Passive vs Active Grid Reliability

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Introduction

• Background

• Passive vs Active

• Examples

• Perspectives
Theory

- Conservation of Energy
  - Newton’s Laws of motion
  - Kirchhoff’s laws of electricity
Grid Stability

- **Synchronization**
  - All generators ideally move together at a common speed (frequency).

- **Stability control**
  - Goal is to keep generators synchronized
  - Primarily controlled thru the generators
  - If grid is over stressed, grid goes **UNSTABLE** = system loses synchronism

- **Frequency control is NOT stability**
  - Frequency control is akin to keeping all the vehicles moving together. Conservation of Energy.
The Physics

Mechanical

Electrical
New Technologies and Goals

• **New Technologies**
  – More efficient, reliable, larger, and cost-effective converters
    • Wind and solar, DC transmission, Reactive modulation (SVC, TCSC, etc.), Dynamic braking, fly wheel storage, battery storage, etc.
  – Wide-area real-time time-synchronized measurements (PMUs).

• **Goals**
  – Reliably operate closer to grid stability limits.
  – Extend grid stability limits without constructing new transmission.
  – Integrate inverter-based generation.
Stability Solutions
Passive vs Active

• Passive
  – Increased transmission
  – Shunt capacitance/reactance
  – Increased inertia and voltage support (e.g., condensers)

• Active – Feedback Controls
  – PSS
  – Synthetic inertia
  – Converter modulation
    • PDCI damping controller
    • Synthetic inertia
Simple Passive Example

![Diagram of a simple passive example with a generator, transmission lines, and a synchronous grid. The diagram shows the impact of different transfer powers (P) on the generator speed.]

- **P = 0.6**
- **P = 0.65**

- **P = 0.95**
- **P = 1**
Large-Scale Damping Control Example
Western Interconnect
Western Interconnect

California-Oregon Intertie (COI)
Malin 500-kV Bus Voltage, Chief Joseph Brake test on July 21, 2011

Malin 500-kV Bus Voltage, June 8 2002 PDCI outage

Malin 500-kV Bus Voltage, August 4 2000 Alberta separation

Malin 500-kV Bus Voltage, August 10 1996 WSCC Outage
Example – Real Power Modulation

- **PDCI Modulation**
  - ±50 MW max.
  - Feedback = speed error across DC ends

- **Thyristor brakes**
  - 250 MW max.
  - Feedback = relative speed across N-S.
  - Only activated when DC control saturates (latched)
Example
(Simulation)
Renewable Integration Example
Simple Model

- Assume fault ride-thru.
- “Synthetic Inertia” concepts evolving for primary frequency control. Not intended for stability to date.
Condenser

Diagram showing a power system with a generator, transmission lines, a synchronous grid, and a condenser/flywheel system. The diagrams illustrate the impact of different power transfer scenarios (P = 0.6, 0.65, 0.7, 0.75) on the generator speed (Hz) over time (sec.).
No Condenser

Generator

Transmission

Synchronous Grid

Fault

P = Transfer Power

60 Hz

Generator

Transmission

Synchronous Grid

Fault

P = Transfer Power

0.3 pu

Gen. speed (Hz)

Time (sec.)

Time (sec.)

Gen. speed (Hz)

0 1 2 3 4 5 6 7 8 9 10

59 59.5 60 60.5 61

P = 0.6
P = 0.65

0 1 2 3 4 5 6 7 8 9 10

59 59.5 60 60.5 61

P = 0.6
P = 0.65
No Condenser

Black = No inverter gen, Red = 50% inverter gen

- Gen angle (deg.)
- Transfer Pe (pu)
- Gen Pe (pu)
- Wind Pe (pu)
Ideal Synthetic Inertia

![Diagram of Ideal Synthetic Inertia](image)

**Chart 1:**
- **Legend:**
  - Black line: $P = 0.6$
  - Red line: $P = 0.65$

**Chart 2:**
- **Legend:**
  - Black line: $P = 0.55$
  - Red line: $P = 0.6$
Ideal Synthetic Inertia

Black = No inverter gen, Red = 50% inverter gen

Gen angle (deg.)

Transfer Pe (pu)

Gen Pe (pu)

Wind Pe (pu)
“Fast” Realistic Synthetic Inertia

[Diagram showing power system components and waveforms]

- Generator
- Transmission
- Synchronous Grid
- Fault
- P = Transfer Power

Waveforms for different power levels:
- P = 0.6
- P = 0.65

Frequency variations over time (sec.)
“Fast” Realistic Synthetic Inertia
“Slow” Realistic Synthetic Inertia
“Slow” Realistic Synthetic Inertia
Perspectives

• Passive
  – Disadvantage: Passive solutions are limited by their physics.
  – Advantage: Passive solutions ALWAYS obey their physics.

• Active
  – Power electronics and wide-area measurements are enabling many new active possibilities.
  – Nearly all active solutions involve a feedback controller at some level.
  – Performance highly depends on controller tuning and settings.
  – Decentralization enables reliability (PSS units vs. PDCI damper).
  – Unintended consequences
    • E.g., synthetic inertia is not really inertia. It’s a controller; therefore, we need to treat it like a controller. Avoid confusing terminology like “synthetic inertia.”
  – Planning studies must consider the reliability of the active solution.