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Tools for Microgrid Design

(The Need for Dynamic Simulations)

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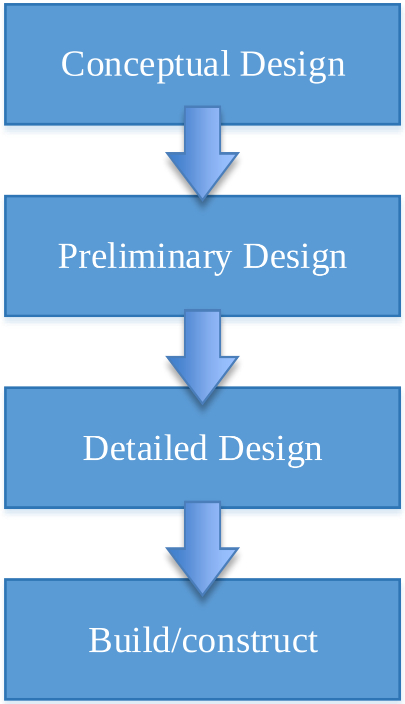
ARPA-E Workshop: Engineering Microgrids with Control Co-Design
September 5th, 2020

Overview

Part 1: Microgrid Design

Part 2: Classes of Simulation and Analysis

Part 1: Microgrid Design



Microgrid Design Process

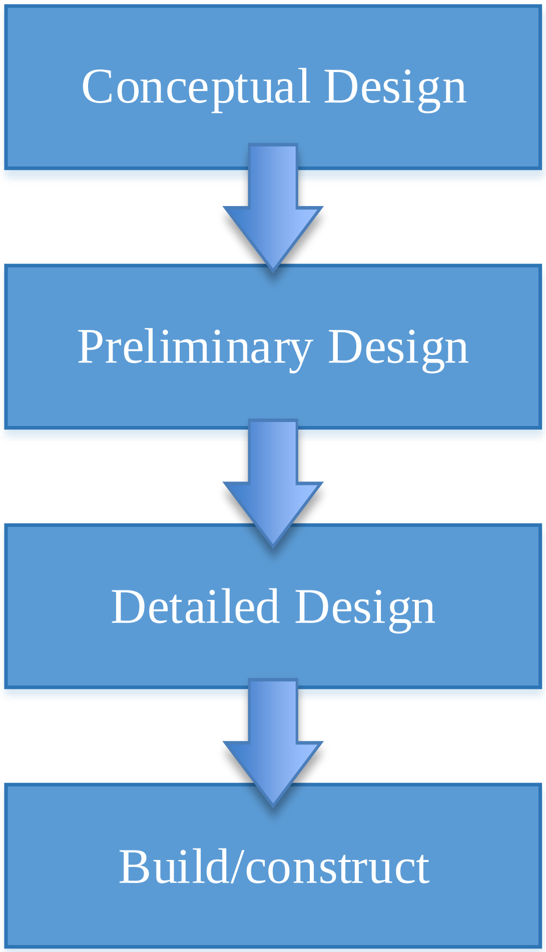
- A microgrid is not a single technology. Instead, a microgrid is a collection of generation sources, end-use loads, interconnecting equipment, and control systems.

- For a complete design it is necessary to ensure:
  - Proper sizing of generation to meet steady-state constraints.
  - Proper sizing of conductors to ensure proper voltages.
  - Validation that controls will support normal operations.
  - Validation of protection and simulations of abnormal conditions.

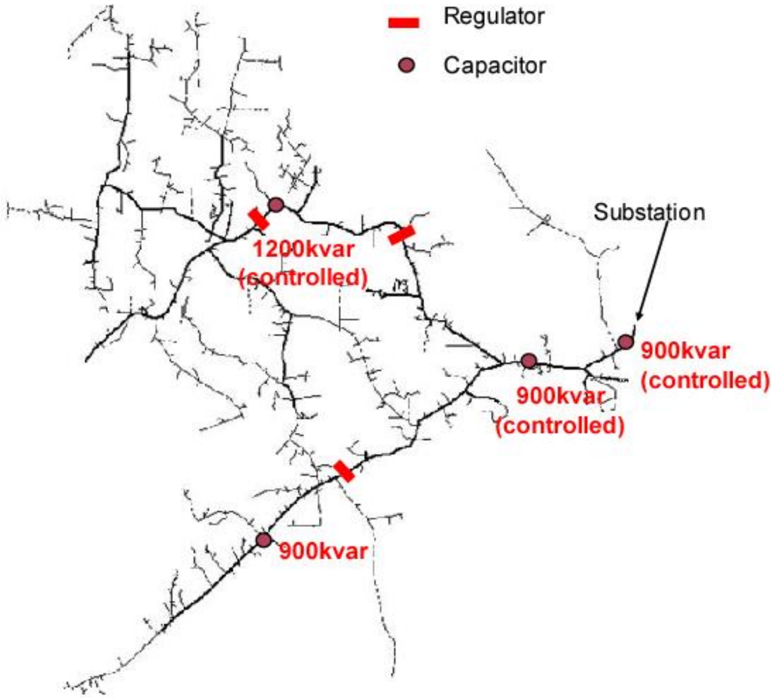
- As such, there is no single tool, or set of tools, that serve as a "standard" method to design a microgrid.

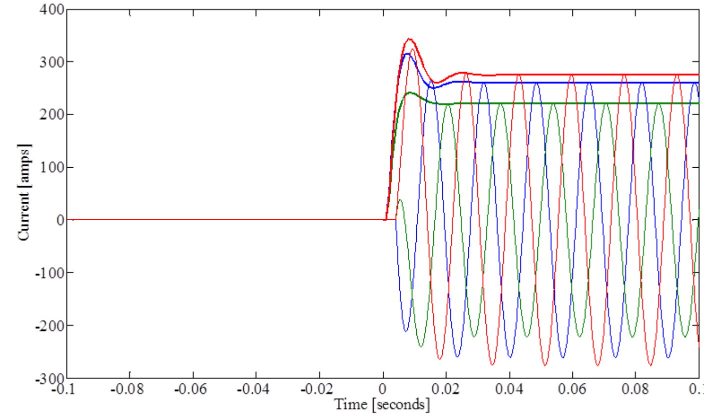
Microgrid Design Process (cont.)

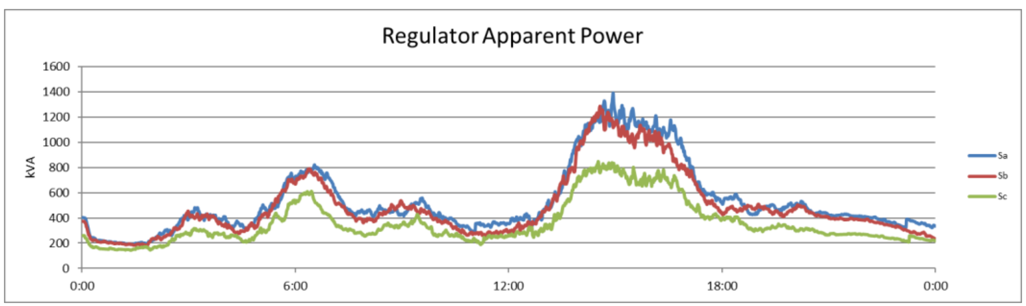
- As a capital project, a proper microgrid design follows the "standard" engineering design approach.
- At each stage of the design various levels of simulation and analysis are used.
  - **Conceptual**: general characteristics are selected, such as generation types. (e.g. diesel and PV generation will be used based on microgrid role(s))
  - **Preliminary**: general characteristics are clarified to specific examples. (e.g. diesel will regular frequency and PV will be grid-following)
  - **Detailed**: specific characteristics are examined, including a 90% design of the operational system. (e.g. equipment sizes are determined by specific vendors/models may not be determined)
  - **Build/construct**: this is the system as deployed. (e.g. deploy 4 1,250 kVA diesel generators with Woodward controls and 2,500 kW of solar PV with ABB PVS800 inverters.
- It should be noted that this is an approximate process, and the specific process will vary to some degree.



Part 2: Classes of Simulation and Analysis







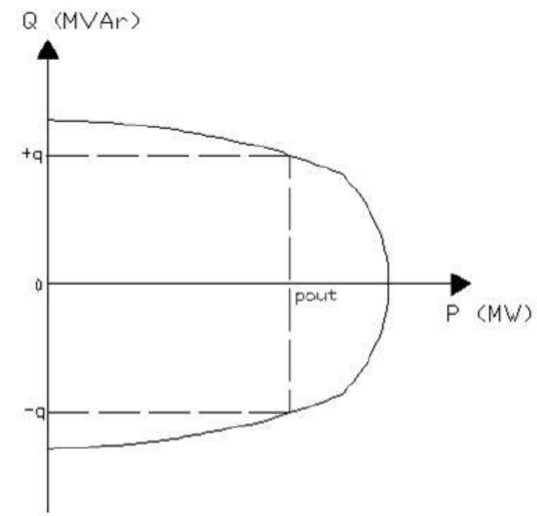


Figure 1. PQ Capability Curve of the Generator (Kundur, 1994)

Classes of Simulation and Analysis

- At each step in the design process simulations of various types are used, each with their own analytic basis.
- Some of these tools are more technologically mature than others.
- Because a microgrid is a complete power system, a wide-rage of simulations can be used to inform the design.
- While there are many commercial tools available, the basic functions can be grouped into four classes of analysis:
  - Forecasting
  - Optimization
  - Power Systems Simulation
  - Hardware-in-the-Loop (HIL)

- Forecasting
  - Loads
  - Weather
  - Distributed Resources
- Optimization
  - Optimal Equipment Sizing
- Power System Simulation
  - Power Flow
  - Fault Analysis
  - Time-Series Analysis
  - Electromechanical Simulation
  - Electromagnetic Simulation
- Hardware-in-the-Loop (HIL)
  - Controller HIL (CHIL)
  - Power HIL (PHIL)

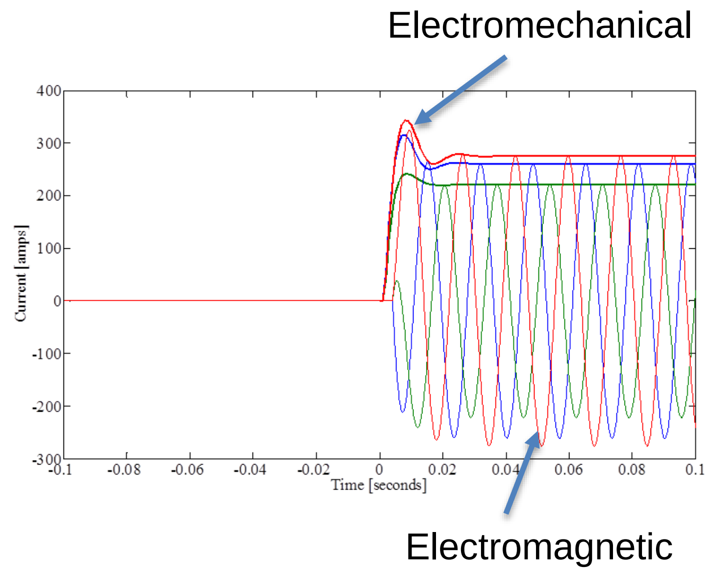
Power System Dynamics

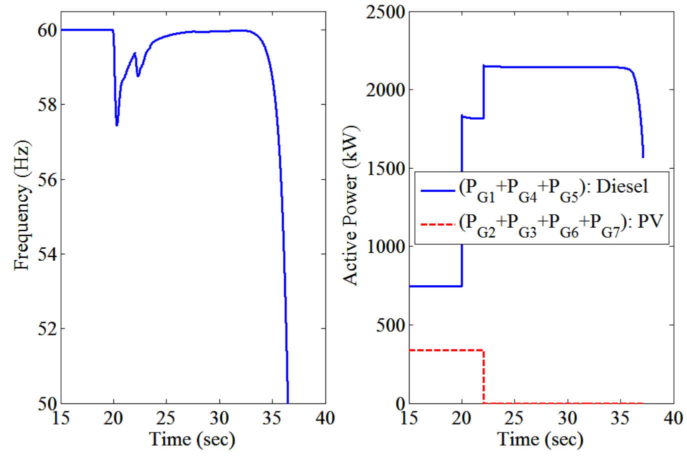
- The majority of existing microgrids were designed without detailed dynamic simulations, instead relying on a high system inertia to ensure stability. This is especially true for the operational transients, such as switching, which can affect stability.

- Power System Stability can be divided into three categories:
  - Rotor angle stability
  - Frequency stability
  - Voltage stability

- Microgrid operations require a system to be stable in all three categories, but the commercial tools do not readily support this type of analysis.

- Challenges to Dynamic Simulations:
  - Electromagnetic simulations can be conducted for small systems, but it is computationally challenging to model large systems.
  - Electromechanical simulations can be conduct on larger systems, but they have less detail.
  - Commercial electromechanical simulation tools often assume a “balanced” system.
  - Obtaining control system detail at a level to support simulation can be difficult, especially for equipment that is older.





Existing Simulation Tools for Microgrids

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- There are several tools that are available to conduct the various stages of analysis. These include, but are not limited to:

- Optimization
  - Microgrid Design Tool (MDT) (Sandia National Laboratories)
  - EPRI DER-VET (EPRI)
  - Distributed Energy Resources Customer Adoption Model (DER-CAM) (Lawrence Berkeley National Laboratory)
  - Remote Off-grid Microgrid Design Support Tool (ROMDST) (Lawrence Berkeley National Laboratory)

- Power Systems Simulation
  - CYME (Eaton)
  - Synergi (DNVGL)
  - WindMil (Milsoft)
  - GridLAB-D (Pacific Northwest National Laboratory)
  - OpenDSS (EPRI)

- Hardware-in-the-Loop (HIL)
  - Typhoon (Typhoon HIL)
  - Opal-RT (Opal RT)
  - Real Time Digital Simulator (RTDS Technologies)

Current Needs (Dynamics and Controls)

- While there are tools available for the various classes of simulation, dynamic simulation of full-size microgrid controls is still one of the existing gaps. The loss of stability can directly lead to blackouts for critical end-use loads.

- Currently dynamics and controls are most often examined with one of three options:
  - Use of a commercial transmission-level electromechanical simulation package that uses a balanced positive sequence representation.
  - Use of an electromagnetic solver that is unbalanced but is computationally expensive and requires a reduced-order model of the system.
  - Use of HIL which is limited in the size of the simulation by the HIL hardware available.

- GridLAB-D is an open-source tool that can do full-scale unbalanced electromechanical simulations, but it is still research grade software.

- There are still multiple needs to properly model the dynamics and controls of full-size microgrids:
  - **Improved solvers**: Most of the differential algebraic equations use the same formulation as 20 years ago.
  - **Improved multi-core capability**: Most solvers still use a single thread approach to solve differential algebraic equations.
  - **Improved generator models**: For accurate dynamics, it is necessary to have accurate models of power electronic inverters and their control modes. Generic models of rotating machines and power electronics are often not accurate enough.
  - **Improved load models**: The dynamics of end-use loads can significantly impact dynamic stability, as seen by the 1996 WECC Blackouts. Dynamic solvers need to move beyond constant power or impendence loads.
  - **Improved representation of active elements**: There is an increasing number of power electronics devices being deployed and their active controls must be modeled.