, day-ahead, intra-day)
- By actively participating to the market, you can obtain the electricity at the price you are willing to pay, or sell only if profitable.
- Examples of market operators: Epex-Spot, NPS, ...
- Microgrids are most of the time too small to access to the market. They’ll have to go through a “third party”, i.e. a retailer + balance responsible party (BRP)
Market operators, retailers and producers should not to be confused with System operators (SO):

✦ E.g. ELIA is the Belgian Transmission System Operator (TSO)
✦ E.g. Nethys Resa and ORES are Distribution System Operators (DSOs) in the Walloon region
Ancillary services markets

• Ancillary services (AS) are offered by entities that have the ability to modulate their generation or consumption, within respecified boundaries and time frame, to help the system:
  ✦ for **balancing** generation and demand
  ✦ for **relieving congestions**
  ✦ for **voltage support**

• AS markets are organized by the TSO (e.g. ELIA in Belgium) for balancing services, and also by the DSO for local services (this is currently a topic of active discussion)
Differences with a classical power system

- Sharing economy
- Local / circular economy
- Increased resilience / robustness
- Capitalise on local data
- Simpler decision chain / interaction model
Community microgrids

**Single-user microgrid**: loads, generation, storage, a network, a connection to the grid (the definition of a micro-grid we have seen so far)

Note: legal, e.g. your house with PV and storage.

**Community microgrid**: a group of single-user microgrids + a microgrid operator.

Note: legal or not depending on the region you live in and the particular situation

Forming a local community allows reaching a critical size, but opens up other issues (regulatory, organizational, of fairness, etc.)
A (grid-tied) microgrid offers many value creation mechanisms

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>BSS*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy markets</td>
<td>Decide on the price you are willing to pay/sell</td>
<td>++</td>
</tr>
<tr>
<td>Ancillary services</td>
<td>Sell services to the grid</td>
<td>++</td>
</tr>
<tr>
<td>Peak reduction</td>
<td>Through local and community optimization</td>
<td>++</td>
</tr>
<tr>
<td>UPS functionality</td>
<td>Operate in islanded mode</td>
<td>++</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Through optimized load and generation management</td>
<td></td>
</tr>
<tr>
<td>Community</td>
<td>Exchange energy locally at a preferred tariff</td>
<td>++</td>
</tr>
</tbody>
</table>

*BSS: Battery Storage System
Advantages for the public grid

<table>
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<tr>
<th>Function</th>
<th>Description</th>
<th>BSS*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak reduction / flow management</td>
<td>Momentarily set constraints to the microgrid</td>
<td>++</td>
</tr>
<tr>
<td>Voltage support</td>
<td>Reactive power flexibility of battery storage and PV</td>
<td>++</td>
</tr>
<tr>
<td>Phase balancing</td>
<td>Using storage DC buffer</td>
<td>++</td>
</tr>
<tr>
<td>Power factor correction</td>
<td>Flexibility of inverters</td>
<td>++</td>
</tr>
<tr>
<td>Frequency support</td>
<td>Primary or secondary reserve</td>
<td>++</td>
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</tbody>
</table>

*BSS: Battery Storage System*
A taxonomy of microgrids

• There are many possible configurations of “microgrids”, depending on whether they are physically or virtually connected (in terms of metering), localized or not, ...

• See Uber-like Models for the Electrical Industry, Damien Ernst, 2017 for a broader picture of possible evolutions of the power system, their advantages and disadvantages.
Off-grid microgrids

• Off-grid microgrids are a special case of microgrid

• They have no connection to a public grid either because
  • the public grid does not exist
  • the public grid exists but is unreliable

• Some people may also want to isolate from the grid for other technical, philosophical or regulatory reasons.

A microgrid is smaller, so necessarily there are less economies of scale than in the current power system

Yes and no!

✦ Yes if it is assumed that

- Generating electricity remotely and in large quantities is economically and environmentally efficient
- Building a large transmission and distribution system is feasible, both economically and financially

✦ No if it assumed that:

- Producing energy locally is actually affordable and easily implementable
- Heat and electricity are both needed
- Building a transmission and distribution is infeasible
- Storage (both short-term and long-term) is affordable and efficient.
Microgrid controllers

A microgrid controller is a software that is sensing the microgrid (currents, voltages, frequency, etc.) and taking control actions so as to operate safely, reliably and optimally the microgrid.

In practice, a microgrid is run by multiple controllers, because there are several levels of control, which vary by their spatial and temporal scopes.

Next to technological advances in production, consumption and storage, controllers are key elements for advanced microgrids.
# Control levels

<table>
<thead>
<tr>
<th>Level</th>
<th>Function</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Device level control</td>
<td>BSS control, reactive control, MPPT</td>
</tr>
<tr>
<td>2</td>
<td>Local area control</td>
<td>Frequency regulation, fast load shedding</td>
</tr>
<tr>
<td>3</td>
<td>Supervisory control</td>
<td>Forecasting, operational planning</td>
</tr>
<tr>
<td>4</td>
<td>Public Grid interaction</td>
<td>Ancillary services, energy markets</td>
</tr>
</tbody>
</table>

We will be mainly focused on levels 3 and 4, and a bit about level 2
Some functions of microgrid controllers

• Frequency control
  ✦ balance generation and load => maintain frequency
  ✦ fast real-time, milli seconds
  ✦ Some predefined primary sources respond to frequency deviation [droop control]

• Voltage control
  ✦ Regulation of voltage a PCC within a respecified range [magnitude and phase]
  ✦ fast real-time, milli seconds
  ✦ Some predefined primary sources respond to voltage deviation [droop control]

• Grid connected to islanded transition : intentional or unintentional
  ✦ Islanded means MG keeps operating but is disconnected from main grid
  ✦ intentional means controller can prepare [e.g. start a genset, reduce current through PCC, etc.]
  ✦ unintentional means in reaction to a large disturbance, either internal or external to the MG
Some functions of microgrid controllers (2)

- Islanded to grid-connected transition
  - MG resynchronizes and reconnects to the distribution system
- Energy management: grid connected
  - Cf. all advantages offered by MG on previous slide
- Energy management: islanded
  - “Economy mode” to power critical loads as long as possible
- Microgrid protection
  - Configuration of protections of devices depending on operating conditions (e.g. islanded or not, a genes is up and running or not, etc.)
- Microgrid black start
  - Restore islanded operation after complete shutdown
The MeryGrid project and the EMS we are developing

With the support of the Wallon Government, in collaboration with Nethys, CE+T, Sirris, MeryTherm, SPI

A **smart** microgrid energy management system (EMS)

- exploits data to make the microgrid flexible, robust, and extract the maximum of value!
- has a community management feature
EMS modules

- Monitoring
  - Pull and store data
- Forecasting
  - Forecast consumption and production using past data
- Operational planning
  - Take decisions for next day
- Energy Market participation
  - Participate actively in energy markets
- Analytics
  - Present data, decisions and results
- State estimation
  - Calibrate models using data
- Real-time control
  - Take decisions for next seconds
- Reserve Market participation
  - Participate actively in reserve markets

Arrows indicate a dependency between functional modules, not a flow of information!
Course organization
Course organization

See my web page at

http://www.montefiore.ulg.ac.be/~cornelusse/

for all related to organization.
Content of the course

• Review microgrid components, technology and trends

• The main focus will be on design and optimal control of a microgrid
  ✦ Formulation of the associated control, optimization and machine learning problems
  ✦ With an introduction to the required mathematical background
  ✦ Detailed models of some components
  ✦ Reliability notions

• Mandatory assignments to practice all these concepts
Optional references for this course

Kwasinski, A., Weaver, W., & Balog, R. S. (2016). Microgrids and other local area power and energy systems. Cambridge University Press.

Mainly for the parts related to components description.


Main features of controllers, standards, use cases.
Important topics that are **not** covered in the course

- Detailed technical models and controllers of components (e.g. inverters):
  - For energy storage, see CHIM0664-1 “Electrochemical energy conversion and storage” by Nathalie Job.
  - For power electronics related topics, see ELEC0055-1 “Element of power Electronics”, by Fabrice Frebel

- Organization of energy markets: ELEC0018-1 “Energy Markets” by Damien Ernst

- Real-time control and stability are covered much more in depth in:
  - ELEC0047-1, “Electric power systems dynamics, control and stability”, by Thierry Van Cutsem

- Protection devices and protection schemes
Evaluation: oral exam + assignments

Nominal evaluation scheme: **100 points to earn**

Oral exam in January, value: 40 points

Assignments along the way (see due dates on the website)

<table>
<thead>
<tr>
<th>#</th>
<th>Description</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lab description</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Operational planning through optimization</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Sizing a microgrid</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>Machine learning for operational planning</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>Real-time control</td>
<td>13</td>
</tr>
</tbody>
</table>

For those that do not pass in January: “only” an oral exam in August
Assignment #1: lab description

Visit the lab, draw a schematic highlighting the equipments, how they are connected together, their ratings, where sensors are placed, and write a small text explaining what you understand of the concept.

- Max 3 pages, 11pt font, one column
- See due date on course webpage
- Send report to me by mail
- Groups are not allowed