Controls & Communications Modeling

Section 5 of Task Force Report for “Microgrid dynamic modeling”

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Background and Motivation

- **System-level MG controllers** coordinate heterogeneous DERs

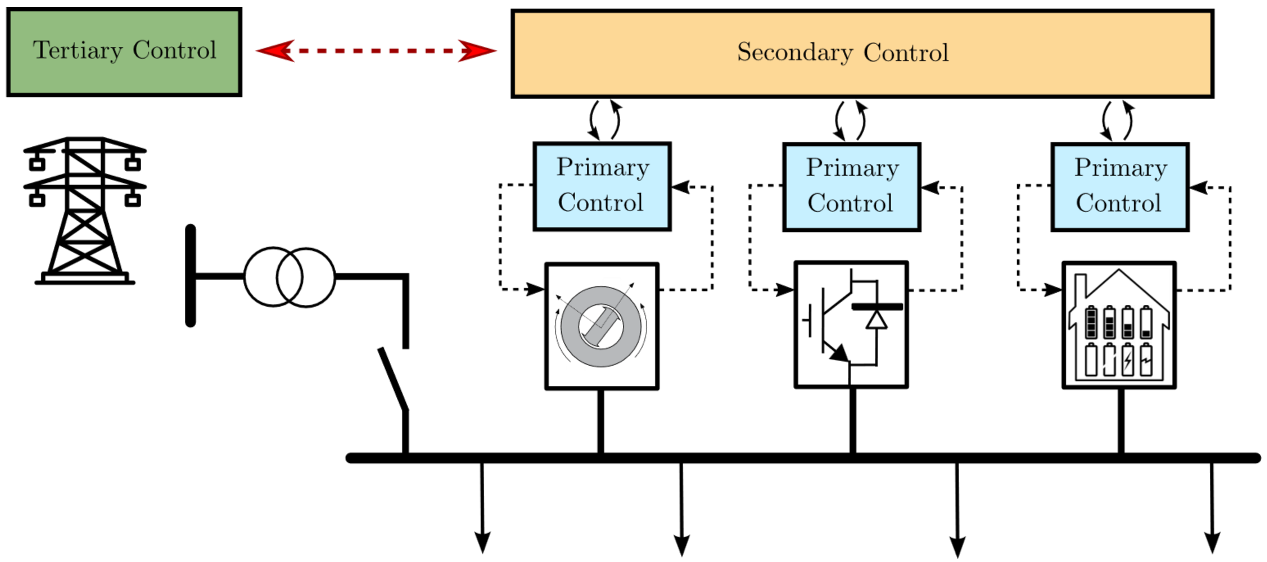
Architectures? Designs? Time-Scales?

- Controllers are implemented **digitally** and use **communication**

Discretization? Sampling rates? Comm. Issues?

Section Objective: Discuss, analyze, and illustrate the impact of these factors on MG dynamic stability and performance

System-Level MG Controls



Primary Control (Fast)

- **Objective**: stabilize MG frequency and voltage
- **Architecture**: decentralized
- **Time Constant:** ≈ 1 second
- **Typical Design:** P/f and Q/V droop control
- **Extras:** virtual impedance loops for IBG

$$\omega_i = \omega^* - m_i(P_i - P_i^*) + u_{\omega i}$$
$$V_i = V^* - n_i(Q_i - Q_i^*) + u_{Vi}$$

Impacts short-term stability

Secondary Control (Slow)

- **Objective**: f/V regulation, power sharing, energy management, …
- **Architecture**: centralized or distributed
- **Time Constant:** ≈ 5-10s
- **Typical Design:** various: integral control, optimization, MPC, …

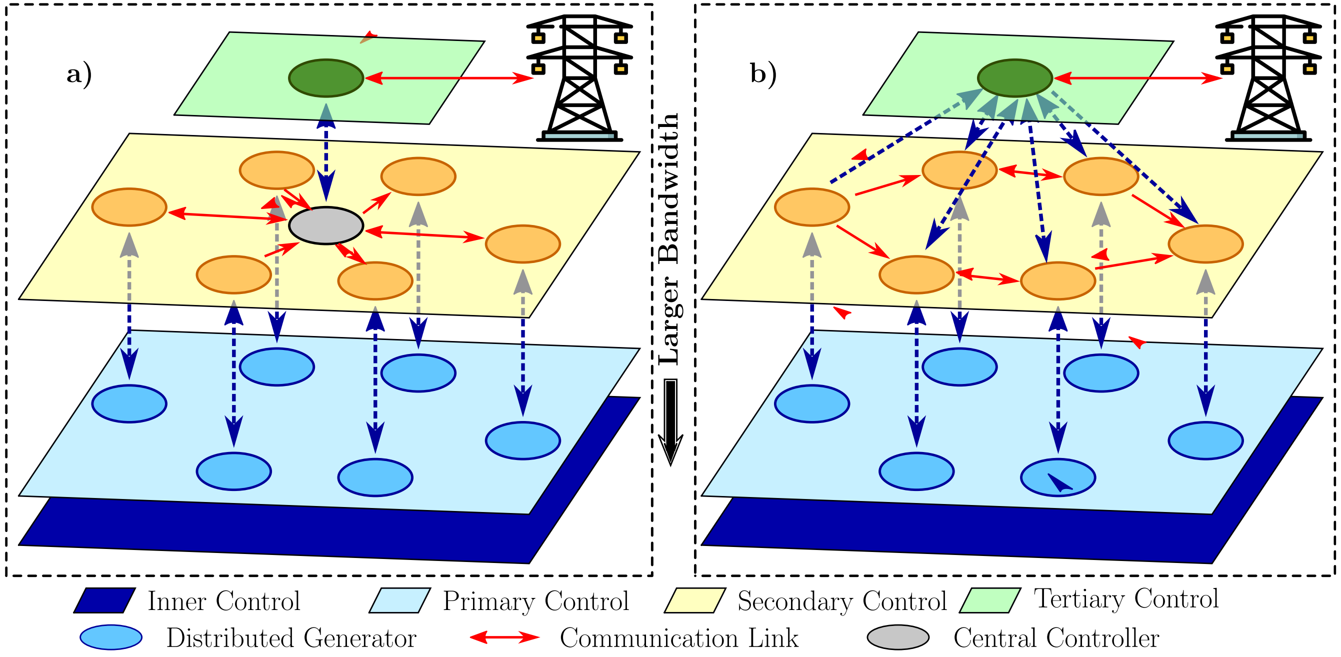
May impact MG stability!

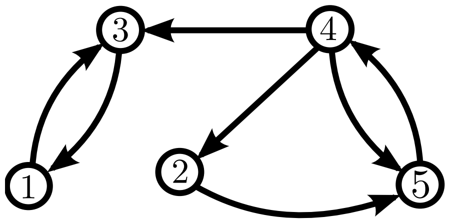
Tertiary Control (Very Slow)

- **Objective**: coordination with utility or other MGs
- **Architecture**: centralized
- **Time Constant:** ≈ minutes to hours

No impact on MG stability.

Centralized vs. Distributed Control





$$A = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

Distributed control is often expressed in the language of graph theory

Centralized Sec. Control

- Central processor collects data and computes control actions
- **Advantages:** simple, enables complex functionality (EMS)
- **Weaknesses:** single point of failure, lack of scalability

Distributed Sec. Control

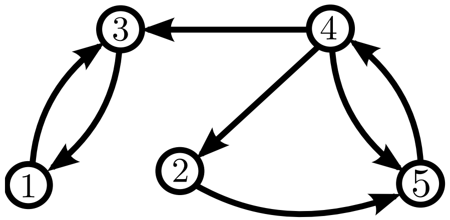
- Distributed processors share information to compute
- **Advantages:** resilience to failure, scalability
- **Weaknesses:** complex functionality difficult

Our focus: centralized vs. distributed secondary freq. and volt. control

Secondary Freq. and Volt. Controllers

Characteristics of good sec. control systems

- No interaction with primary control loops
- Adjustable time-constants
- Designed using zero or little model information



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Centralized integral control

$$e_\omega = -\Delta\omega_{MG}, \qquad u_{\omega\_i} = PI(e_\omega),$$

$$e_V = -\frac{1}{N}\sum_{i=0}^{N} \Delta V_i\,, \qquad u_{V\_i} = PI(e_V),$$

Commands broadcasted out

Centralized error signal

Distributed integral control

$$e_{\omega i} = -\Delta\omega_i - \sum_{i=1}^{N} a_{ij}\left(\Delta P_i - \Delta P_j\right), \qquad u_{\omega i} = PI(e_{\omega i}).$$

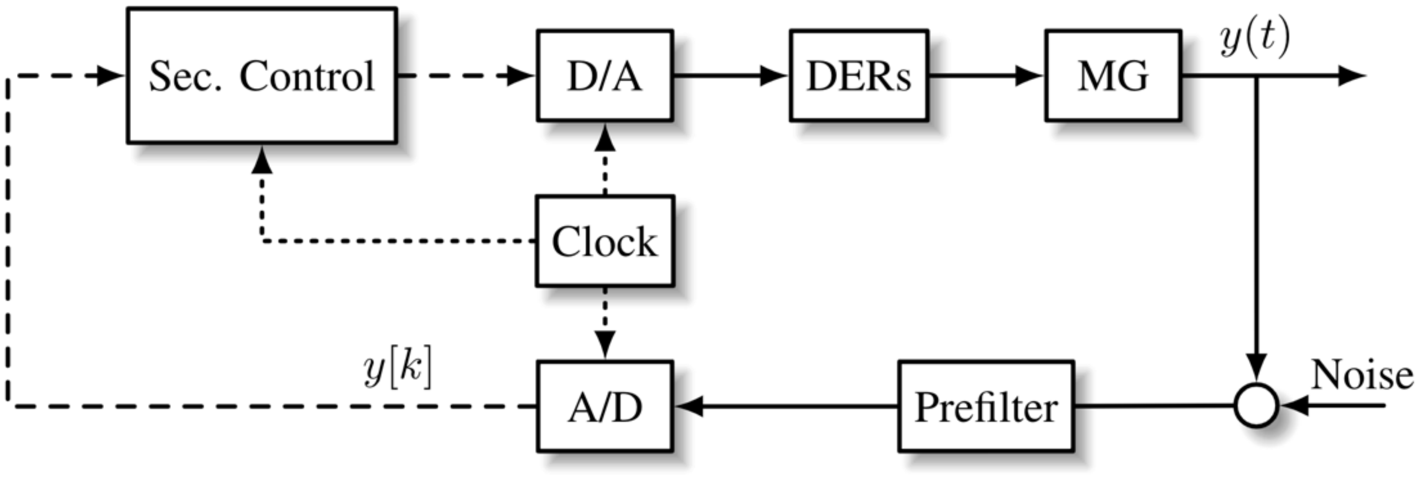
$$e_{Vi} = -\beta_i \Delta V_i - b_i \sum_{i=1}^{N} a_{ij}\left(\Delta Q_i - \Delta Q_j\right), \qquad u_{Vi} = PI(e_{Vi}).$$

***Local** error*

Communication between neighbouring controllers

Analog vs. Digital Control

- Practical secondary control systems are digital control systems
  - **Emulation Design:** design an analog controller, then discretize
  - **Direct Design**: directly design a discrete controller



Key Issues

1. **Sampling period**
   - $\boldsymbol{\omega_s \geq 10\omega_b}$
2. **Anti-aliasing filters**
   - **Ensures data quality**

Communications Modelling

Type	Technology	Cost	Scalability complexity	Distance coverage	Latency	Control level		
						P	S	T
Wired	Optical fiber	✓✓✓	✓✓✓	✓✓✓	✓	✓	✓	
	Twisted pairs	✓✓	✓✓✓	✓	✓	✓	✓	
	Power line	✓	✓✓✓	✓	✓✓			✓
Wireless	Wi-Fi	✓	✓	✓	✓		✓	✓
	ZigBee	✓	✓	✓	✓✓			✓
	Bluetooth	✓✓	✓	✓	✓✓			✓
	Cellular 3G	✓✓✓	✓	✓✓	✓✓			✓
	Cellular 4G	✓✓✓	✓	✓✓	✓✓			✓
	Cellular 5G	✓✓✓	✓	✓✓	✓			✓
	LoRa	✓✓	✓	✓✓	✓✓✓			✓

Standard	Comments	Application
IEC 61850 (61850-7-420)	Communication between devices in transmission, distribution, and substation automation system	DER/microgrid
IEC 61968	Data exchange between device and networks in the power distribution domain	Energy management system
IEEE 1547.x	Interconnecting DERs with Electric Power System	DER/microgrid
IEEE 1646	Communication requirements	Substation automation

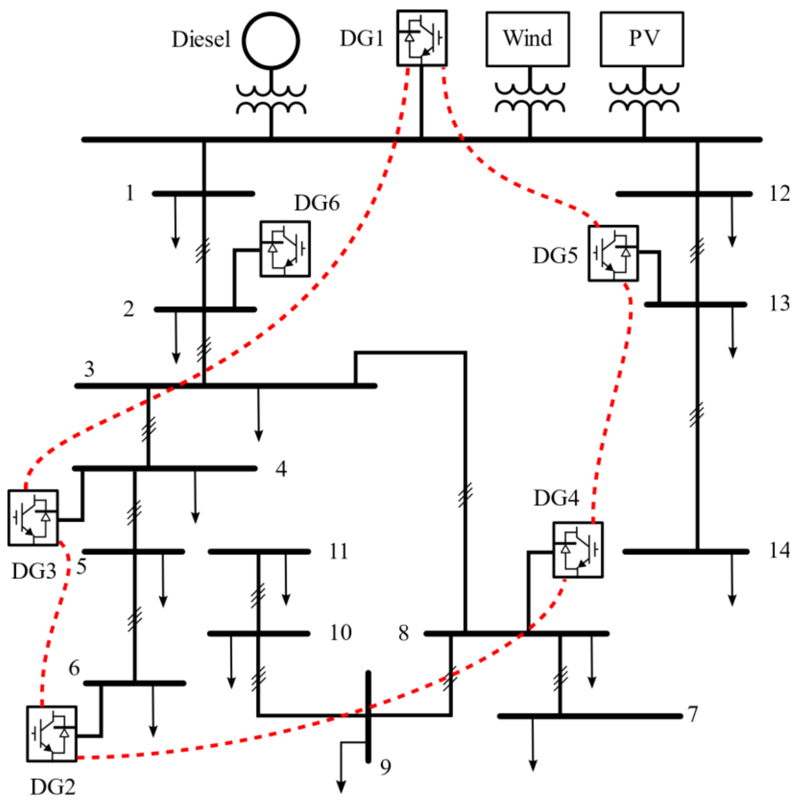
Technological Factors

- Wired vs. wireless
- Short range vs. long range
- Low-latency vs. high-latency
- Capital costs
- Maintenance costs
- Security

Critical Issues for Control

- Delays
- Reliability and data loss

Case Study: CIGRE Microgrid



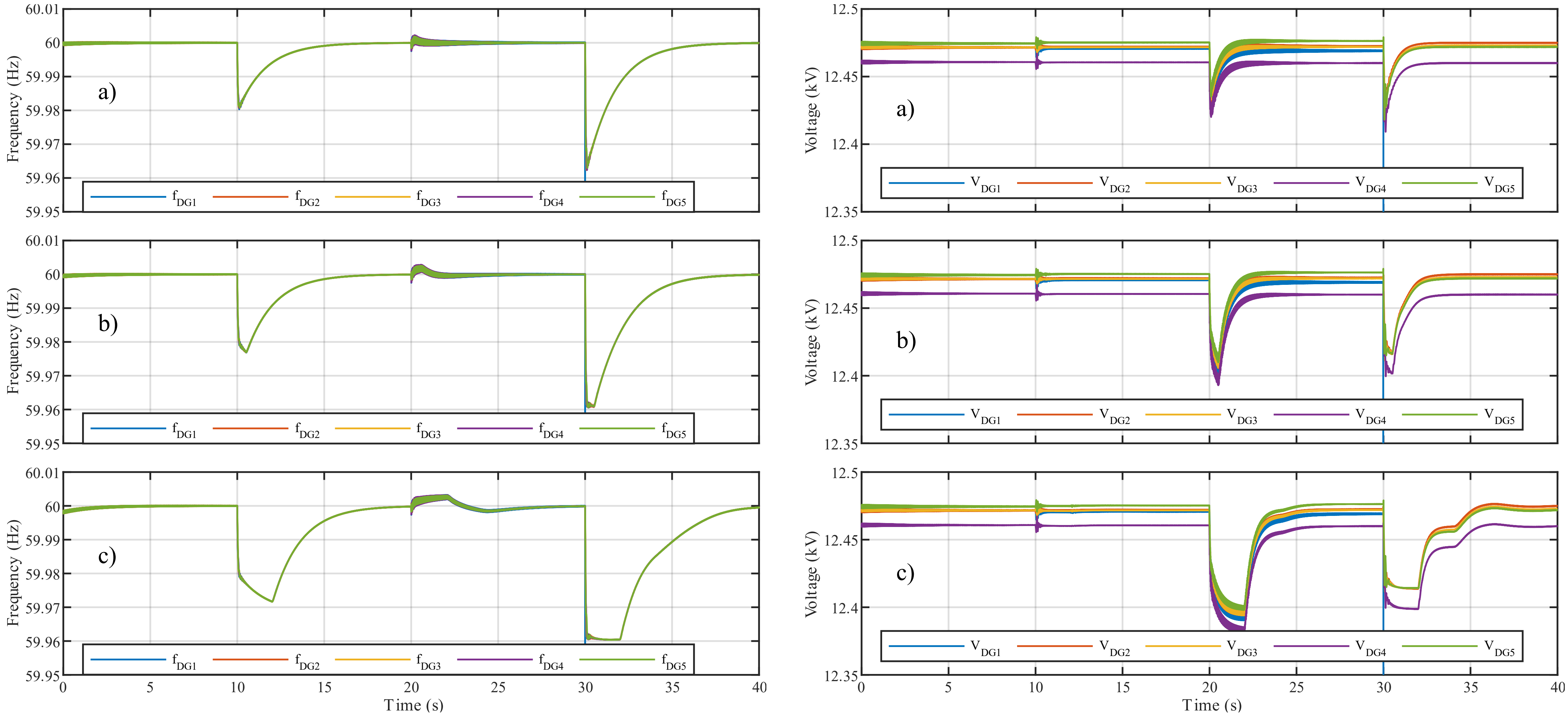
Test System Overview

- IBG units operating w/ inner loops in grid-forming mode
- Primary controller bandwidth ≈ 5Hz
- Communication links between IBGs
- **Objective:** focus on distributed secondary control effects

Case Studies for Distributed Secondary Control

1. Effect of controller sampling period
2. Effect of communication delays
3. Effect of communication failure

Communication Delays (0s, 0.5s, 2s)



Conclusions for Control & Comms.

- Secondary control impacts MG dynamics
- Centralized and distributed controllers are possible; trade-offs!
- Communication technology may or may not bottleneck control capabilities
- **Interacting factors influence dynamic response**
    1. desired bandwidth
    2. control design and architecture
    3. sampling periods for digital implementation
    4. communication delays for digital implementation

Questions, Comments, or Feedback?

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