Frequency stability of the national grid in the solar era

Power systems dynamics &

Challenges and opportunities of integration of PV and storage systems

Geffen Ben Yosef

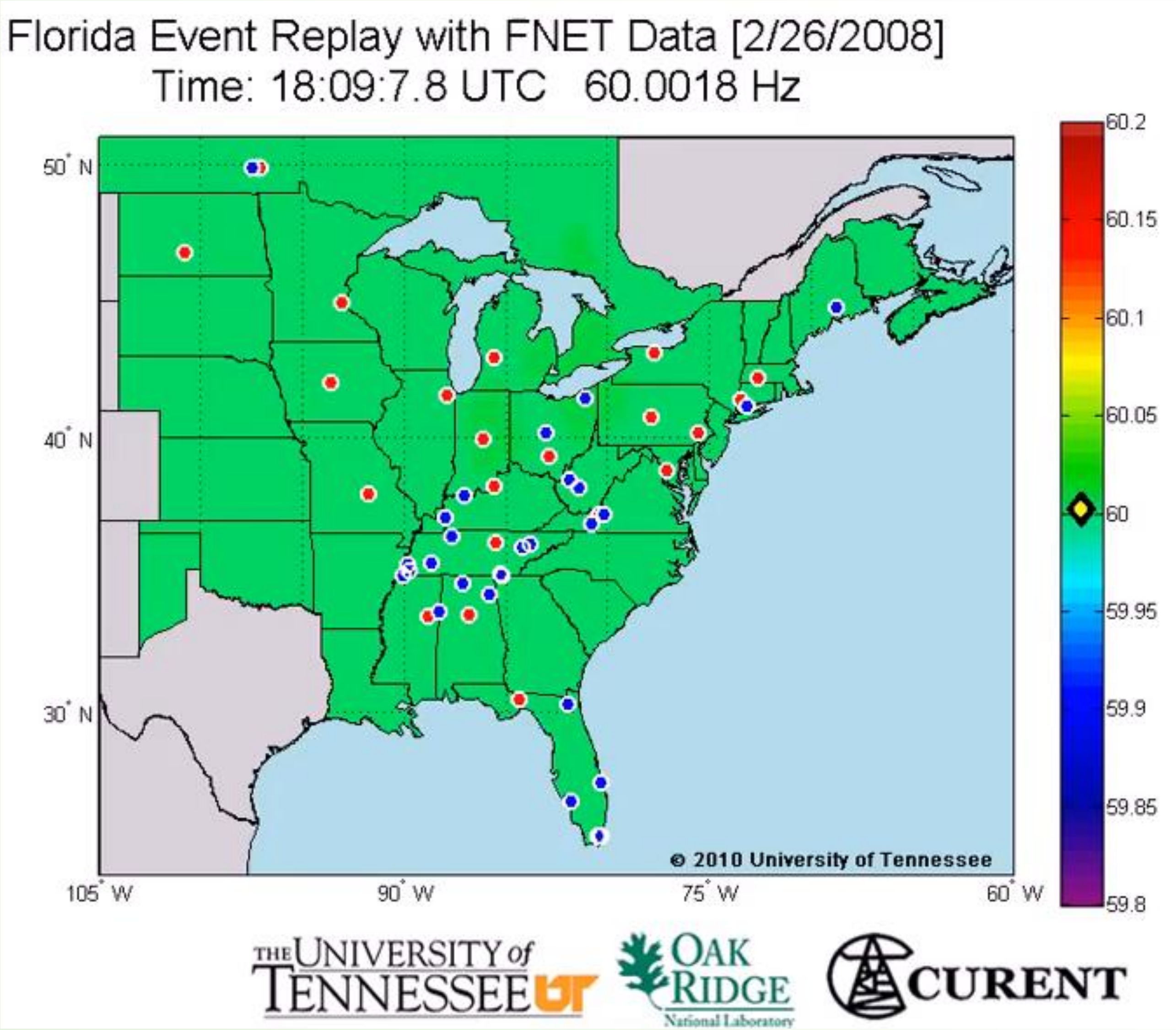
Introduction

- **PV system have clear advantages:**
  Energy security, Costs, Greenhouse gas and pollution reduction, and more.

- **Main challenge – maintaining the power system dynamic stability.**

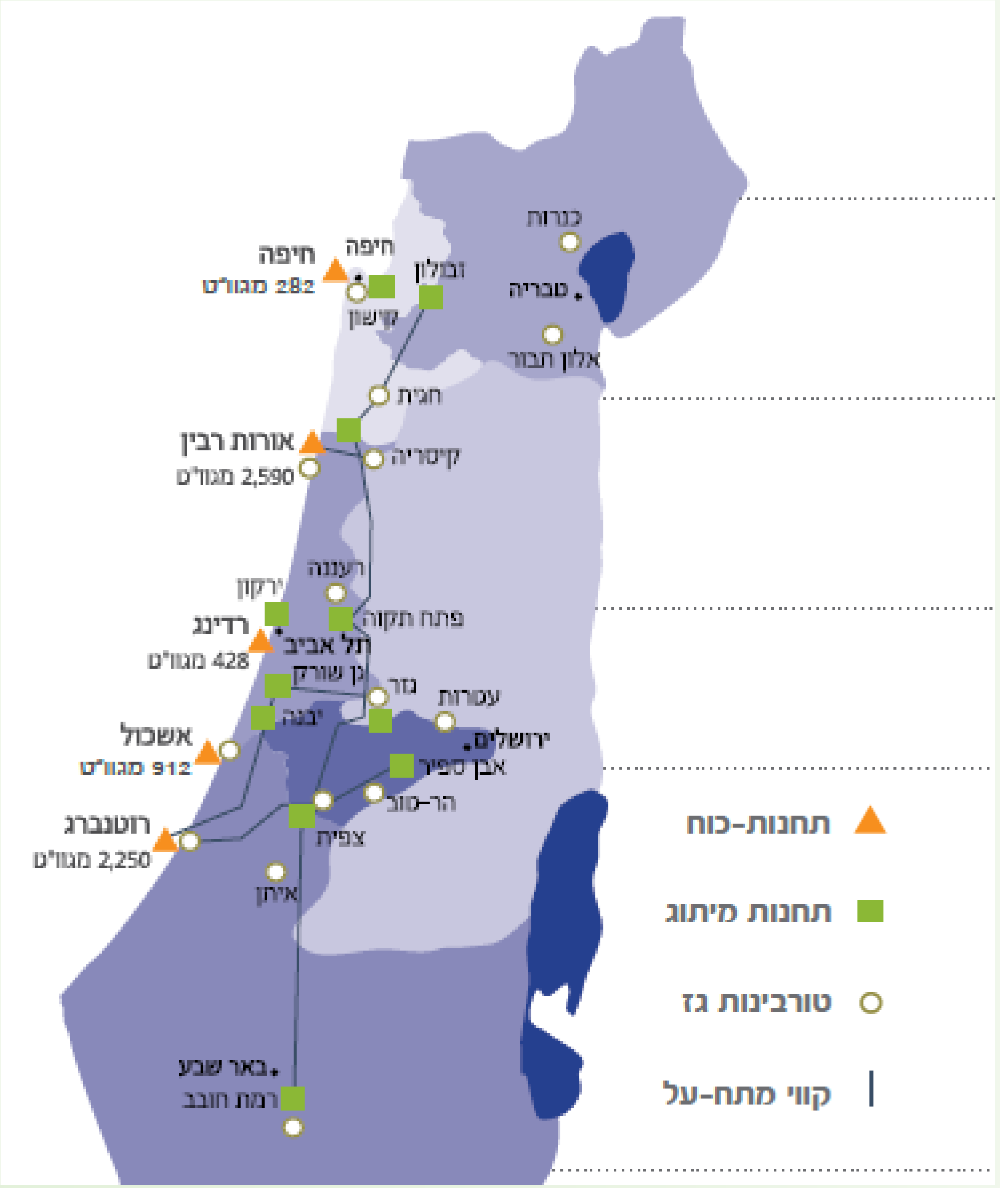
- **Power systems around the world, from Australia through Europe and the USA, are already encountering this challenge.**

- **In Israel the momentary power from PV systems reached 15%, and frequency stability issues are expected due to further increment.**


Florida Event Replay with FNET Data [2/26/2008]
Time: 18:09:7.8 UTC 60.0018 Hz
50° N
40° N
30° N
105° W
90° W
75° W
60° W
60.2
60.15
60.1
60.05
60
59.95
59.9
59.85
59.8
© 2010 University of Tennessee
THE UNIVERSITY of TENNESSEE UT
OAK RIDGE National Laboratory
CURENT

Agenda

- **Introduction to power system dynamics**
  - **Structure of power systems and how the frequency is formed**
  - **Importance of maintaining a stable frequency**
  - **Dynamics of synchronous systems, inertia and frequency control**
- **Dynamic properties challenges and opportunities of PV**
- **Low inertia frequency control**
- **Frequency stability in Israel**

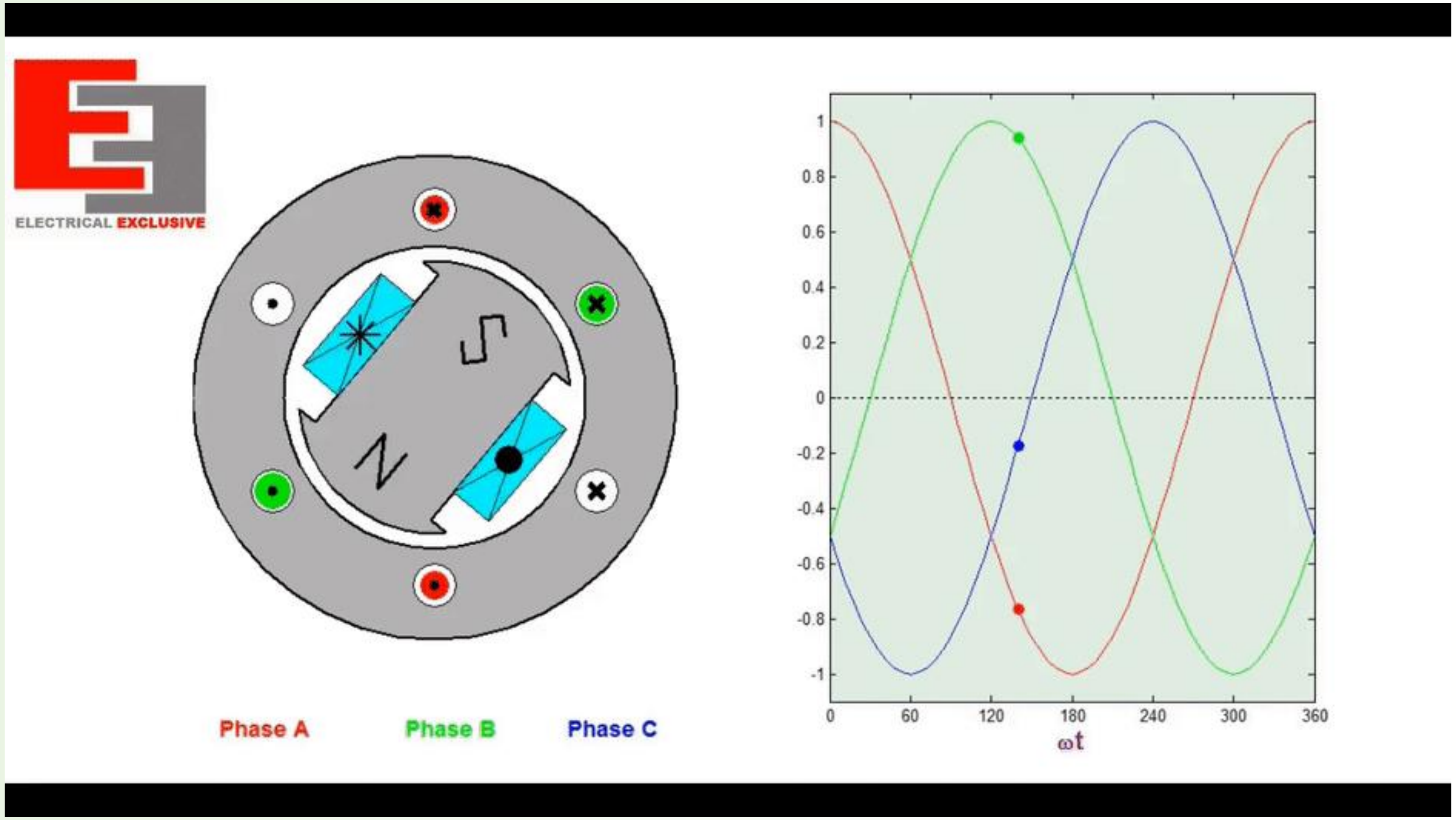


iec.co.il/about/pages/generation.aspx

Power system structure

Velocity/Frequency of a synchronous machine (generator)

Spinning Rotor,
Stator + Windings



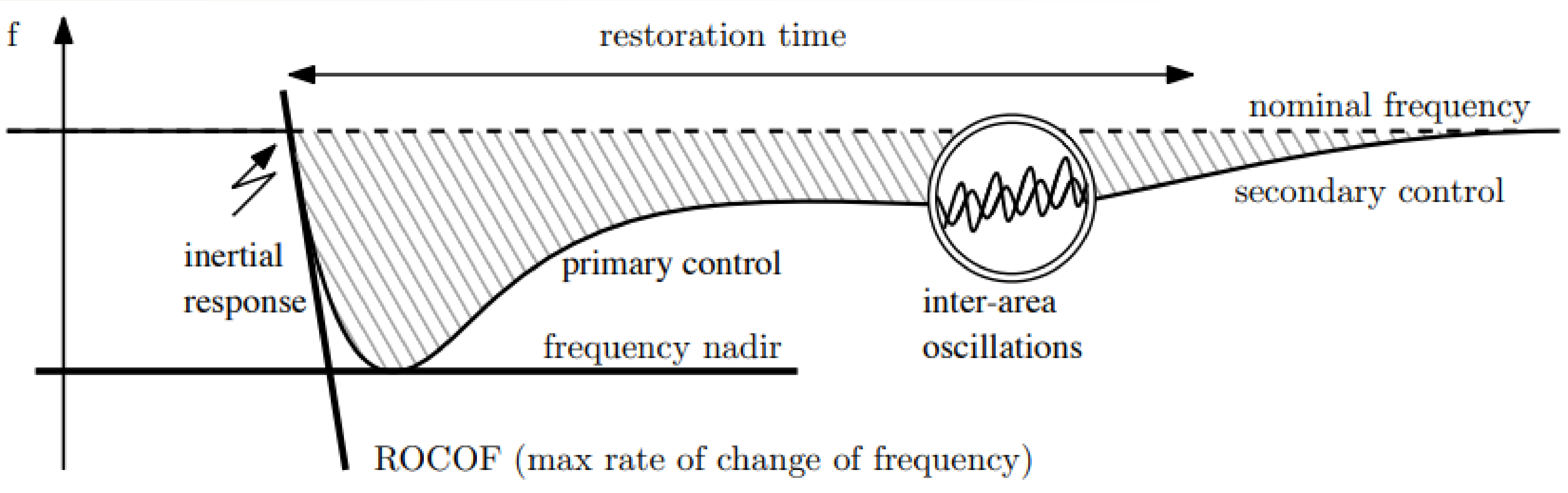
Importance of maintaining a stable frequency

- **Electro-Mechanic devices designed to operate under nominal conditions.**
- **Generators – Increased mechanical stress on the components.**
- **Loads – designed to operate with an optimal frequency.**

Introduction to power system dynamics

- Structure of power systems and how the frequency is formed
- Importance of maintaining a stable frequency
- **Dynamics of synchronous systems, inertia and frequency control**

Frequency response to a loss of a generator - Three stages of response and control



F. Milano, F. Dörfler, G. Hug, D. J. Hill and G. Verbič, "Foundations and Challenges of Low-Inertia Systems (Invited Paper)," 2018 Power Systems Computation Conference (PSCC), Dublin, 2018, pp. 1-25.

Frequency control

Load Shedding

	Control location	Reaction and control times	Function	Controlled metrices
Inertial response	local	Immediate to few seconds	Constrain the RoCoF	No measurement, Natural response
Primary control	local	seconds	Change mechanical power in relation to the reference power	Local frequency measurement
Secondary control	Systematic/ centralized	minutes	Change reference powers	System frequency measurement

RoCoF – Rate of Change of Frequency

Inertia

- **Resistance to a change in velocity.**
- **Rotational inertia (J) – measure of the torque needed for a desired angular acceleration $d\omega/dt$.**
- **Measure of the stored kinetic energy in the system -** $E_k = \frac{1}{2}J\omega^2$**.**
- **For a single generator with rated power S define inertia constant** $H = E_k/S[seconds]$**.**

Power system dynamics – Inertial response

$$\frac{d}{dt}\omega(t) = \frac{1}{M}\left(P_G(t) - P_L(t)\right)$$

Load Shedding

P_G	**Total power generated**
P_L	**Total load power**
M	**Total system Inertia**
ω	**Mean system frequency**

Synchronous generator dynamics

$$\frac{d}{dt}\omega = \left(\frac{p_f}{2}\right)^2 \frac{1}{J\omega_s}(P_m - 3P)$$

P	Single phase average electrical power
P_m	The mechanical power accelerating the rotor
J	Rotor's moment of inertia
ω_s	The system's nominal angular velocity
p_f	Number of the rotor's magnetic poles
$\frac{d}{dt}\omega$	Rotor's electrical angular acceleration

Primary and secondary control – DROOP!

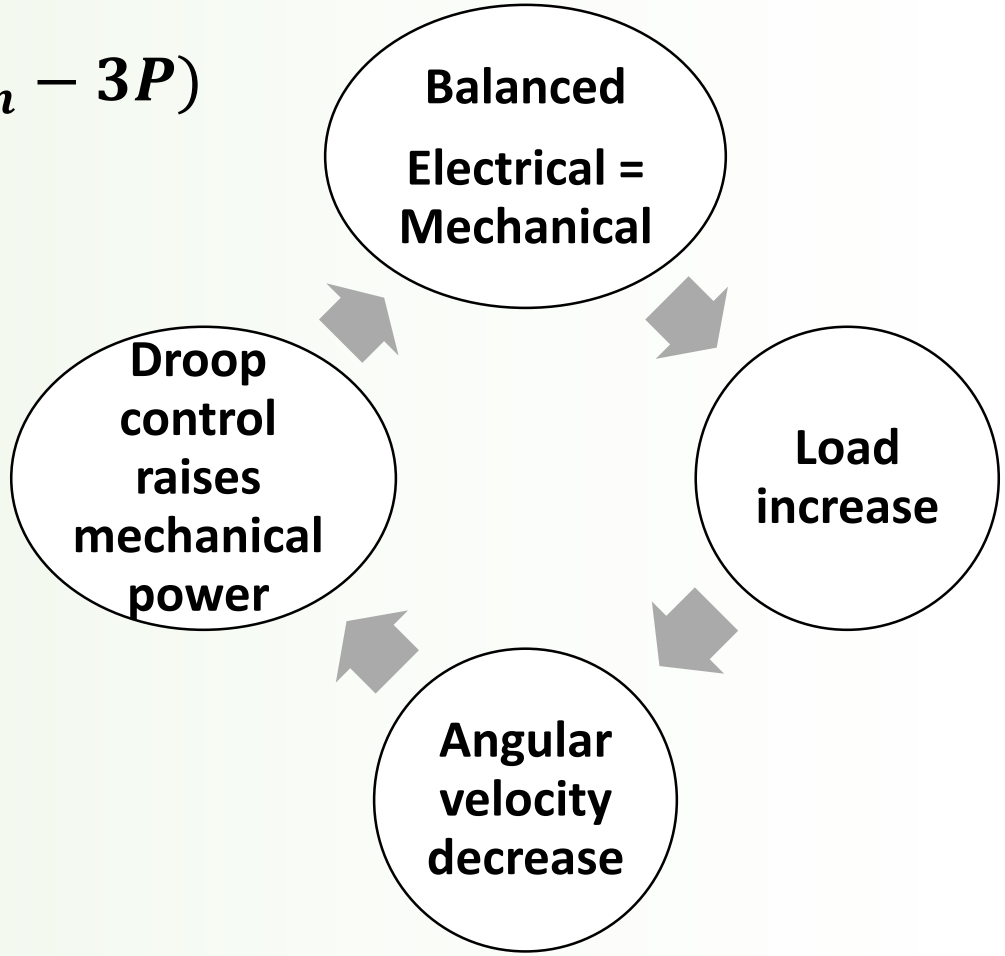
$$\boldsymbol{P_m = 3P_{ref} - \frac{1}{D}(\omega - \omega_s)}$$

$\boldsymbol{P_m}$	**Mechanical power accelerating the rotor**
$\boldsymbol{P_{ref}}$	**Electrical power reference (secondary control)**
$\boldsymbol{D}$	**Droop constant**
$\boldsymbol{\omega_s}$	**Nominal system angular velocity**
$\boldsymbol{\omega}$	**Rotor's electrical angular velocity**

DROOP control - $\boldsymbol{P_m = 3P_{ref} - \frac{1}{D}(\omega - \omega_s)}$

$$\frac{d}{dt}\omega = \left(\frac{p_f}{2}\right)^2 \frac{1}{J\omega_s}(P_m - 3P)$$

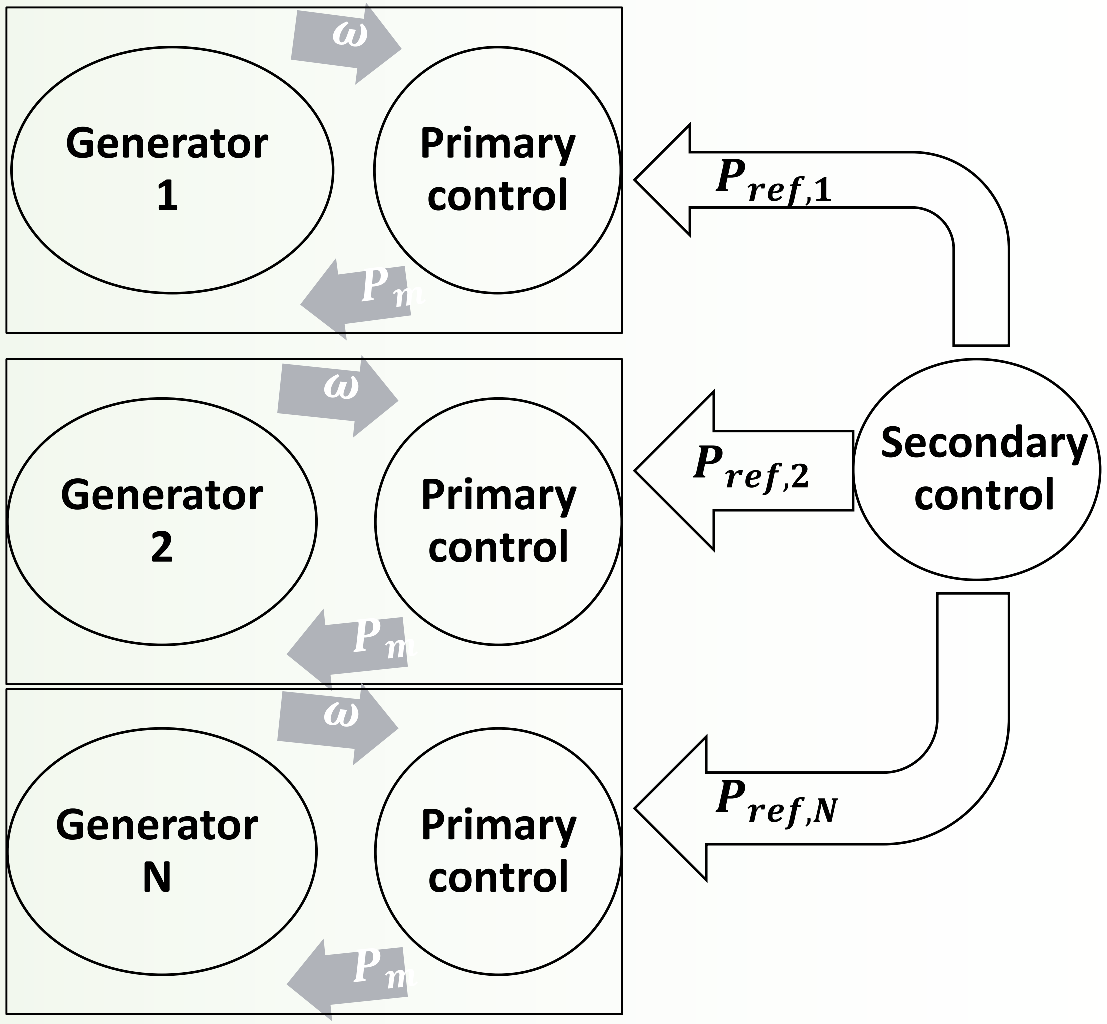
- **Local, distributed control, no exchange of information.**
- **Negative feedback loop -**
- **Matches mechanical and electrical powers,**
- **Stabilizes the frequency.**



Secondary control

$$P_m = 3P_{ref} - \frac{1}{D}(\omega - \omega_s)$$

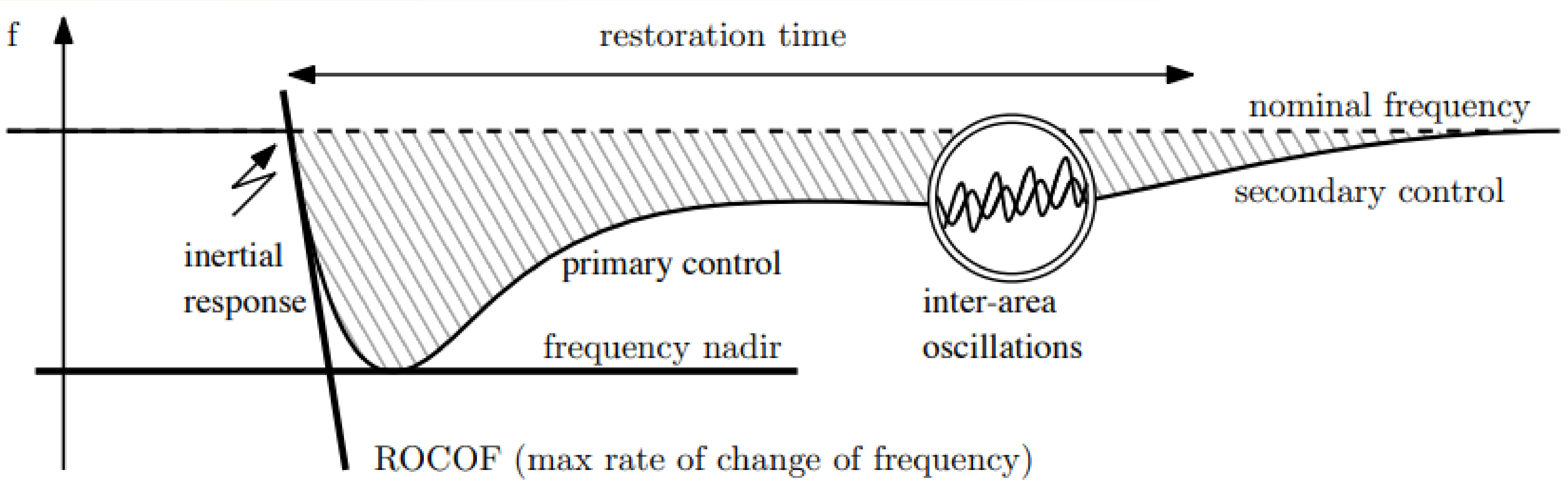
- **Central control**
- **Frequency recovery**
- **Economical operation**



Primary and secondary control - DROOP

- **Fast control loops are local**
- **No information transfer between generators – the frequency is the information**
- **High reliability primary control – no central control**
- **Primary control allow a reliable operation**
- **Secondary control allow economical operation**

Frequency response to a loss of a generator - Three stages of response and control



F. Milano, F. Dörfler, G. Hug, D. J. Hill and G. Verbič, "Foundations and Challenges of Low-Inertia Systems (Invited Paper)," 2018 Power Systems Computation Conference (PSCC), Dublin, 2018, pp. 1-25.

Power dispatch operational strategies

- **Sufficient system inertia**

$$\frac{d}{dt}\omega(t) = \frac{1}{M}\left(P_G(t) - P_L(t)\right)$$

- **Maximum power for a generator**
- **Sufficient spinning reserve**
- **Operational constraints of the generators and the grid**
  - **Line loadings, maximum power at the transformers, voltages, minimum power…**
- **Regulatory, Economic, and environmental constraints**

Agenda

- Introduction to power system dynamics
  - Structure of power systems and how the frequency is formed
  - Importance of maintaining a stable frequency
  - Dynamics of synchronous systems, inertia and frequency control
- **Dynamic properties challenges and opportunities of PV**
- **Low inertia frequency control**
- Research questions regarding frequency stability in Israel

PV system properties – challenges & opportunities

- **Inertia-less**
- **Time and weather dependent available power**
- **Free and clean “fuel”**
- **Fast control of the available power**

Energy storage as a solution for frequency stability

- **Fast control of the available power**

- **Economic price**

Low inertia frequency control

- **Electronics interface allow fast control and response to regulate frequency deviations.**
- **Challenging frequency measurements.**
- **Distributed control.**

Agenda

- **Introduction to power system dynamics**
  - **Structure of power systems and how the frequency is formed**
  - **Importance of maintaining a stable frequency**
  - **Dynamics of synchronous systems, inertia and frequency control**
- **Dynamic properties challenges and opportunities of PV**
- **Low inertia frequency control**
- **Frequency stability in Israel**

Properties of the Israeli grid

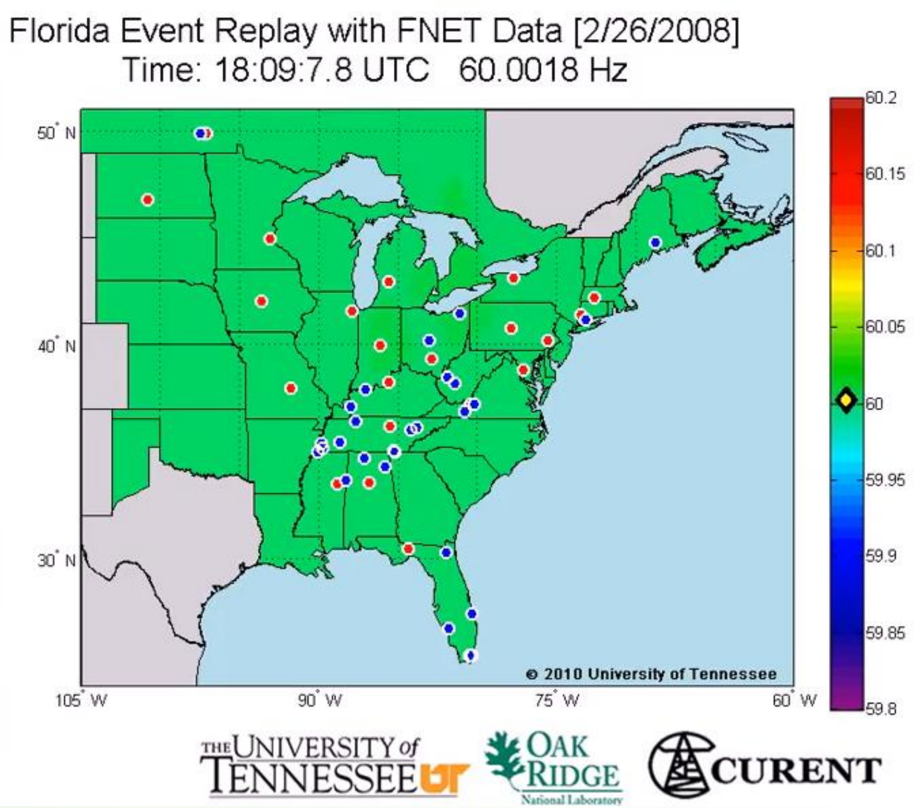
- **Energetic island**
- **South region with low consumption but high PV potential**
- **Most of the consumption in the crowded center-north region**

Research with IEC cooperation

- **What is the impact of adding PV on the frequency stability?**

- **What is the impact of the distribution and the operation of PV and energy storage systems?**

Thank You



Refrences:

- F. Milano, F. Dörfler, G. Hug, D. J. Hill and G. Verbič, "Foundations and Challenges of Low-Inertia Systems (Invited Paper)," 2018 Power Systems Computation Conference (PSCC), Dublin, 2018, pp. 1-25.
- Levron, Y. and Belikov, J., “Lecture 1: Introduction to Power System Dynamics: Time-varying Phasors and Primary Frequency Control”.
- P. Kundur, Power system stability and control. McGraw-Hill, 1994.
- Andreas Ulbig, Theodor S. Borsche, Göran Andersson, Impact of Low Rotational Inertia on Power System Stability and Operation, IFAC Proceedings Volumes, Volume 47, Issue 3, 2014