Synchronized Measurements for Modeling and Control of Inverter-Based Resources

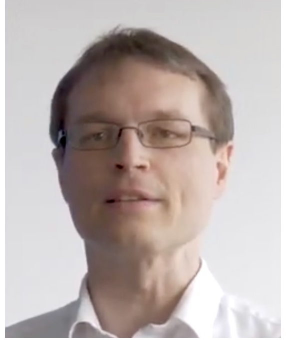
NASPI Work Group Meeting

Panel Presentation & Discussion October 6, 2021

NASPI North American SynchroPhasor Initiative

Synchronized Measurements for Modeling and Control of Inverter-Based Resources




Sascha von Meier | University of California, Berkeley (Moderator)

Yashen Lin | National Renewable Energy Laboratory

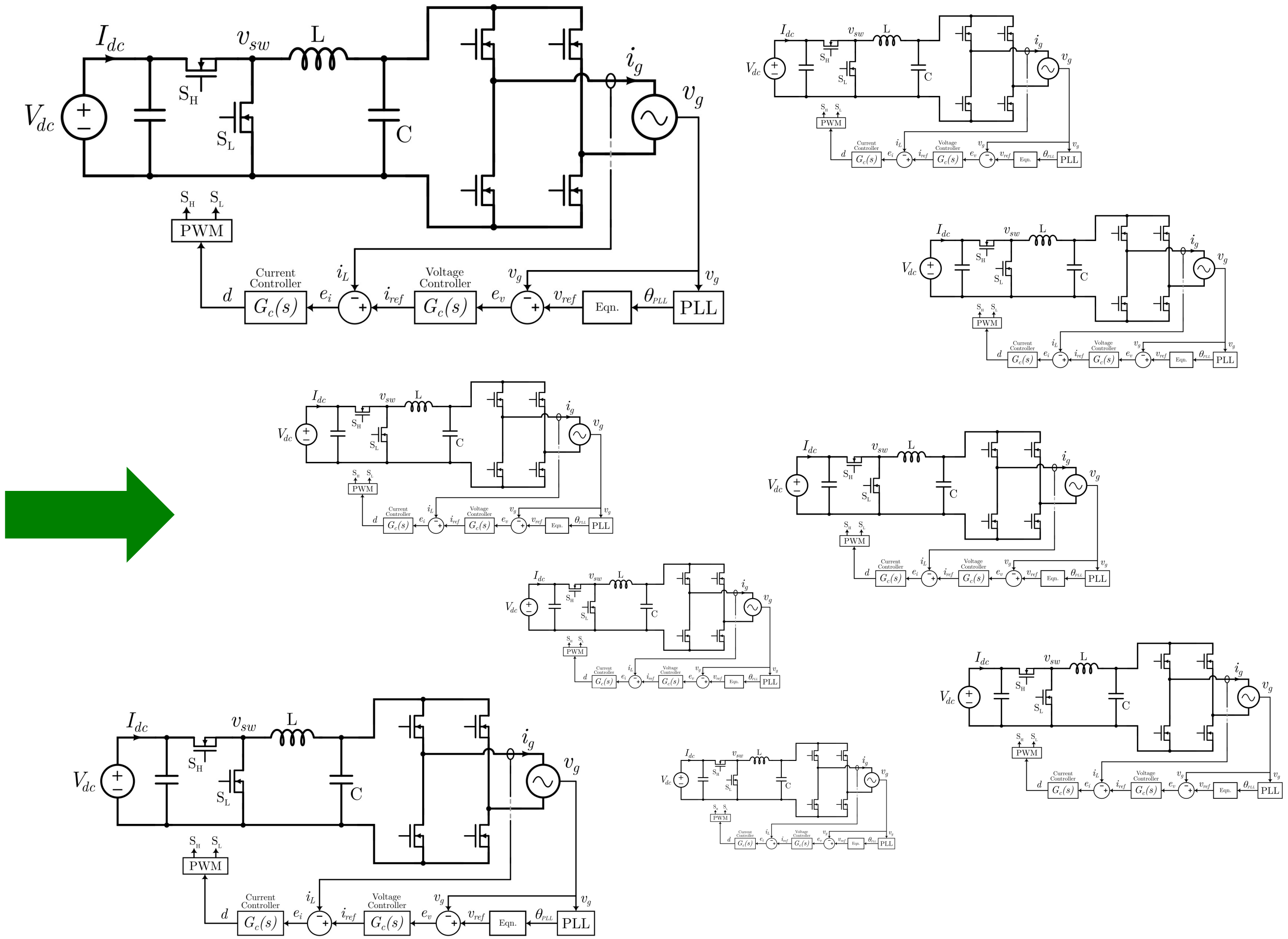
Yasutoshi Yoshioka | Fuji Electric Corporation

Gunnar Kaestle | Technische Universität Clausthal

Ryan Quint | National Electric Reliability Corporation

NASPI North American SynchroPhasor Initiative

The Transition



NASPI North American SynchroPhasor Initiative

Questions to Panelists

- What are the main challenges for stability and control in low-inertia grids?
- What are the challenges for modeling the behavior of inverter-based resources? What measurements are needed to inform state-of-the-art models?
- What is today's state of the art for inverter control strategies to enhance grid stability? What measurements are needed to inform these – purely local?
- Are there systemic functionalities that can be achieved only with synchronized measurements?
- What are the opportunities and challenges for embedding PMUs and UTC synchronized Point-on-wave measurements in inverter hardware, and sharing measurement data?
- What topics are IEC, IEEE and NERC Working Groups currently focused on, what are the main challenges, and how might engagement with the NASPI community be useful?

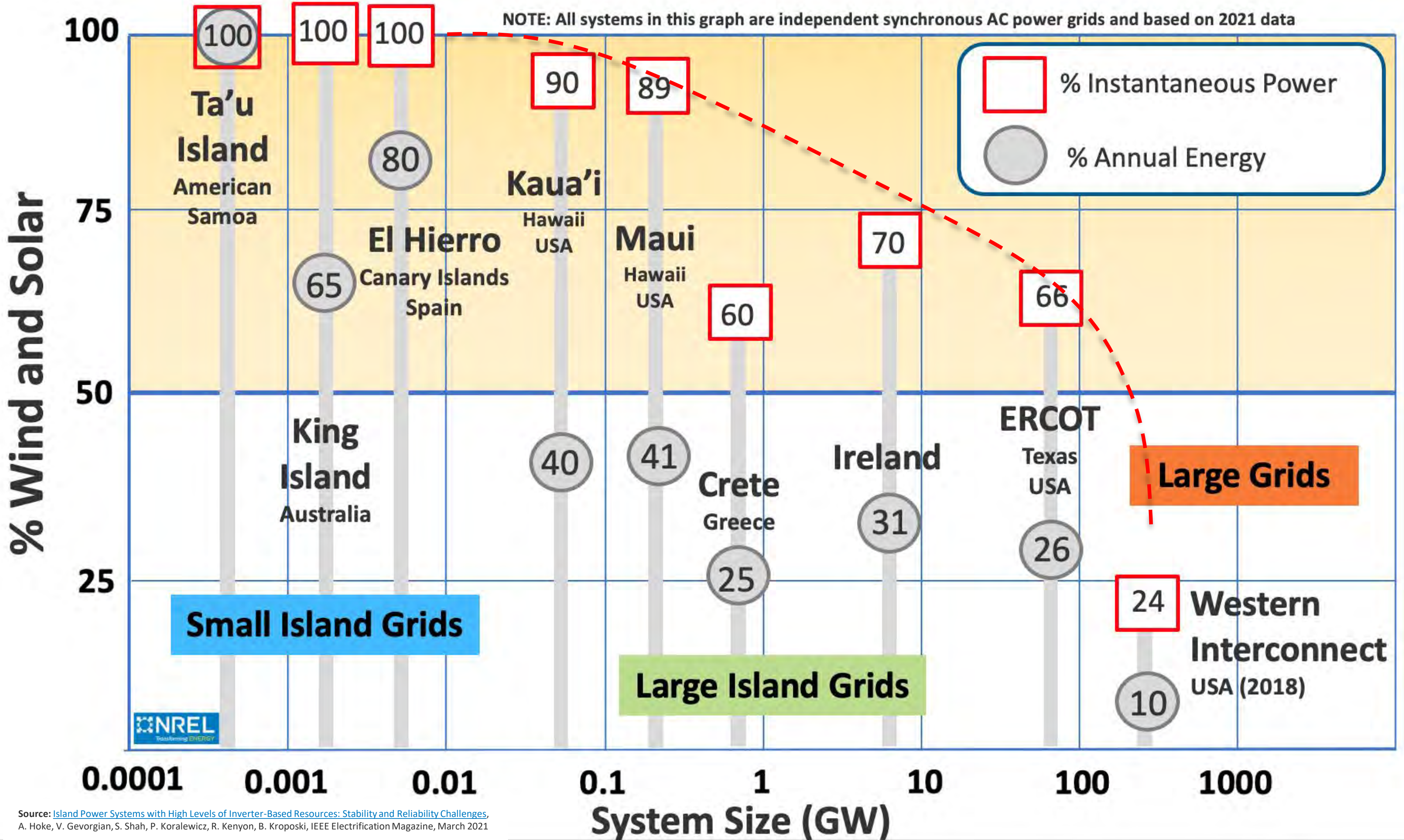
NREL
Transforming ENERGY

Integrating High Levels of Inverter-based Resources into Power Grids

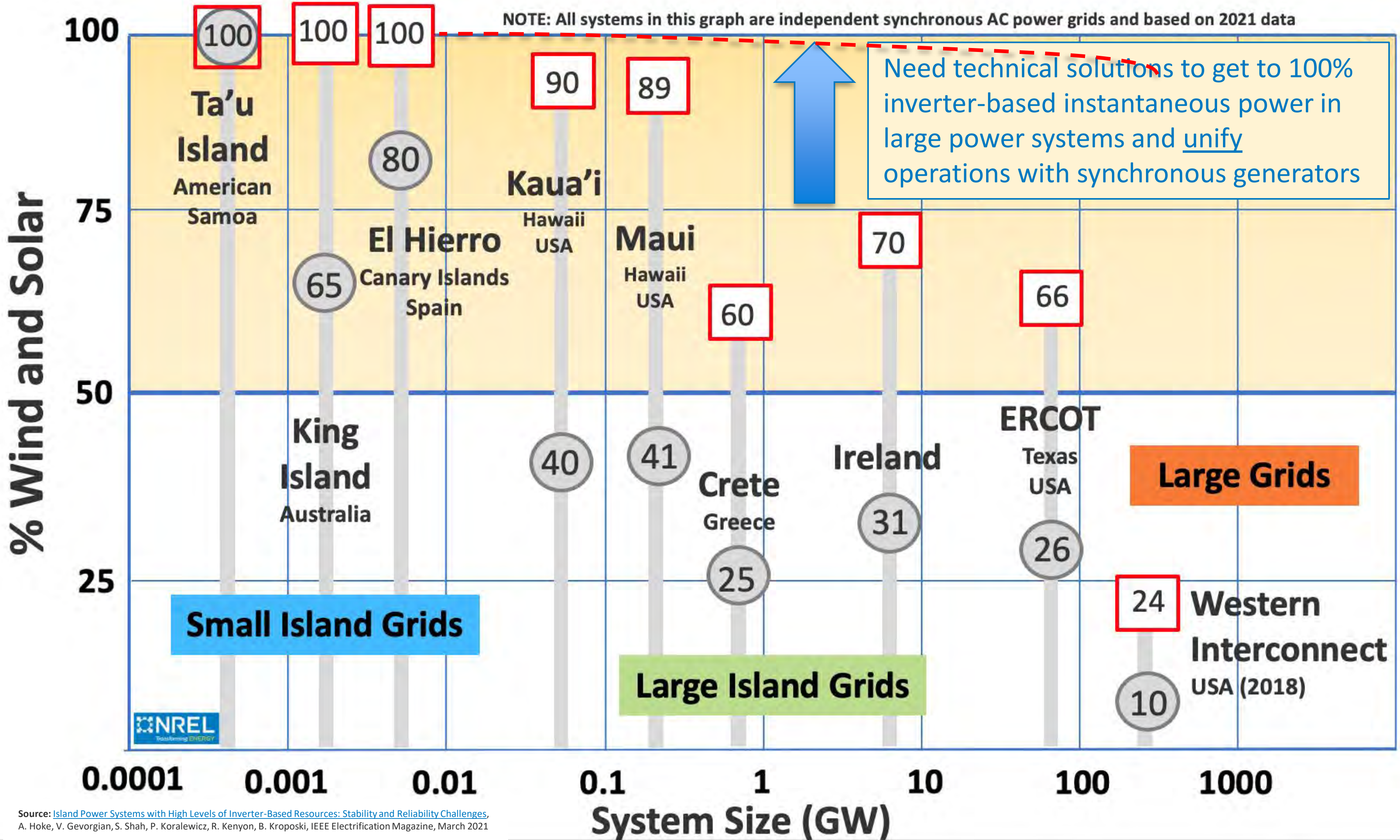
Yashen Lin
Senior Research Engineer
National Renewable Energy Laboratory

Current Power Systems Operating with Variable Renewable Energy

(what do we know)



Source: Island Power Systems with High Levels of Inverter-Based Resources: Stability and Reliability Challenges, A. Hoke, V. Gevorgian, S. Shah, P. Koralewicz, R. Kenyon, B. Kroposki, IEEE Electrification Magazine, March 2021



Source: Island Power Systems with High Levels of Inverter-Based Resources: Stability and Reliability Challenges, A. Hoke, V. Gevorgian, S. Shah, P. Koralewicz, R. Kenyon, B. Kroposki, IEEE Electrification Magazine, March 2021

Technical Challenges with Higher Inverter-based Resources

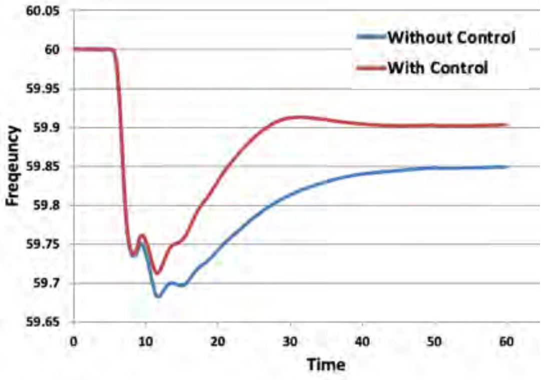
Challenges:

- Frequency Stability (Lower System Inertia)
- Voltage Stability and Regulation
- System Protection
- Grid Forming capability
- Black Start capability
- Control system interactions and resonances
- Cybersecurity

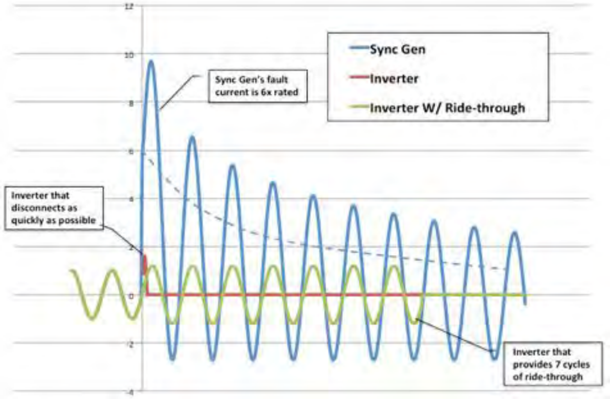
Source: B. Kroposki et al., "Achieving a 100% Renewable Grid – Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy," http://ieeexplore.ieee.org/document/7866938/

Source: Blackstart of Power Grids with Inverter- Based Resources, H. Jain, G. Seo, E. Lockhart, V. Gevorgian, B. Kroposki, 2020 IEEE Power and Energy General Meeting: https://www.nrel.gov/docs/fy20osti/75327.pdf

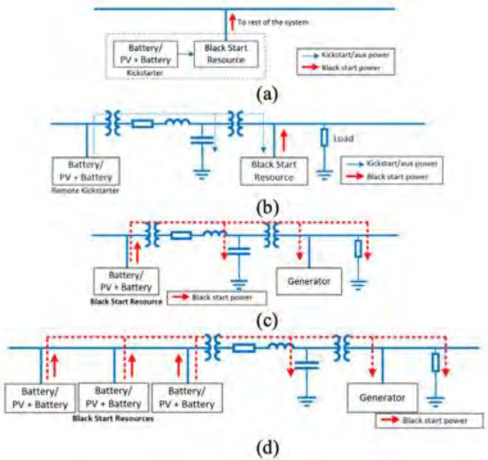
Stability



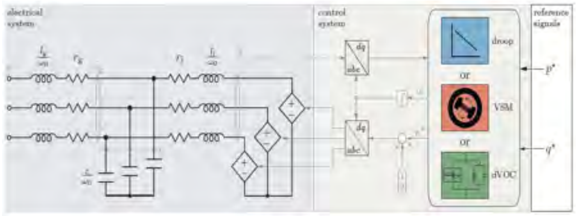
Protection



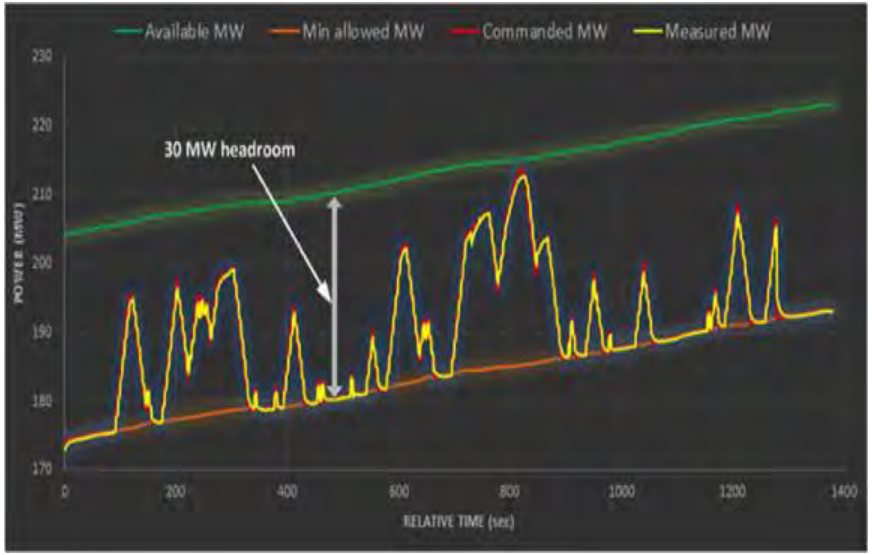
Grid-forming/Blackstart



Control system interactions and resonances



Inverter Based Resources can Provide Grid Services



NREL/FirstSolar/CAISO experiment: 300-MW plant following Automatic Generator Control (AGC) signal

300-MW PV Plant in California *(Photo from First Solar)*

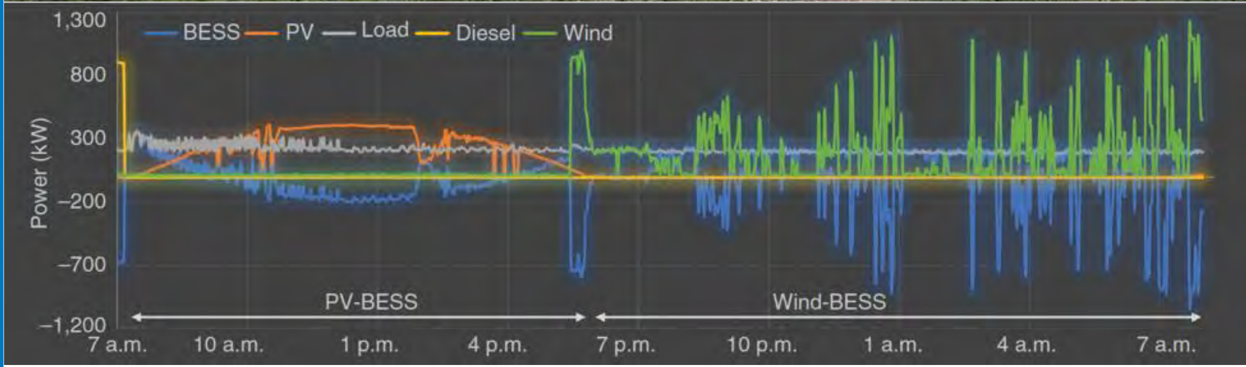
Demonstrated that PV plants (and wind power plants on next slide) can deliver essential grid services.

Source: C. Loutan, P. Klauer, S. Chowdhury, S. Hall, M. Morjaria, V. Chadliev, N. Milam, C. Milan, V. Gevorgian, *Demonstration of Essential Reliability Services by a 300-MW Solar Photovoltaic Power Plant*, http://www.nrel.gov/docs/fy17osti/67799.pdf

Operations of a 100% Wind-Solar-Battery Power Grid

including Blackstart

- 1.5MW Wind turbine, 450kW PV system, and 1MW/1MWh Battery
- NREL operated a 100% Wind-PV-Battery Grid for 72 Hours during a site outage
- Demonstrating new control techniques for these types of systems



24-hour operation of Wind-PV-Battery System at NREL's Flatiron Campus

Source: Island Power Systems with High Levels of Inverter-Based Resources: Stability and Reliability Challenges, A. Hoke, V. Gevorgian, S. Shah, P. Koralewicz, R. Kenyon, B. Kroposki, IEEE Electrification Magazine, March 2021

UNIFI Consortium

Unifying the integration and operation of inverters and synchronous machines

Universal Interoperability for Grid-forming Inverters (UNIFI) Consortium

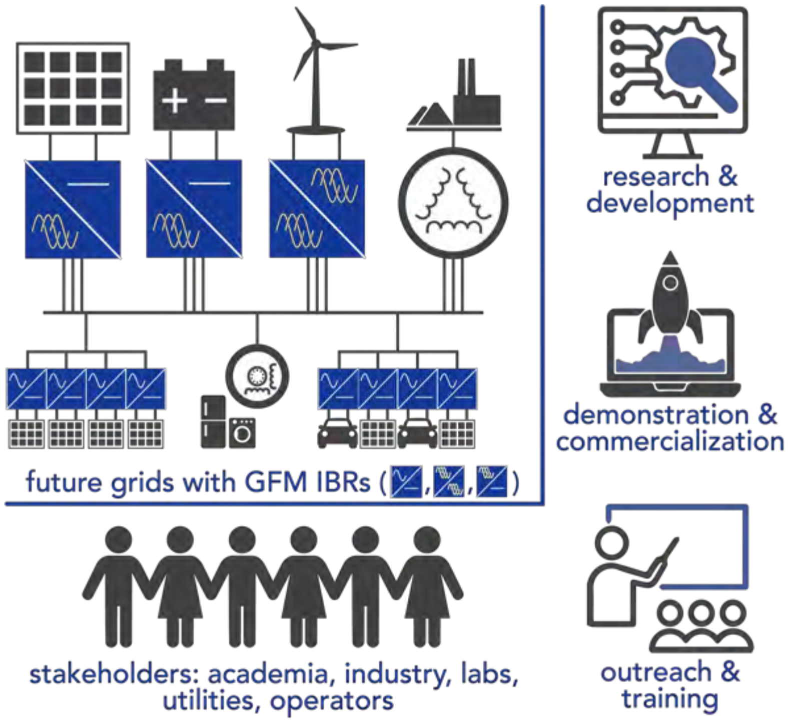
The **UNIFI Consortium** is a forum to address fundamental challenges in seamless integration of grid-forming (GFM) technologies into power systems of the future

Bringing the industry together to unify the integration and operation of inverter-based resources and synchronous machines

Three major focuses:

- Research & Development
- Demonstration & Commercialization
- Outreach & Training

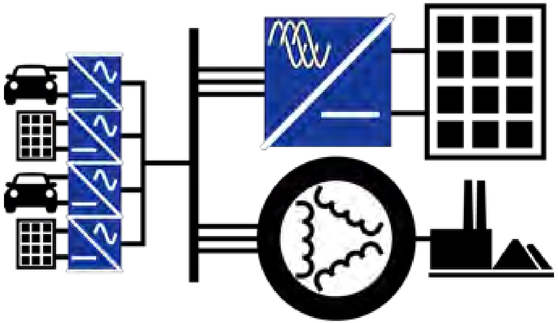
Team includes: 4 National Labs, EPRI,
12 Universities, and 20+ Industry partners



UNIFI – Standardizing Inverter-Machine Integration

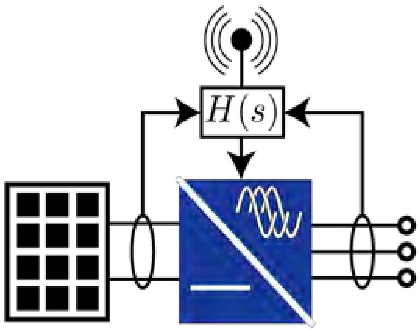
System-level Interoperability Guidelines

- Promote the coordinated and seamless operation of a plurality of GFM technologies from multiple vendors while ensuring stability and reliability
- Scalable Secondary Control; System-level Stability; Frequency and Voltage Regulation Metrics; Black-start Capabilities; Cyber-secure



Unit-level Functional Requirements

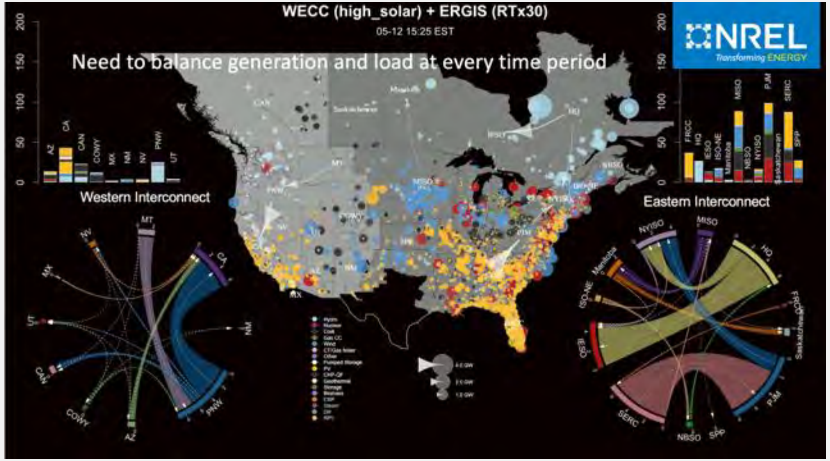
- Establish baseline GFM-IBR/plant/aggregation-level capabilities to comply with Interoperability Guidelines
- Real-time Control with Integrated Dynamic Protection; Autonomous Primary Control; Signal I/O Interface; GFM-IBR/Plant/Aggregation-level Stability; Power-quality and Protection Requirements



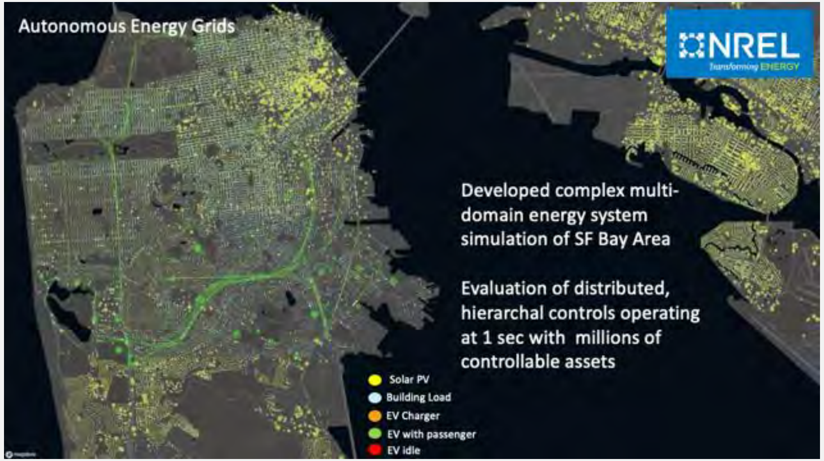
The Need for Better Measurements

As more inverter-based resources (PV, wind, batteries, EV, smart loads) are integrated into the grid, better, faster measurements of grid conditions will be useful to ensure proper grid operation.

Transmission System



Distribution System



Summary

- The power industry is seeing a shift towards 100% clean energy goals and each region has a variety of resources to tap into to meet these goals
- Inverter-based resources (IBR) are being integrated into power gids at increasing levels
- Several technical challenges exist for integration of IBR at high levels
- Better sensing, measurement, and data analytics can help solve some of these challenges
- All these challenges are solvable and we need to work together to address them

For More Information

- *Lazards's Levelized Cost of Energy Analysis-Version 14.0 – 2020* https://www.lazard.com/perspective/lcoe2020
- "Achieving a 100% Renewable Grid – Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy," B. Kroposki et al., IEEE Power & Energy Magazine, Nov/Dec 2017 http://ieeexplore.ieee.org/document/7866938/
- *"Addressing technical challenges in 100% variable inverter-based renewable energy power systems",* B. Hodge et al., WIREs Energy and Environment, April 2020, https://onlinelibrary.wiley.com/doi/full/10.1002/wene.376
- *"WWSIS: Phase 3A",* N.W. Miller et al., http://www.nrel.gov/docs/fy16osti/64822.pdf
- *"Autonomous Energy Grids: Controlling the Future Grid with Large Amounts of Distributed Energy Resources",* B. Kroposki, A. Bernstein, J. King, D. Vaidhynathan, X. Zhou, C. Chang, and E. Dall'Anese IEEE Power and Energy Magazine, November/December 2020, https://ieeexplore.ieee.org/document/9229208
- *"Impact of Flexibility Options on Grid Economic Carrying Capacity of Solar and Wind: Three Case Studies",* P. Denholm, J. Novacheck, J. Jorgenson, and M. O'Connell, National Renewable Energy Laboratory, NREL/TP-6A20-66854, December 2016, https://www.nrel.gov/docs/fy17osti/66854.pdf
- *"The challenges of achieving a 100% renewable electricity system in the United States",* P. Denholm, D. Arent, S. Baldwin, D. Bilello, G. Brinkman, J. Cochran, W. Cole, B. Frew, V. Gevorgian, J. Heeter, B. Hodge, B. Kroposki, T. Mai, M. O'Malley, B.Palmintier, D. Steinberg, and Y. Zhang, Joule, May 2021, https://www.sciencedirect.com/science/article/pii/S2542435121001513
- *"Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States",* Mai, Trieu, Paige Jadun, Jeffrey Logan, Colin McMillan, Matteo Muratori, Daniel Steinberg, Laura Vimmerstedt, Ryan Jones, Benjamin Haley, and Brent Nelson, 2018, NREL/TP-6A20-71500. https://www.nrel.gov/docs/fy18osti/71500.pdf
- *"Island Power Systems with High Levels of Inverter-Based Resources: Stability and Reliability Challenges",* A. Hoke, V. Gevorgian, S. Shah, P. Koralewicz, R. Kenyon, B. Kroposki, IEEE Electrification Magazine, March 2021 https://ieeexplore.ieee.org/document/9371251

Thank you

NREL
Transforming ENERGY

Study of smart inverter functions in Japan

1. What is the synthetic Inertia ?
2. Fundamental problem in Power systems due to DER
3. Experimental study on inverter power control functions, grid protection and support
4. Experimental study on information exchange to recruit advanced inverter functions (Smart inverter functions)

Yasutoshi Yoshioka
European Research & Technical Center
Fuji Electric Europe GmbH

1. What is the synthetic Inertia ?
2. Fundamental problem in Power systems due to DER
3. Experimental study on inverter power control functions, grid protection and support
4. Experimental study on information exchange to recruit advanced inverter functions (Smart inverter functions)

Definition of the synthetic inertia in IEC

Fuji Electric
Innovating Energy Technology

IEC 60050-601 ED2
International Electrotechnical Vocabulary (IEV) - Part 601: Generation, transmission and distribution of electricity - General

601-04-48
synthetic inertia, <in an electric power system>
capability of a grid-connected converter to emulate the inertial effect of a synchronous generator to a prescribed level of performance

IEC: International Electrotechnical Commission

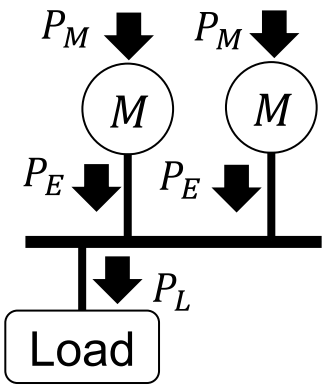
Background (Frequency deviations due to DER)

Fuji Electric Innovating Energy Technology

Conventional grid

"M" represents synchronous generators

Balanced



M: Inertia Constant

Swing equation $\omega = \frac{1}{M}\int (P_M - P_E)$ …(1)

Mechanical Input $P_M = \frac{P_L}{2}$ …(2)

Electrical output $P_E = \frac{P_L}{2}$ …(3)

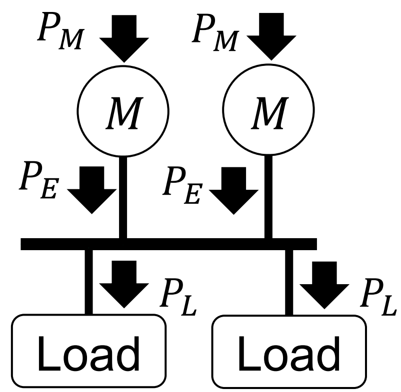
Eq. (1) becomes Eq. (4):

$$\omega = \frac{1}{M}\int \left(\frac{P_L}{2} - \frac{P_L}{2}\right) \quad \text{…(4)}$$

Frequency is stable with Eq. (5):

$$\omega = \frac{1}{M}\int (0) \quad \text{…(5)}$$

Unbalanced



Mechanical Input $P_M = \frac{P_L}{2}$ …(6)

Electrical output $P_E = P_L$ …(7)

Eq. (1) becomes Eq. (8):

$$\omega = \frac{1}{M}\int \left(\frac{P_L}{2} - P_L\right) \quad \text{…(8)}$$

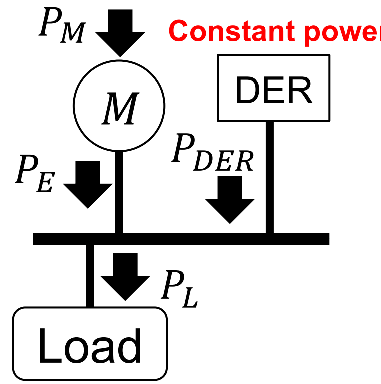
Frequency decreases with Eq. (9):

$$\omega = \frac{1}{M}\int \left(-\frac{P_L}{2}\right) \quad \text{…(9)}$$

Current grid with DER

"M" is replaced with DER (Distributed energy resources)

Balanced



DER output $P_{DER} = \frac{P_L}{2}$ …(10)

Mechanical Input $P_M = \frac{P_L}{2}$ …(11)

Electrical output $P_E = \frac{P_L}{2}$ …(12)

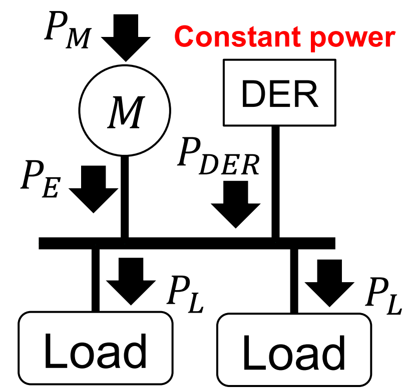
Eq. (1) becomes Eq. (12):

$$\omega = \frac{1}{M}\int \left(\frac{P_L}{2} - \frac{P_L}{2}\right) \quad \text{…(13)}$$

Frequency is stable with Eq. (14):

$$\omega = \frac{1}{M}\int (0) \quad \text{…(14)}$$

Unbalanced



DER output $P_{DER} = \frac{P_L}{2}$ …(15)

Mechanical Input $P_M = \frac{P_L}{2}$ …(16)

Electrical output $P_E = \frac{3}{2}P_L$ …(17)

Eq. (1) becomes Eq. (18):

$$\omega = \frac{1}{M}\int \left(\frac{P_L}{2} - \frac{3}{2}P_L\right) \quad \text{…(18)}$$

Frequency decreases with Eq. (19):

$$\omega = \frac{1}{M}\int (-P_L) \quad \text{…(19)}$$

Frequency deviations become two times larger due to DER

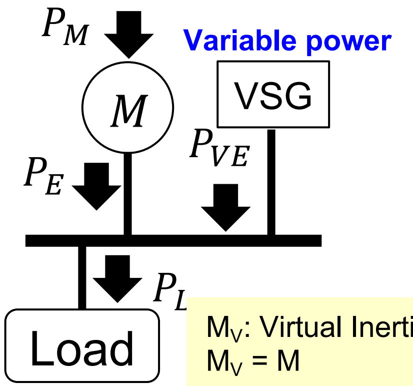
What is the synthetic inertia?

Fuji Electric
Innovating Energy Technology

New grid with VSG-DER (Virtual SG)

"DER" is replaced with VSG (Synthetic Inertia)

Balanced



M_V: Virtual Inertia Constant
$M_V = M$

Victual swing equation $\omega = \frac{1}{M_V}\int (P_{VM} - P_{VE})$ …(20)

VSG output $P_{VE} = \frac{P_L}{2}$ …(21)

Mechanical Input $P_M = \frac{P_L}{2}$ …(22)

Electrical output $P_E = \frac{P_L}{2}$ …(23)

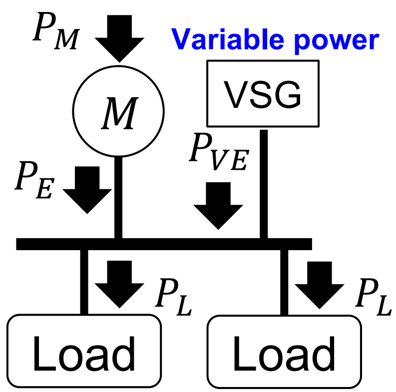
Eq. (20) becomes Eq. (24):

$$\omega = \frac{1}{M_V}\int \left(\frac{P_L}{2} - \frac{P_L}{2}\right) \quad ..(24)$$

Frequency is stable with Eq. (25):

$$\omega = \frac{1}{M_V}\int (0) \quad …(25)$$

Unbalanced



VSG output $P_{VE} = P_L$ …(26)

Mechanical Input $P_M = \frac{P_L}{2}$ …(27)

Electrical output $P_E = P_L$ …(28)

Eq. (20) becomes Eq. (29):

$$\omega = \frac{1}{M_V}\int \left(\frac{P_L}{2} - P_L\right) \quad ..(29)$$

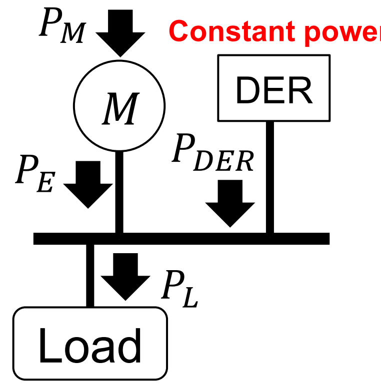
Frequency decreases with Eq. (30):

$$\omega = \frac{1}{M_V}\int \left(-\frac{P_L}{2}\right) \quad …(30)$$

Current grid with DER

"M" is replaced with DER (Distributed energy resources)

Balanced



DER output $P_{DER} = \frac{P_L}{2}$ …(10)

Mechanical Input $P_M = \frac{P_L}{2}$ …(11)

Electrical output $P_E = \frac{P_L}{2}$ …(12)

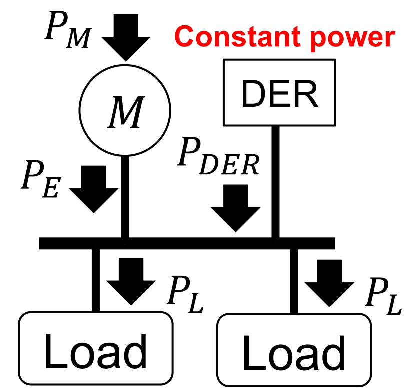
Eq. (1) becomes Eq. (12):

$$\omega = \frac{1}{M}\int \left(\frac{P_L}{2} - \frac{P_L}{2}\right) \quad …(13)$$

Frequency is stable with Eq. (14):

$$\omega = \frac{1}{M}\int (0) \quad …(14)$$

Unbalanced



DER output $P_{DER} = \frac{P_L}{2}$ …(15)

Mechanical Input $P_M = \frac{P_L}{2}$ …(16)

Electrical output $P_E = \frac{3}{2}P_L$ …(17)

Eq. (1) becomes Eq. (18):

$$\omega = \frac{1}{M}\int \left(\frac{P_L}{2} - \frac{3}{2}P_L\right) \quad …(18)$$

Frequency decreases with Eq. (19):

$$\omega = \frac{1}{M}\int (-P_L) \quad …(19)$$

Frequency deviations are reduced by half

What is the synthetic inertia?

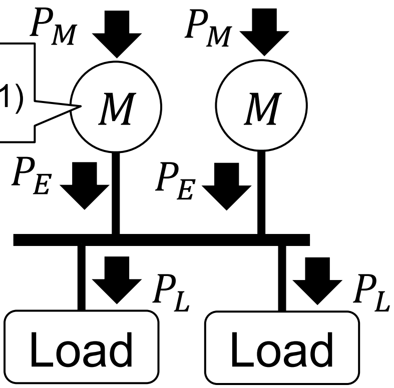
Fuji Electric
Innovating Energy Technology

Conventional grid

"M" represents synchronous generators

Unbalanced

Swing equation $\omega = \frac{1}{M}\int (P_M - P_E) \ldots(1)$



Mechanical Input $P_M = \frac{P_L}{2} \ldots(6)$

Electrical output $P_E = P_L \ldots(7)$

Eq. (1) becomes Eq. (8):

$$\omega = \frac{1}{M}\int \left(\frac{P_L}{2} - P_L\right) \ldots(8)$$

Frequency decreases with Eq. (9):

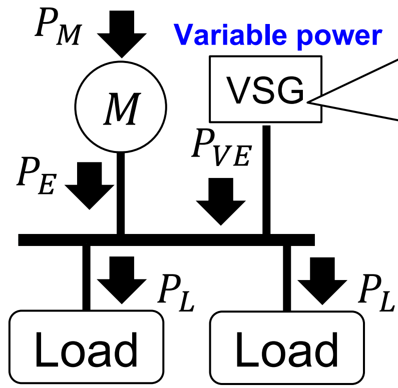
$$\omega = \frac{1}{M}\int \left(-\frac{P_L}{2}\right) \ldots(9)$$

Identical

New grid with VSG-DER (Virtual SG)

"DER" is replaced with VSG (Synthetic Inertia)

Unbalanced



Victual swing equation $\omega = \frac{1}{M_V}\int (P_{VM} - P_{VE}) \ldots(20)$

M_V: Virtual Inertia Constant
M_V = M

VSG output $P_{VE} = P_L \ldots(26)$

Mechanical Input $P_M = \frac{P_L}{2} \ldots(27)$

Electrical output $P_E = P_L \ldots(28)$

Eq. (20) becomes Eq. (29):

$$\omega = \frac{1}{M_V}\int \left(\frac{P_L}{2} - P_L\right) ..(29)$$

Frequency decreases with Eq. (30):

$$\omega = \frac{1}{M_V}\int \left(-\frac{P_L}{2}\right) \ldots(30)$$

Next topic

1. What is the synthetic Inertia ?
2. Fundamental problem in Power systems due to DER
3. Experimental study on inverter power control functions, grid protection and support
4. Experimental study on information exchange to recruit advanced inverter functions (Smart inverter functions)

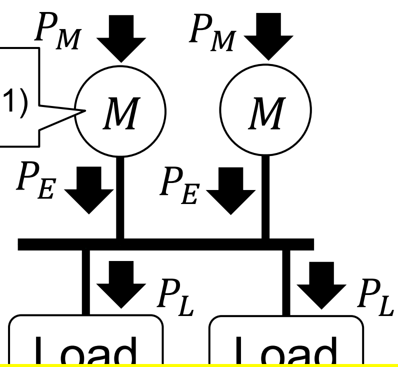
Fundamental problem in power systems

Conventional grid

“M” represents synchronous generators

Unbalanced

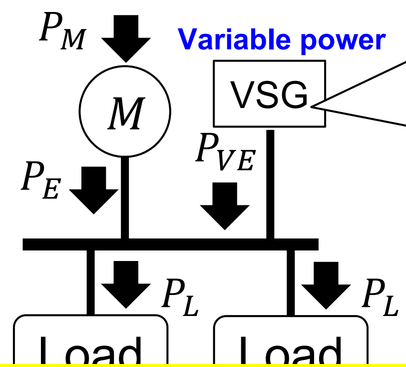
Swing equation $\omega = \frac{1}{M}\int (P_M - P_E)$ …(1)



New grid with VSG-DER (Virtual SG)

“DER” is replaced with VSG (Synthetic Inertia)

Unbalanced



Victual swing equation $\omega = \frac{1}{M_V}\int (P_{VM} - P_{VE})$ …(20)

M_V: Virtual Inertia Constant
$M_V = M$

Do DER always have to have the synthetic inertia?

Mechanical Input $P_M = \frac{P_L}{2}$ …(6)

Electrical output $P_E = P_L$ …(7)

Eq. (1) becomes Eq. (8):

$$\omega = \frac{1}{M}\int \left(\frac{P_L}{2} - P_L\right) \text{ …(8)}$$

Frequency decreases with Eq. (9):

$$\omega = \frac{1}{M}\int \left(-\frac{P_L}{2}\right) \text{ …(9)}$$

Identical

Mechanical Input $P_M = \frac{P_L}{2}$ …(27)

Electrical output $P_E = P_L$ …(28)

Eq. (20) becomes Eq. (29):

$$\omega = \frac{1}{M_V}\int \left(\frac{P_L}{2} - P_L\right) \text{..(29)}$$

Frequency decreases with Eq. (30):

$$\omega = \frac{1}{M_V}\int \left(-\frac{P_L}{2}\right) \text{..(30)}$$

Fundamental problem in power systems

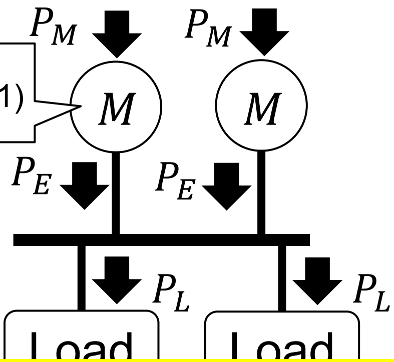
Fuji Electric
Innovating Energy Technology

Conventional grid

"M" represents synchronous generators

Unbalanced

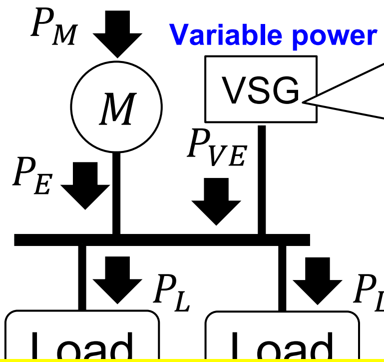
Swing equation $\omega = \frac{1}{M}\int (P_M - P_E)$ …(1)



New grid with VSG-DER (Virtual SG)

"DER" is replaced with VSG (Synthetic Inertia)

Unbalanced



Victual swing equation $\omega = \frac{1}{M_V}\int (P_{VM} - P_{VE})$ …(20)

M_V: Virtual Inertia Constant
$M_V = M$

In regard to the problem of frequency deviations, it does not matter whether generators have the inertia or not

Eq. (1) becomes Eq. (8):

$$\omega = \frac{1}{M}\int \left(\frac{P_L}{2} - P_L\right) \ldots(8)$$

Frequency decreases with Eq. (9):

$$\omega = \frac{1}{M}\int \left(-\frac{P_L}{2}\right) \ldots(9)$$

Eq. (20) becomes Eq. (29):

$$\omega = \frac{1}{M_V}\int \left(\frac{P_L}{2} - P_L\right) ..(29)$$

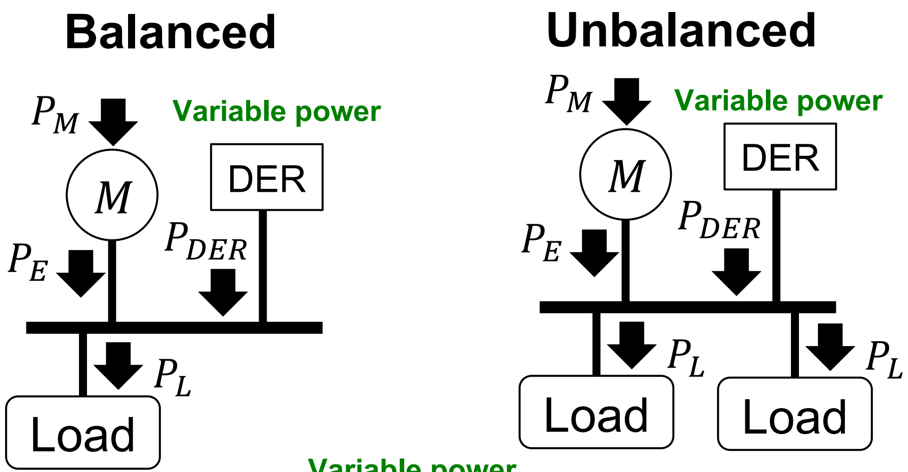
Frequency decreases with Eq. (30):

$$\omega = \frac{1}{M_V}\int \left(-\frac{P_L}{2}\right) ..(30)$$

Identical

Fundamental problem in power systems

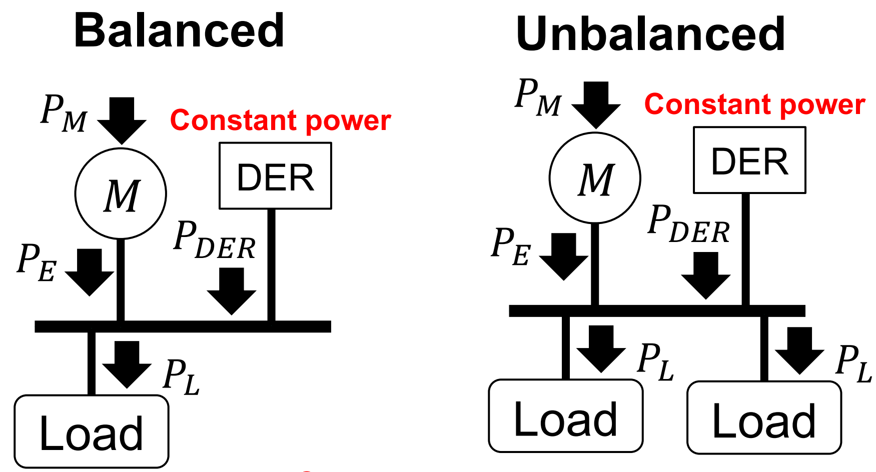
New grid with DER as a variable power source



Variable power

	Balanced		Unbalanced
DER output	$P_{DER} = \frac{P_L}{2}$	→	$P_{DER} = P_L$
Electrical output	$P_E = \frac{P_L}{2}$		$P_E = P_L$

Current grid with DER as a constant power source



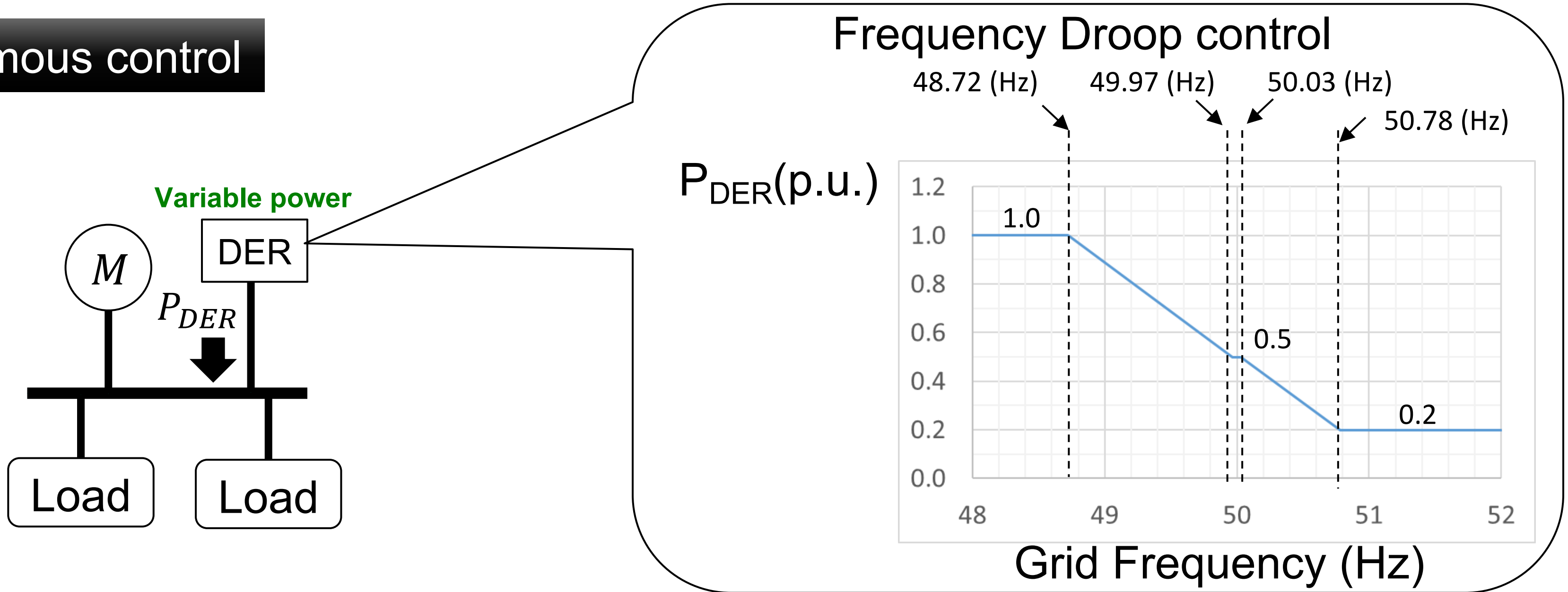
Constant power

	Balanced		Unbalanced
DER output	$P_{DER} = \frac{P_L}{2}$	→	$P_{DER} = \frac{P_L}{2}$
Electrical output	$P_E = \frac{P_L}{2}$		$P_E = \frac{3}{2} P_L$

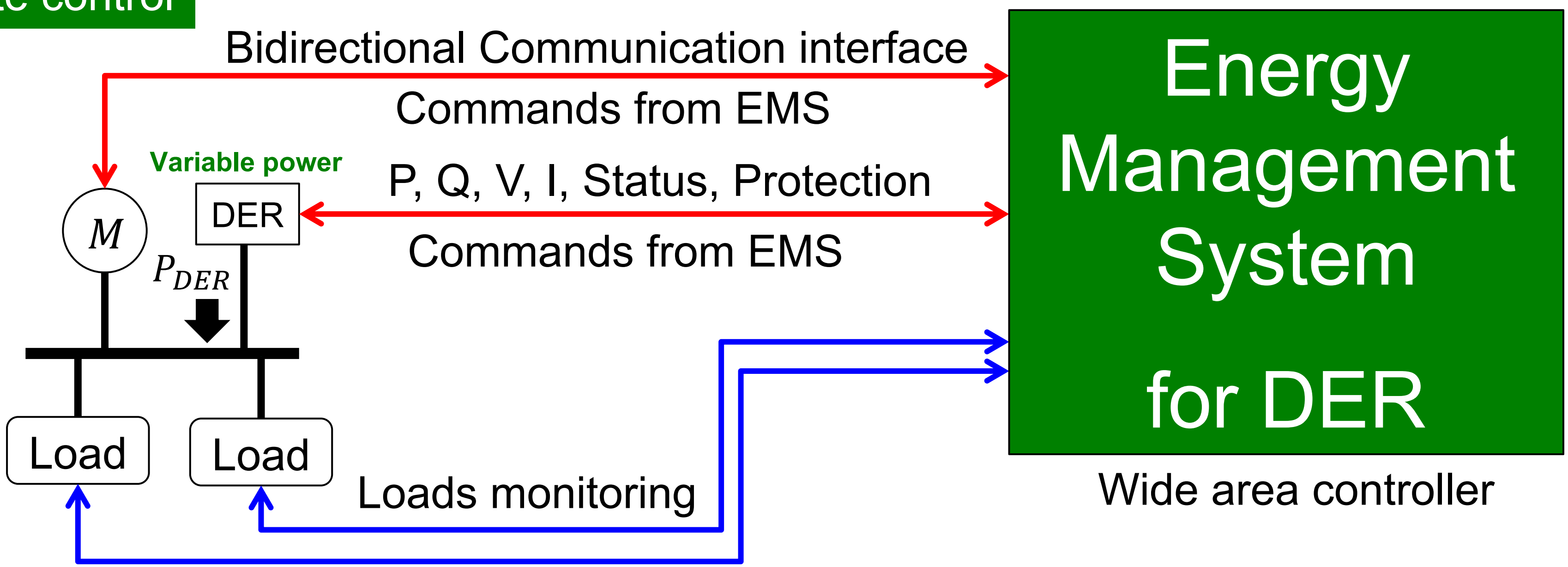
It is just a matter of power control

Variable power control methods (Not only VSG)

Autonomous control



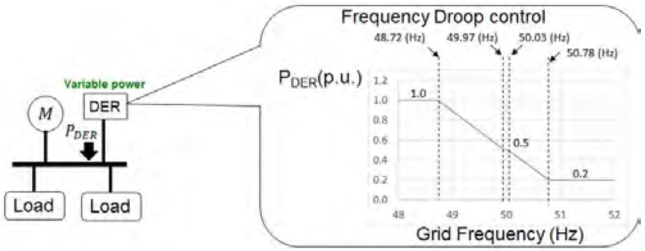
Remote control



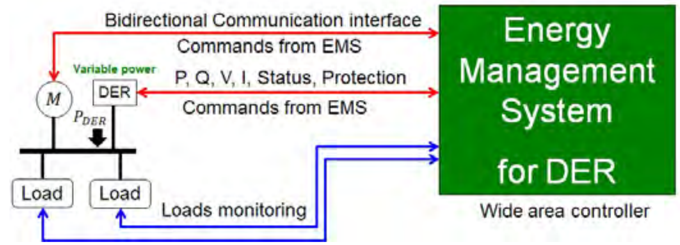
Example of smart inverter functions for power control (protection)

Fuji Electric
Innovating Energy Technology

Autonomous control



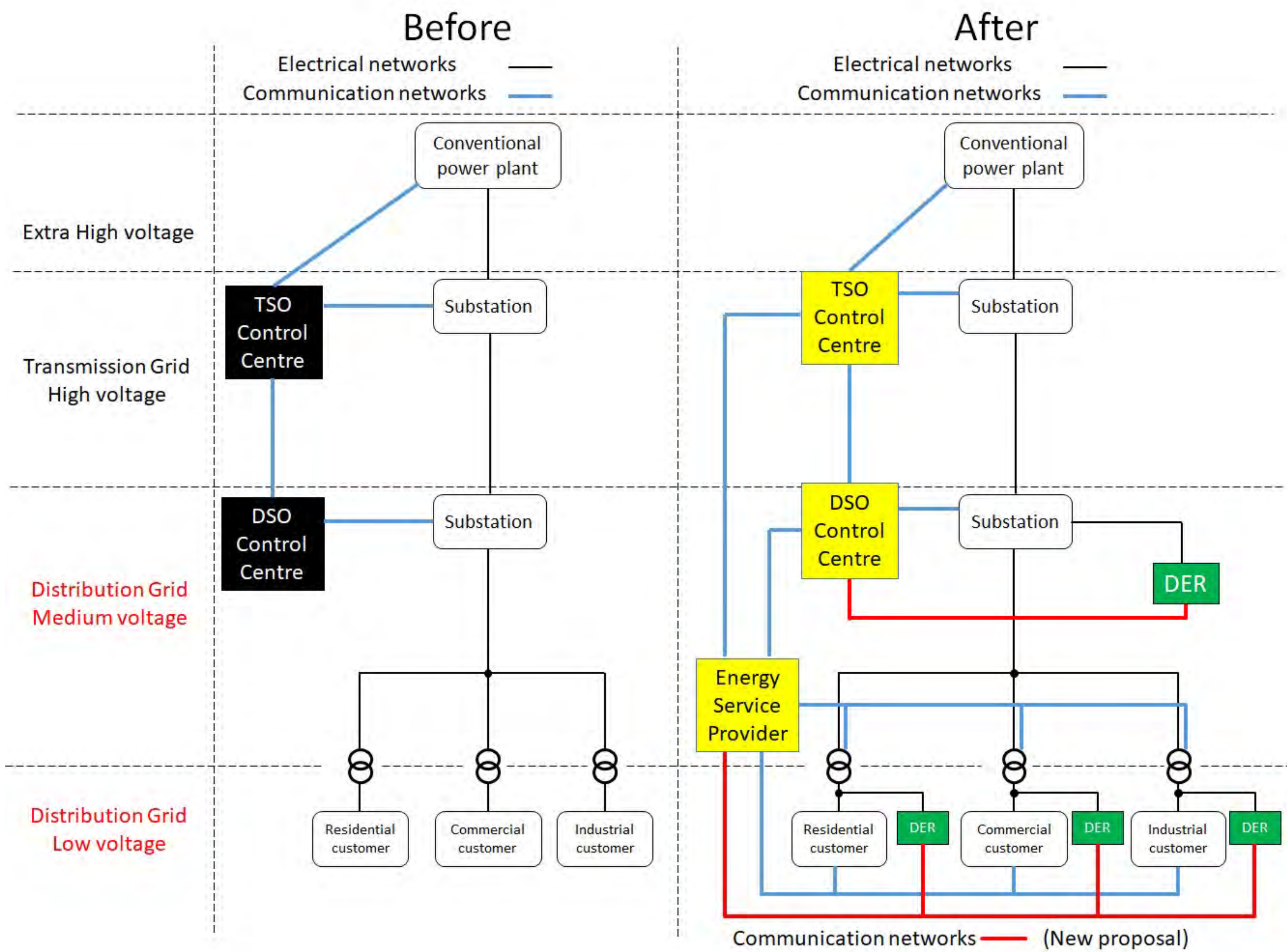
Remote control



	Smart inverter functions	Autonomous	Remote
1	Anti-Islanding detection (Protection)	Y	
2	Fault Ride Through (Immunity)	Y	
3	Voltage-Var Control	Y	Y
4	Frequency-Watt Control (Droop)	Y	Y
5	Voltage-Watt Control	Y	Y
6	Dynamic-reactive current control	Y	Y
7	Virtual synchronous generator	Y	
8	Ramp Rate/Soft Start	Y	Y
9	Constant power factor control	Y	Y
10	Maximum active power control		Y
11	Active power control		Y
12	Reactive power control		Y
13	DER monitoring		Y
14	DER Connect/Disconnect		Y
15	Scheduling function		Y

Future power systems with wide area controllers

Fuji Electric
Innovating Energy Technology



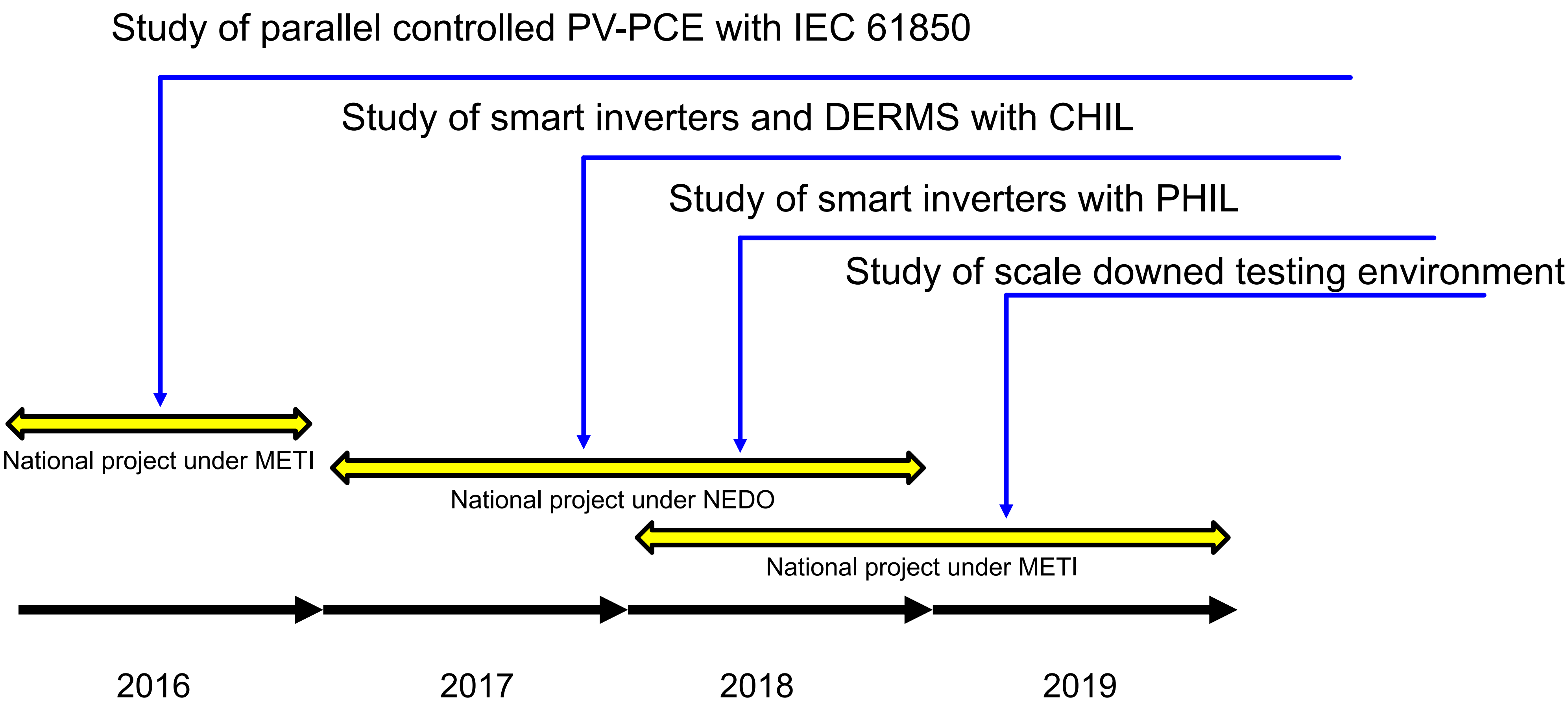
From extra high to low voltage networks, power control can be managed by wide are controllers equipped with communication networks.

Next topic

1. What is the synthetic Inertia ?
2. Fundamental problem in Power systems due to DER
3. Experimental study on inverter power control functions, grid protection and support
4. Experimental study on information exchange to recruit advanced inverter functions (Smart inverter functions)

Fuji Electric
Innovating Energy Technology

4 projects have been implemented for 4 years since 2016 as follows.



- PV-PCE: Photovoltaic Power Conversion Equipment
- DERMS: Energy Management System for DER
- CHIL: Controller Hardware In the Loop
- PHIL: Power Hardware In the Loop

- METI: Ministry of Economy, Trade and Industry
- NEDO: New Energy and Industrial Technology Development Organization

Study of parallel controlled PV-PCE with IEC 61850

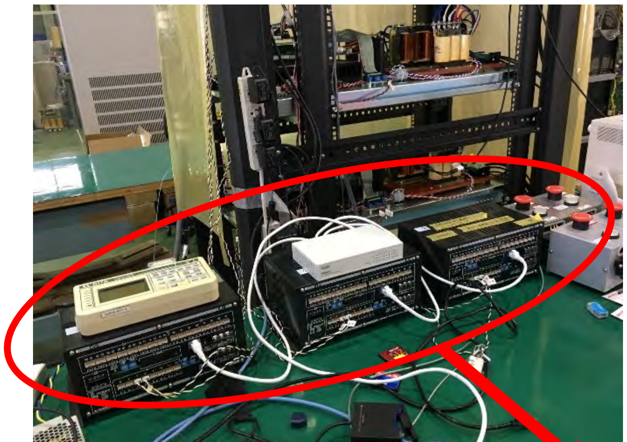
Fuji Electric
Innovating Energy Technology

National project under METI

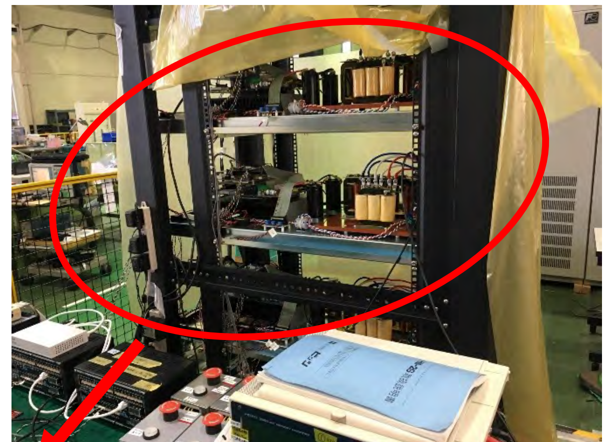
Purpose of the experimental study in 2016

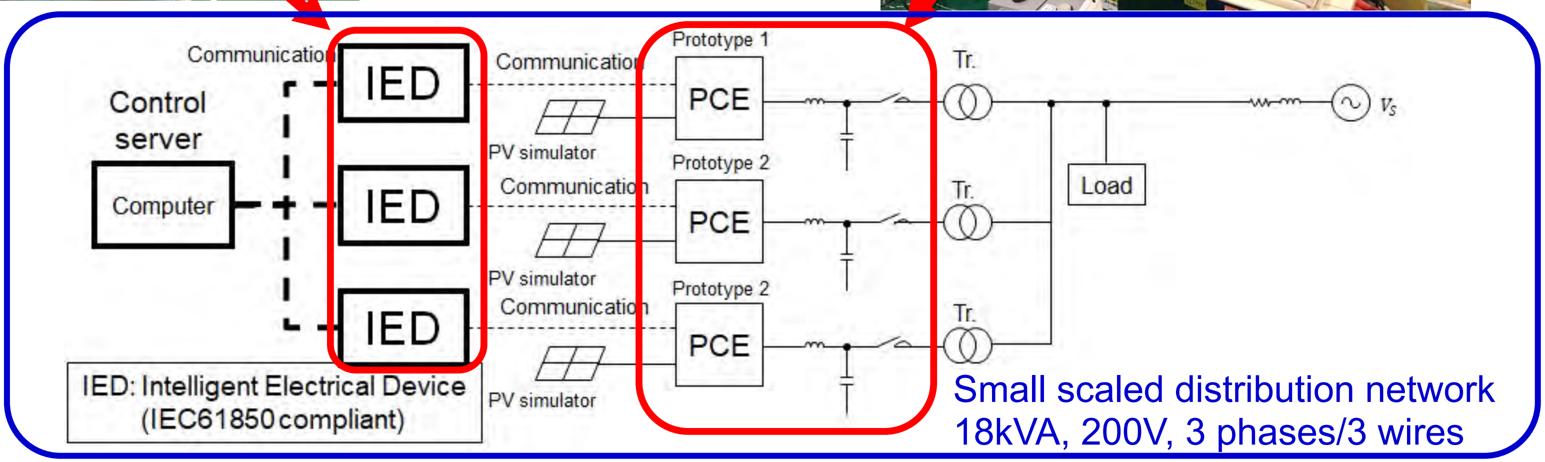
1. Verification of remote control with communication interface based on IEC 61850
2. Evaluation of grid connection requirements (FRT and anti-islanding)
3. Investigation of mutual interference of smart inverters

3 IEDs



3 prototypes of 3kW PV-PCE





PCE: Power Conversion Equipment

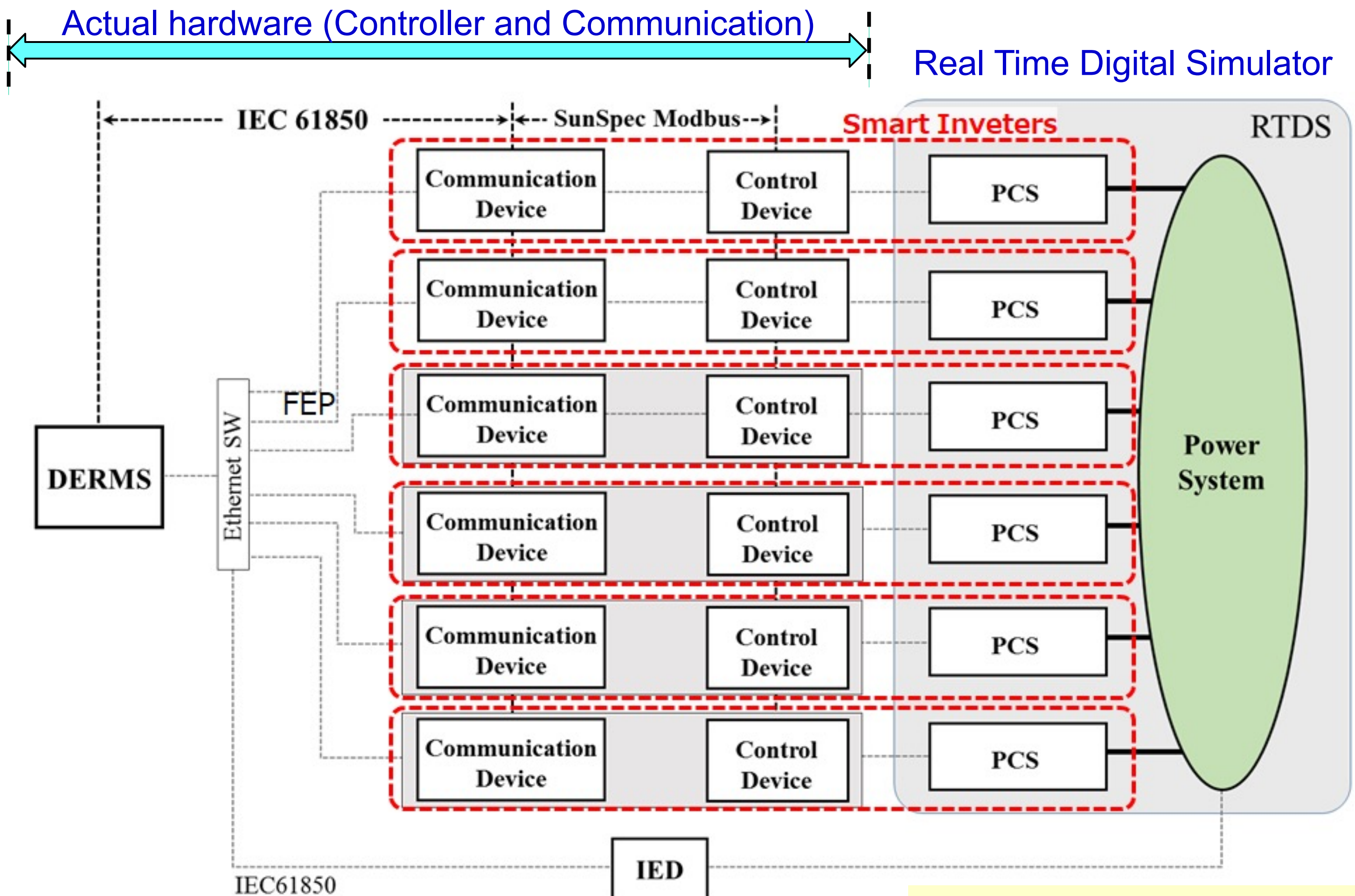
Study of smart inverters and DERMS with CHIL

Fuji Electric
Innovating Energy Technology

Purpose of the experimental study in 2017 and 2018

National project under NEDO

1. Development of smart inverters on the basis of Sunspec information models
2. Development of an energy management system for DER based on IEC 61850



DERMS: Energy Management System for DER

PCS: Power Conversion System

Study of smart inverters with PHIL

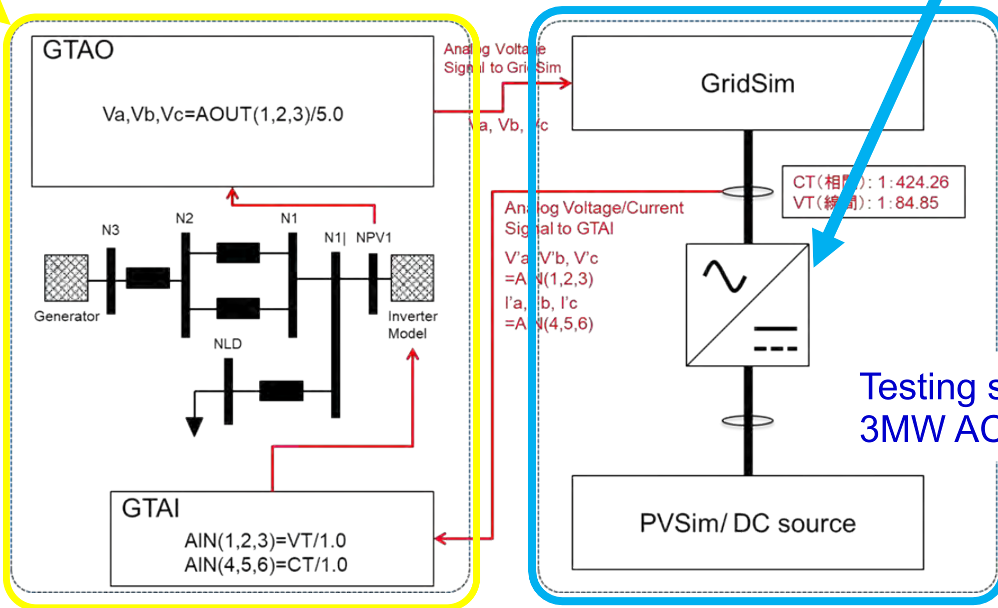
National project under NEDO

Purpose of the experimental study in 2017 and 2018

1. Verification of smart inverter functions with an actual product
2. Evaluation of the simulation performance of PHIL

500kW 3 phases/3 wires PV-PCE

Real Time Digital Simulator



Testing system
3MW AC and DC power sources

Study of scale downed testing environment

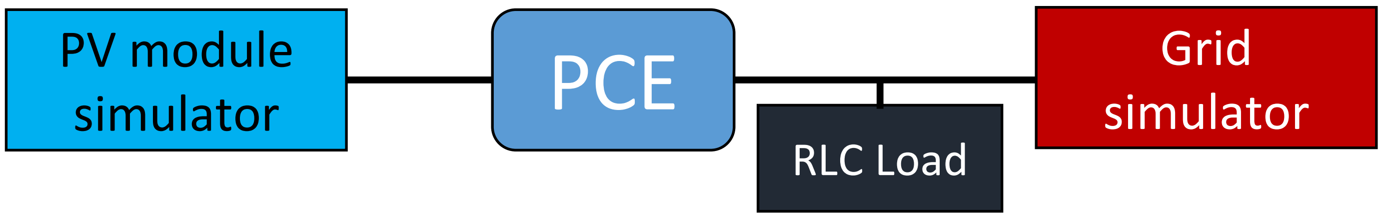
National project under METI

Purpose of the experimental study in 2019

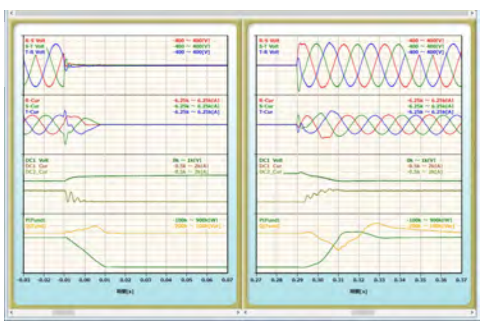
1. Evaluation of applicability of scale downed testing environment
2. Standardization of requirements for the identification of scale downed PCE

Scale down items	Rated power PCE	Scale downed PCE 1	Scale downed PCE 2
Capacity	500 kW	20 kW	2 kW
Voltage	200 Vrms	200 Vrms	200 Vrms
Cutoff frequency of filter	694.6 Hz	694.6 Hz	694.6 Hz

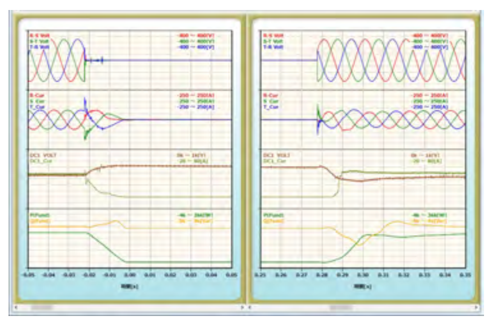
- Actual PCE and two scale downed PCE have identical electrical characteristics
- The actual PCE with rated power was tested in the **full scale** testing environment
- Two scale downed PCE were tested in the **scale downed** testing environment



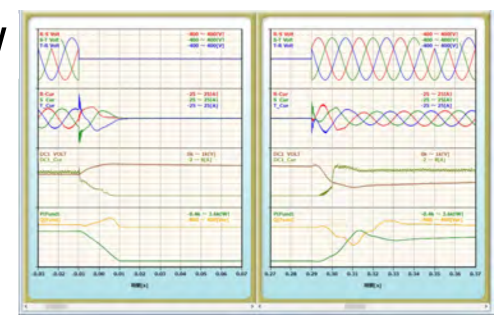
500kW



20kW



2kW



- ✓ Test results of LVRT showed that two scale downed PCE were identical with the actual PCE
- ✓ Test results showed the applicability of the scale down for functional testing of power control

Next topic

Fuji Electric
Innovating Energy Technology

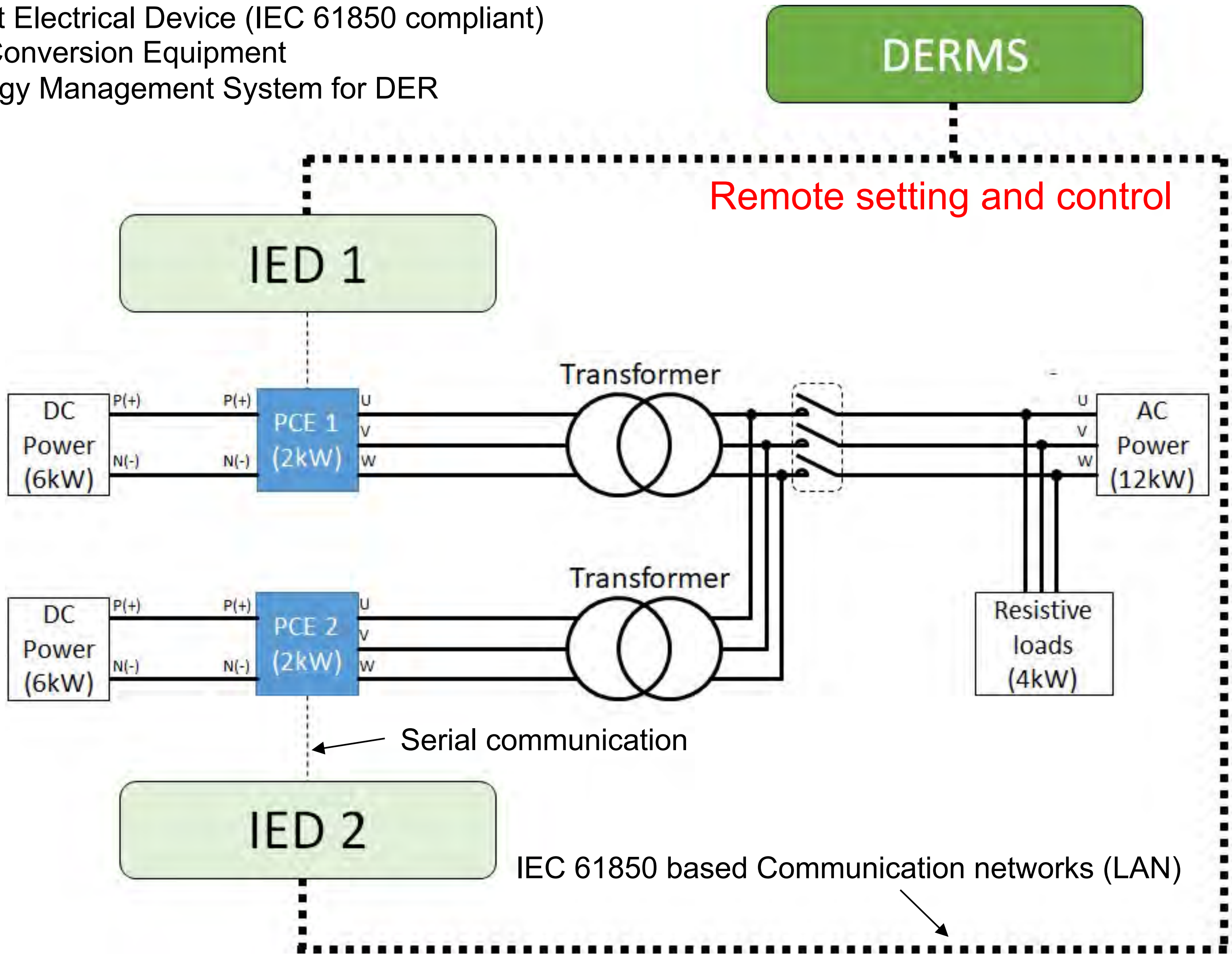
1. What is the synthetic Inertia ?
2. Fundamental problem in Power systems due to DER
3. Experimental study on inverter power control functions, grid protection and support
4. Experimental study on information exchange to recruit advanced inverter functions (Smart inverter functions)

Study of information exchange

Fuji Electric
Innovating Energy Technology

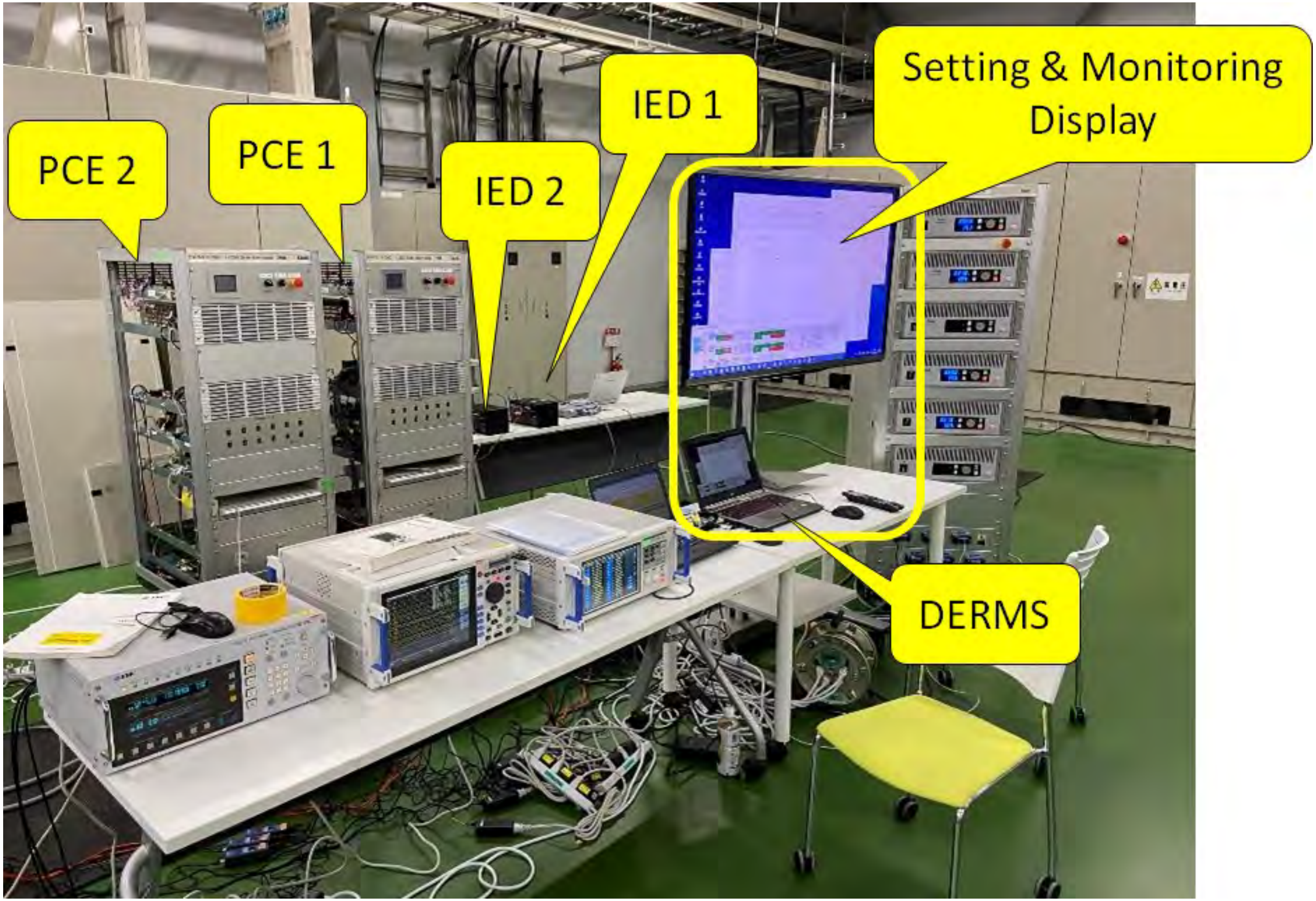
Experimental study on information exchange in January 2021, in Japan

IEC: Intelligent Electrical Device (IEC 61850 compliant)
PCE: Power Conversion Equipment
DERMS: Energy Management System for DER



Study of information exchange

Experimental study on information exchange in January 2021, in Japan



In parallel with the study of information exchange:

– The prioritization of power control functions which were developed under NEDO project in 2017 and 2018 was verified by referring to IEEE 1547.1-2020.

List of integrated control functions

1. ~~Islanding Detection~~
2. Fault Ride Through
3. Voltage - Var Control
4. ~~Ramp Rate / Soft Start~~
5. Constant Power Factor Control
6. DER Monitoring
7. DER Disconnection/Re-interconnection
8. Maximum Active Power Control
9. Active Power Control
10. Reactive Power Control
11. Frequency - Watt Control
12. Voltage - Watt Control
13. ~~Dynamic - Reactive Current Control~~
14. ~~Scheduling Function~~

- Not applied
- Autonomous
- Remote control
- Prioritization was verified

Study of information exchange

初期データ設定画面 No.0030 デモ確認用

S－INV No. 1

指令値配分

S－INV 機器容量		S－INV ／模擬定格出力 模擬容量	S－INV 機器容量		S－INV ／模擬定格電圧 模擬容量
500000.0 W	／	500.0 kW	200.0 V	／	200.0 V

単独運転検出 L/HVRT L/HFRT Volt-Var制御 Ramp-rate,Soft-Start 力率一定制御 解列/再連系 最大有効電力制御 有効電力制御 無効電力制御 Freq-Watt制御 Volt-Watt制御 動的無効電流制御 スケジュール機能

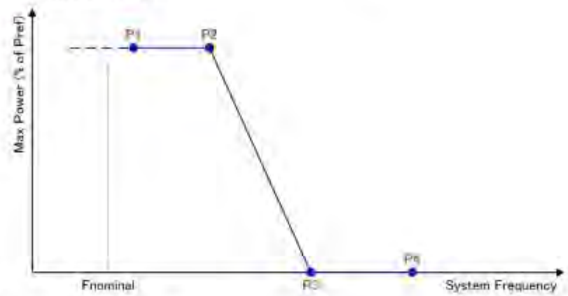
Frequency－Watt制御機能

最終送信状態 ： 使用　　S-INV状態 ： 使用　　変更設定 ： ◉ 使用　○ 不使用

設定項目	最終送信値	S-INV値	変更設定値
F1 (Hz)	48.72	48.72	48.72
F2 (Hz)	49.97	49.97	49.97
F3 (Hz)	50.03	50.03	50.03
F4 (Hz)	50.78	50.78	50.78
P1 (%)	100.0	100.0	100.0
P2 (%)	50.0	50.0	50.0
P3 (%)	50.0	50.0	50.0
P4 (%)	20.0	20.0	20.0

※有効電力単位は「%WRef」で定義し、最大有効電力を基に入力する。

<曲線設定イメージ>



状態取得　設定　データ送信　戻る

Setting Display for “Frequency-Watt Function (Frequency Droop)”

Study of information exchange

Fuji Electric
Innovating Energy Technology

初期データ設定画面　No.0030　デモ確認用

S－INV　No. 1

指令値配分

S－INV　／模擬定格出力

S－INV　機器容量		模擬容量	
500000.0	W ／	500.0	kW

S－INV　／模擬定格電圧

S－INV　機器容量		模擬容量	
200.0	V ／	200.0	V

単独運転検出　L/HVRT　L/HFRT　Volt-Var制御　Ramp-rate,Soft-Start　力率一定制御　解列/再連系　最大有効電力制御　有効電力制御　無効電力制御　Freq-Watt制御　Volt-Watt制御　動的無効電流制御　スケジュール機能

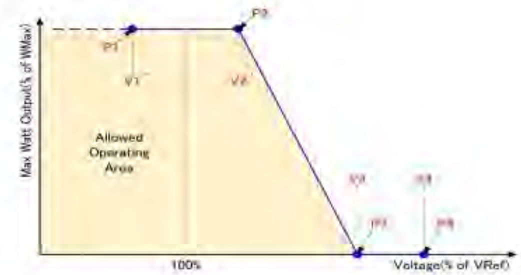
Volt－Watt制御機能

最終送信状態　：　使用　　S-INV状態　：　使用　　変更設定　：　◉ 使用　○ 不使用

設定項目	最終送信値	S-INV値	変更設定値
V1　(%)	100.0	100.0	100.0
V2　(%)	106.0	106.0	106.0
V3　(%)	110.0	110.0	110.0
V4　(%)	115.0	115.0	115.0
P1　(%)	100.0	100.0	100.0
P2　(%)	100.0	100.0	100.0
P3　(%)	20.0	20.0	20.0
P4　(%)	20.0	20.0	20.0

※電圧単位は「%VRef」で定義し、基準電圧を基に入力する。
※有効電力単位は「%WRef」で定義し、最大有効電力を基に入力する。

<曲線設定イメージ>



状態取得　設定　データ送信　戻る

Setting Display for “Volt-Watt Function”

Study of information exchange

Fuji Electric
Innovating Energy Technology

初期データ設定画面　No.0030　デモ確認用

S−INV　No. 1

指令値配分

S−INV　機器容量		S−INV　／模擬定格出力 模擬容量		S−INV　機器容量		S−INV　／模擬定格電圧 模擬容量	
500000.0	W	500.0	kW	200.0	V	200.0	V

単独運転検出　L/HVRT　L/HFRT　Volt−Var制御　Ramp-rate,Soft-Start　力率一定制御　解列/再連系　最大有効電力制御　有効電力制御　無効電力制御　Freq−Watt制御　Volt−Watt制御　動的無効電流制御　スケジュール機能

Volt−Var制御

最終送信状態　：不使用　　S−INV状態　：　不使用　　変更設定　：　○ 使用　◉ 不使用

最終送信曲線　：曲線1　　S−INV有効曲線　：　曲線1　　変更設定　：　◉ 曲線1　○ 曲線2

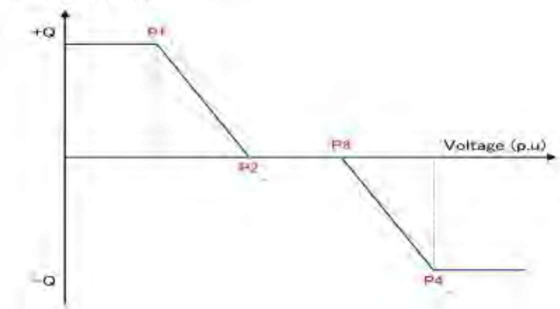
曲線パターン1

設定項目	最終送信値	S−INV値	変更設定値
V1 (%)	92.0	92.0	92.0
V2 (%)	98.0	98.0	98.0
V3 (%)	102.0	102.0	102.0
V4 (%)	108.0	108.0	108.0
Q1 (%)	44.0	44.0	44.0
Q2 (%)	0.0	0.0	0.0
Q3 (%)	0.0	0.0	0.0
Q4 (%)	−44.0	−44.0	−44.0

曲線パターン2

設定項目	最終送信値	S−INV値	変更設定値
V1 (%)	0.0	0.0	0.0
V2 (%)	0.0	0.0	0.0
V3 (%)	0.0	0.0	0.0
V4 (%)	0.0	0.0	0.0
Q1 (%)	−999.9	−999.9	−999.9
Q2 (%)	−999.9	−999.9	−999.9
Q3 (%)	−999.9	−999.9	−999.9
Q4 (%)	−999.9	−999.9	−999.9

＜曲線設定イメージ＞

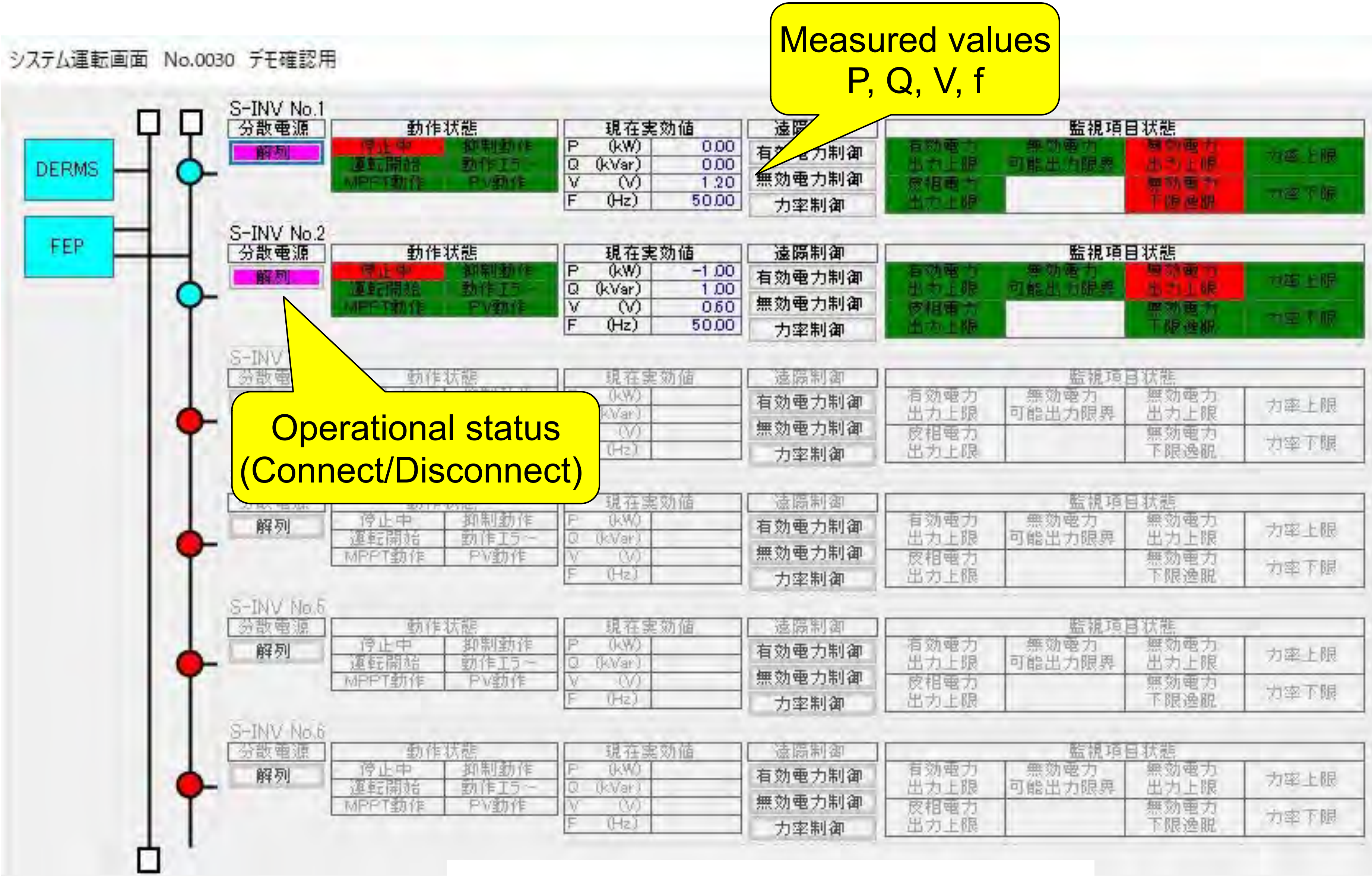


※電圧単位は「%VRef」で定義し、基準電圧を基に入力する。
※無効電力単位は「%VArAval」で定義し、出力可能無効電力を基に入力する。

Setting Display for “Volt-Var Function”

状態取得　設定　データ送信　戻る

Study of information exchange



Monitoring Display for 2 PCE

Thank you for your attention

Study of smart inverter functions in Japan

1. What is the synthetic Inertia ?
2. Fundamental problem in Power systems due to DER
3. Experimental study on inverter power control functions, grid protection and support
4. Experimental study on information exchange to recruit advanced inverter functions (Smart inverter functions)

Yasutoshi Yoshioka
European Research & Technical Center
Fuji Electric Europe GmbH

A devil‘s advocate view on

Synchronized Measurements for Modeling and Control of Inverter-Based Resources

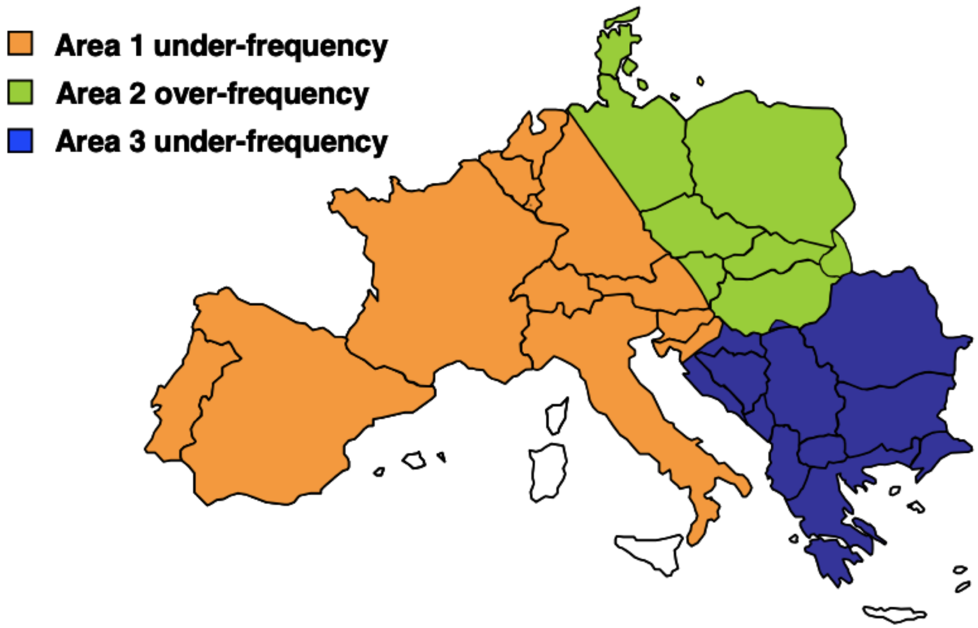
Gunnar Kaestle

North American Synchrophasor Initiative Work Group

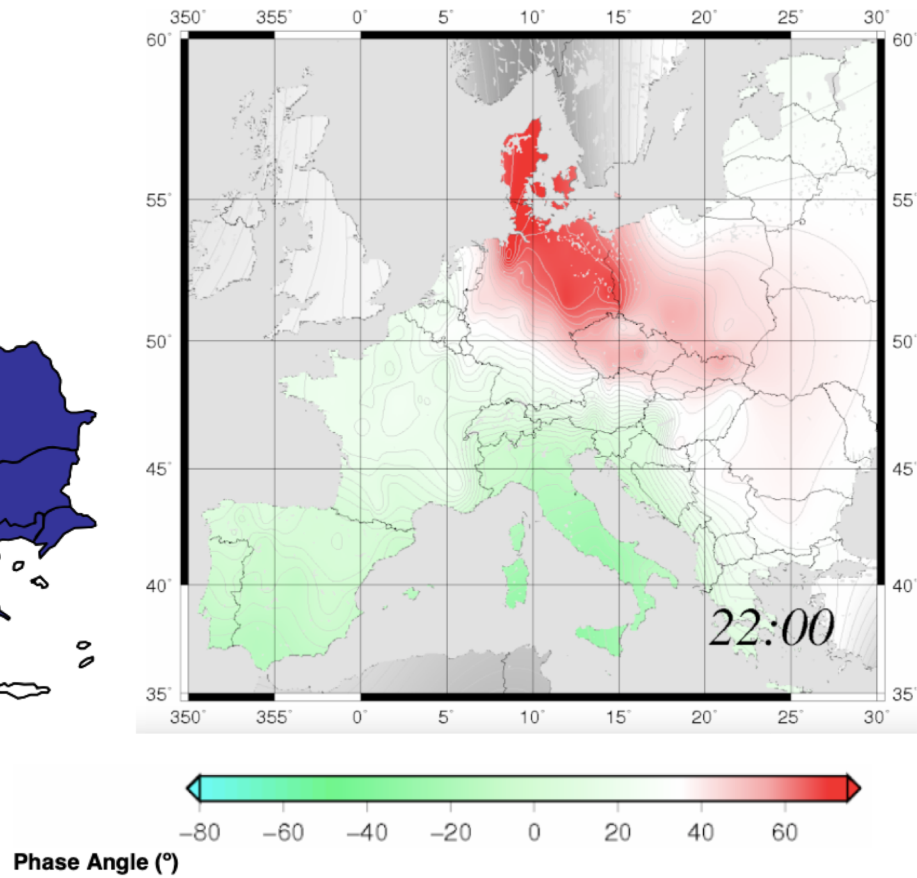
Wednesday, 2021-10-06, Virtual Meeting

Synchronized Measurements / WAMS – what for?

- European System Split of 2006-11-04

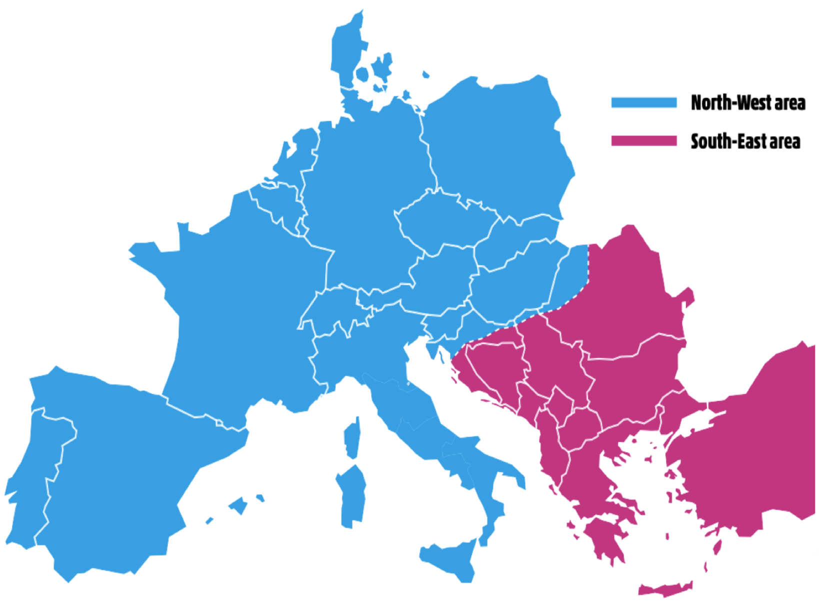


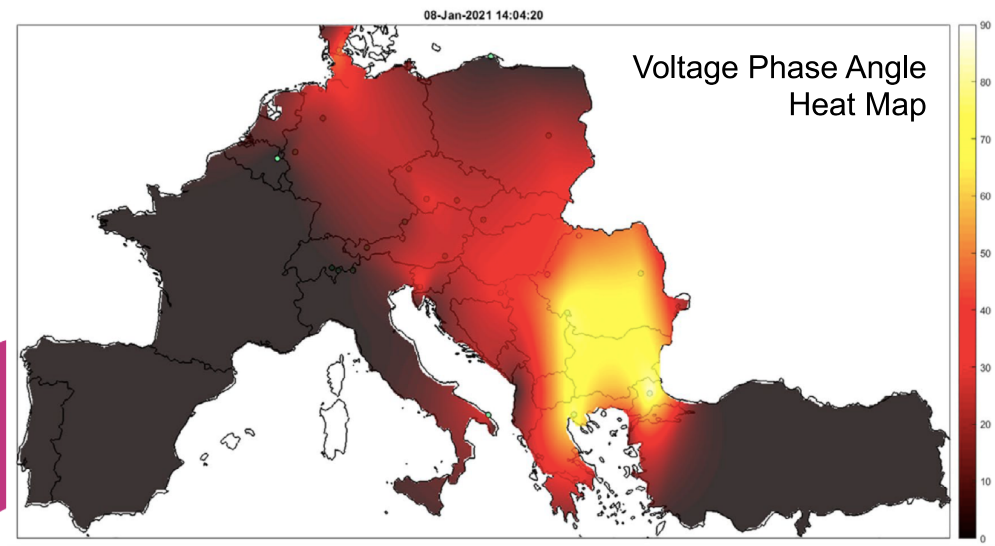
Source: UCTE 2007



Improved Situational Awareness

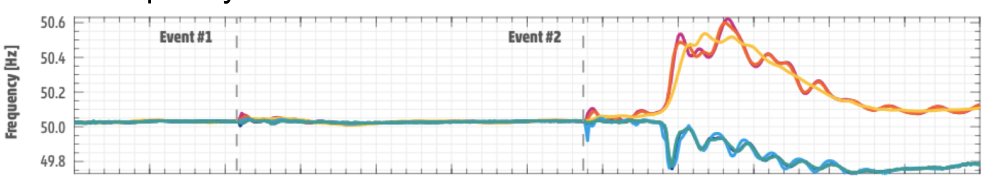
- European System Split of 2021-01-08



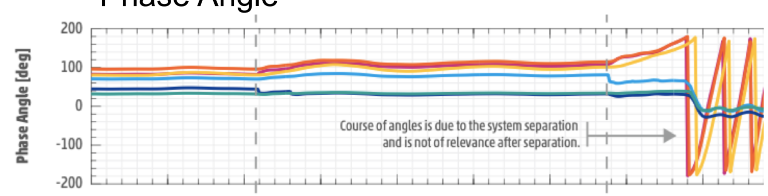


Source: ENTSOE 2021

Frequency



Phase Angle



Everywhere? – No.

- Why not?
- Synchronized Measurements (timestamped)
  - have higher cost
  - cause higher complexity

- Transmission Level
  - Benefit is clearly visible for large interconnections
  - Which density is sufficient for situation awareness?

- Distribution Level
  - What needs to be measured?
  - Observer approach with only a few measurement points

Cellular Approach for Distributed Energy Systems

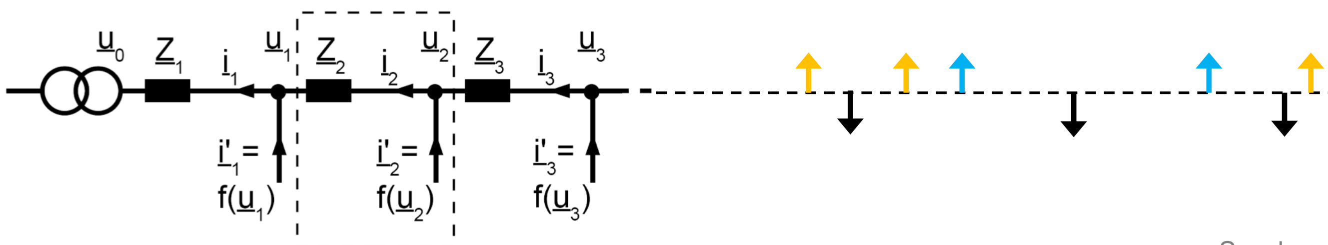
- Subsidiarity principle
- Self-regulation
- Local control as far as possible
- Emergence of resilient structures
- Communication via grid parameters

- Less is more:
- Avoiding the complexity trap

- VDE Study: The Cellular Approach, 2015
  - https://shop.vde.com/en/vde-study-the-cellular-approach

European Grid Codes

- Legal Documents: EU Network Codes (NC)
  - Requirements for Generators (RfG)
  - Demand Connection Code (DCC)
- CENELEC Standards: EN 50549 Series
  - Part 1: Low Voltage Generators
  - Part 2: Medium Voltage Generators
  - Part 10: Conformity Assessment
- Grid stability issues
  - Immunity: UVRT, OVRT, ROCOF, under-frequency
  - Local feedback: P(f) control, Q(U) control, P(U) allowed

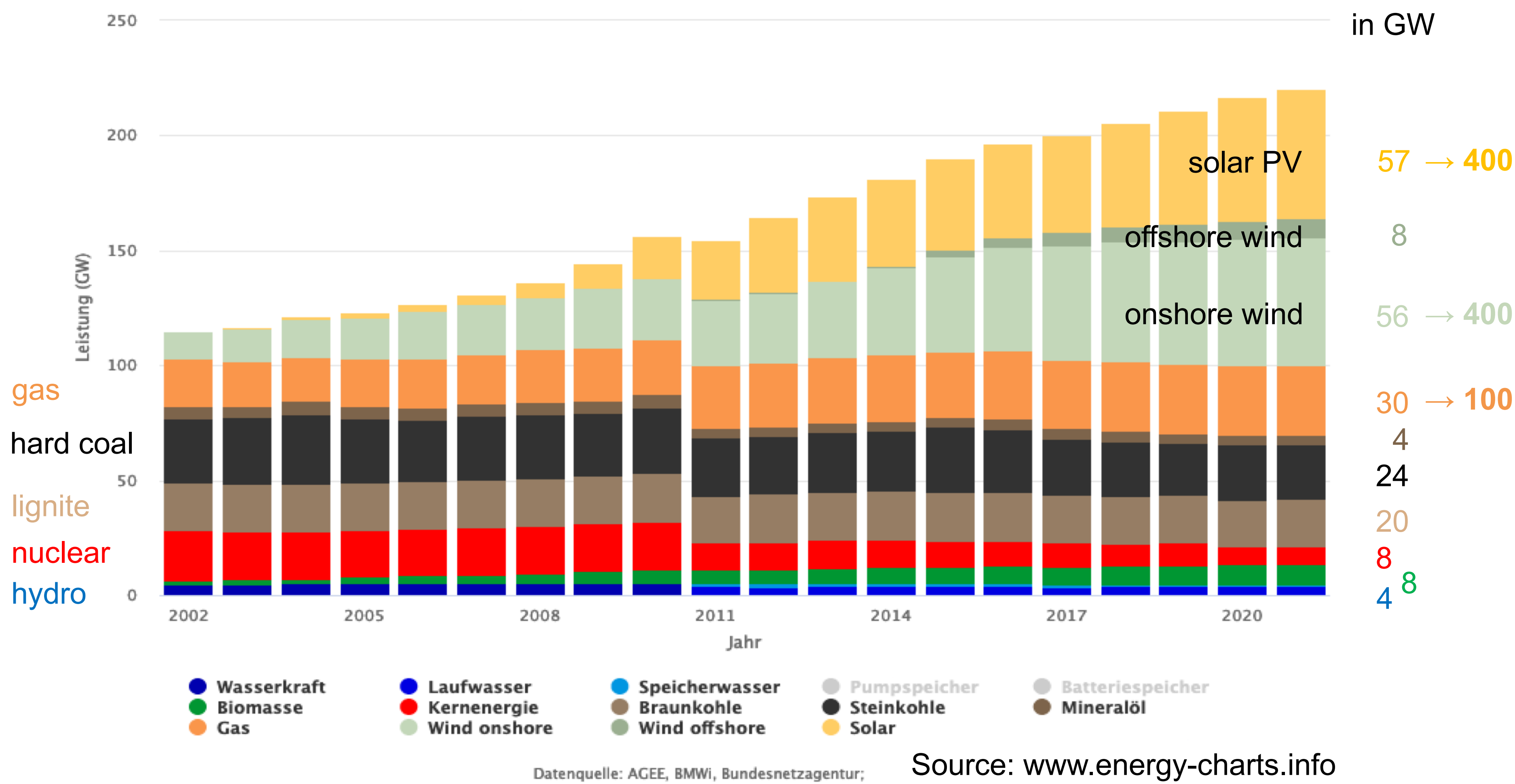


Conflicting Interests: TSO vs DSO

- Grid stabilizing features vs unintentional islanding
  - Mutual interests in stable and robust network operation
  - But: fear of unwanted electrical island by DSOs
  - Problem: False positive triggering of anti-island protection
- What is an island?
  - Land where water is expected
  - Voltage where no voltage is expected
- Solution for MV islands: voltage presence indicator
  - No automatic protection, but informed decision by DSO
  - 5 rules for electrical safety (cf EN 50110) avoid personal injury

Kerber, Kaestle, Oechsle: Strategies for Coping with Unintentional Islanding as a Result of Robust Grid Connection Rules for Distributed Generation, ETG-Kongress 2013, Berlin. https://www.researchgate.net/publication/263654529_Strategies_for_Coping_with_Unintentional_Islanding_as_a_Result_of_Robust_Grid_Connection_Rules_for_Distributed_Generation

Net Power Generating Capacity in Germany



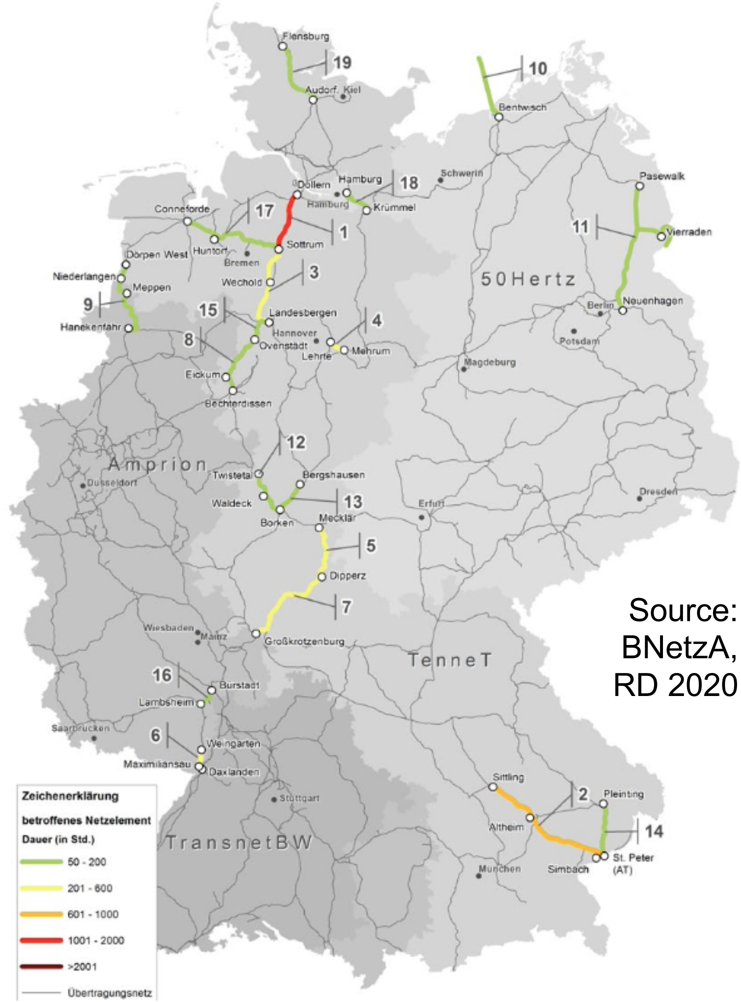
Source: www.energy-charts.info

Redispatch as Application?

- Renewables are deployed not only next to load centers
- Expansion of transmission networks has a time constant of ca. 20 years
- Balancing network expansion vs deployment of flexibility options

- Role of synchronised measurements?
  - None.

- But may be needed to identify oscillations at regional level.



Source: BNetzA, RD 2020

Further Future Topics

- Grid-forming inverters
  - Rotating voltage vector
  - Current follows the phase difference between grid and generator
  - Emulation of inertia

- Network control strategies based on nodal voltage angle control
  - Possible without a central time standard

- Damping issues
  - Dissipating characteristics dissapear

openVPP

Would you like to know more?

gunnar.kaestle@tu-clausthal.de
Tel. +49 5323 997724

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

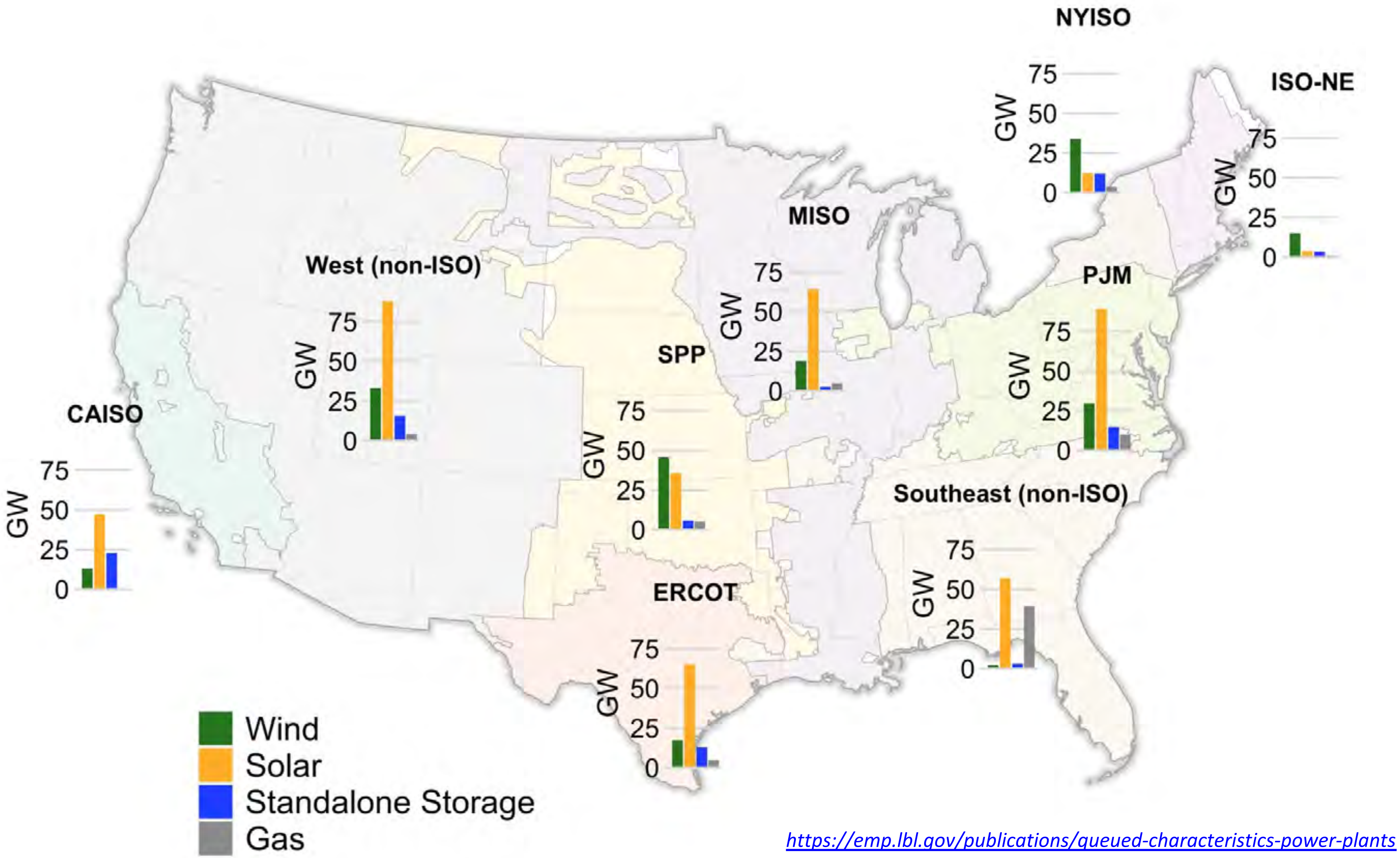
Toward a World of Inverter-Based Resources

Ryan Quint, PhD, PE
Senior Manager, NERC
NASPI Work Group Meeting
October 2021

RELIABILITY | RESILIENCE | SECURITY




Interconnection Queues



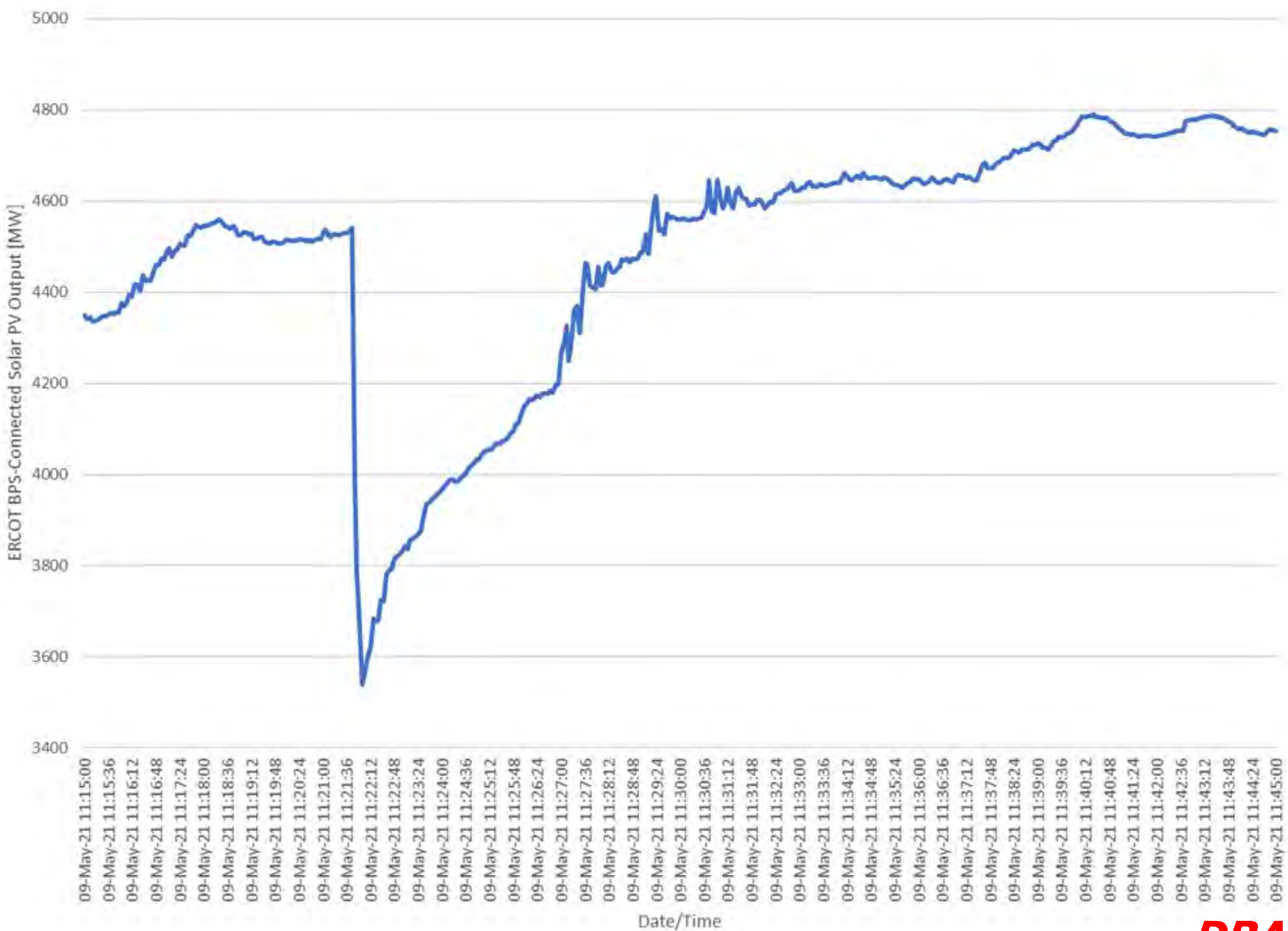
https://emp.lbl.gov/publications/queued-characteristics-power-plants

NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

NERC Disturbance Reports and Alerts

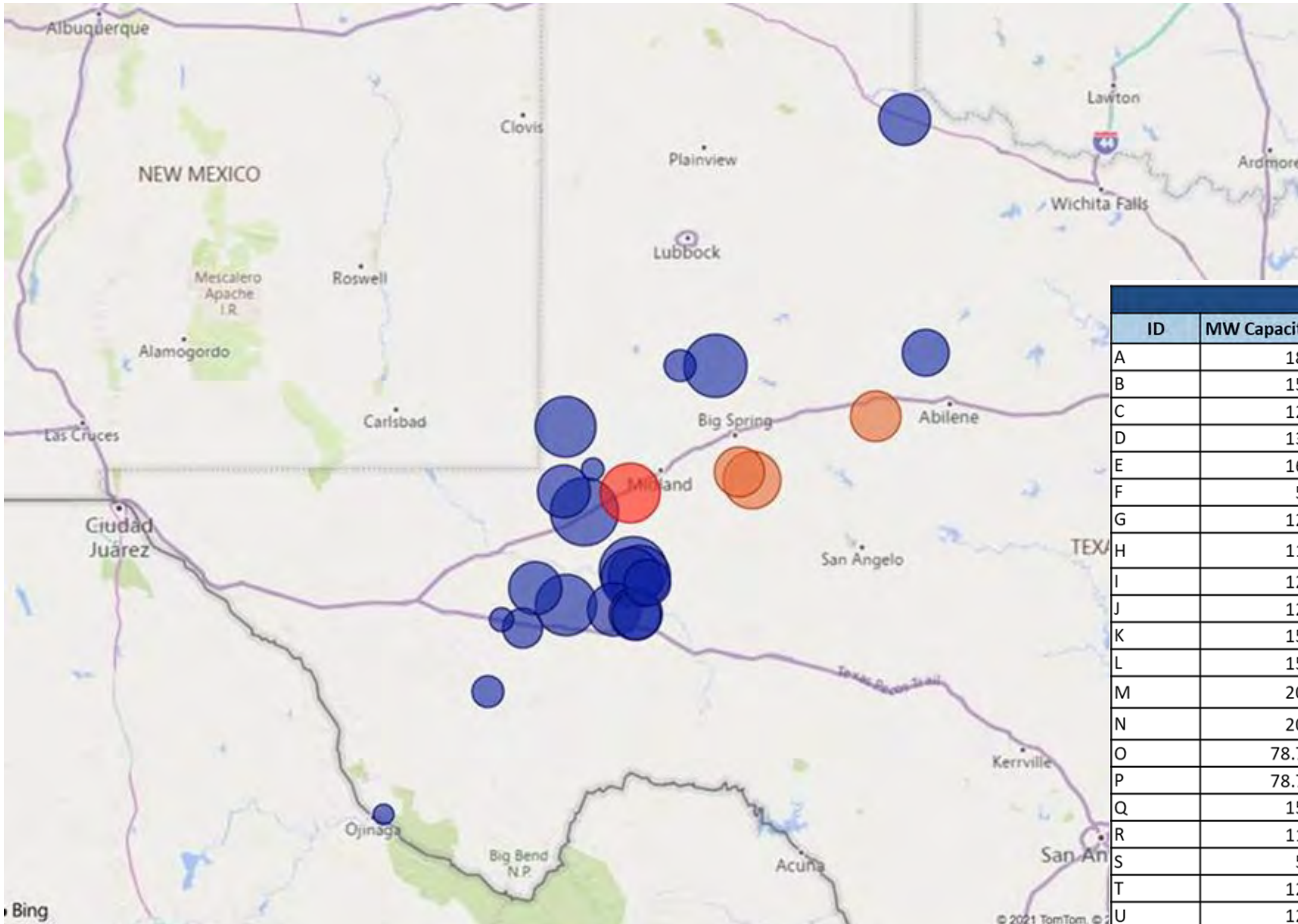
NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Overall SCADA Data – Wide-Area "What Happened"



DRAFT

May 9 Disturbance in Texas



Review of Solar PV Facilities					
ID	MW Capacity	Reduction	POI Voltage	Bulk Electric System?	In-Service Date
A	180	28	138	Yes	6/2018
B	152	150	138	Yes	6/2020
C	126	TBD	345	Yes	11/2020
D	132	18	345	Yes	11/2020
E	162	27	138	Yes	5/2021
F	50	47.6	69	No	9/2017
G	121	239	345	Yes	12/2019
H	119				12/2019
I	125	TBD	138	Yes	10/2019
J	128		138	Yes	10/2019
K	154	204.6	345	Yes	6/2020
L	150		345	Yes	6/2020
M	200	44.5	345	Yes	12/2019
N	200		345	Yes	4/2020
O	78.75	153	138	Yes	9/2016
P	78.75		138	Yes	9/2016
Q	155	146.93	138	Yes	3/2018
R	110	23.1	138	Maybe	3/2017
S	50		138		11/2016
T	126	101.7	138	Yes	12/2020
U	129		138	Yes	12/2020
V	10	5.38	69 kV	No	12/2012
W	104	7.5	345	Yes	12/2020
X	22	2.1	138	No	7/2014
Y	50	6	138	No	12/2018
Z	180	TBD	138	Yes	3/2020
AA	17	4.4	138	No	7/2019
AB	157.5	9	138	Yes	8/2017

Plant SCADA Data – Oscillations

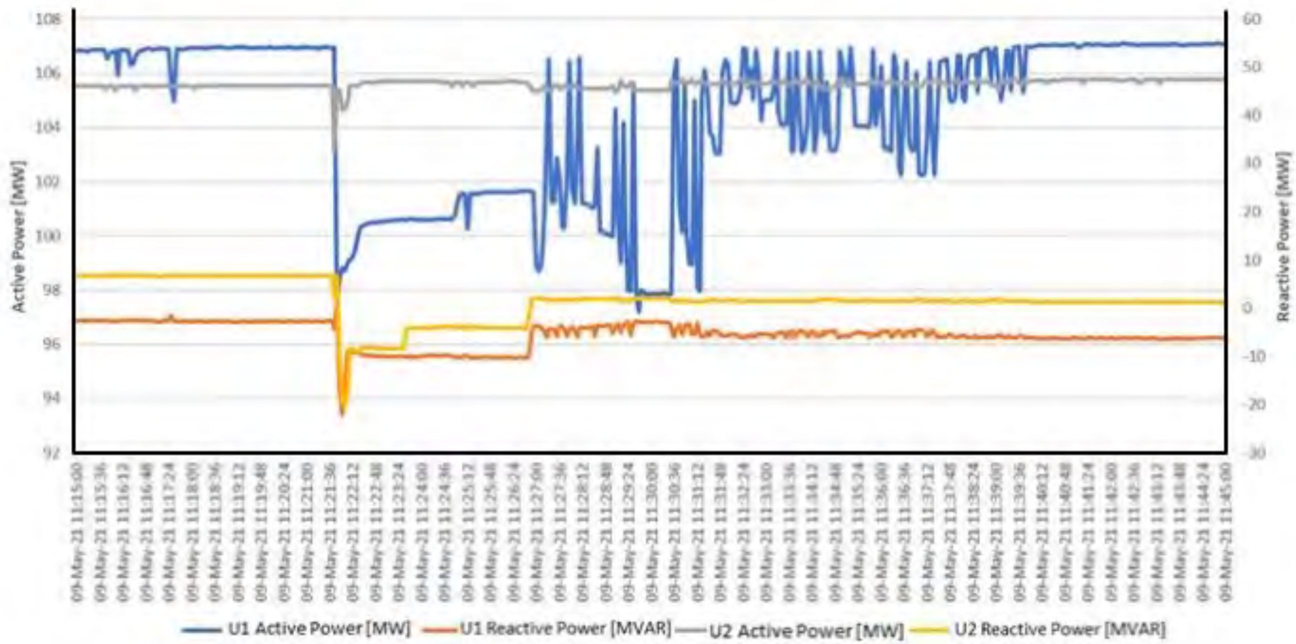


Figure B.16: Plant Active and Reactive Power Output

Plant SCADA Data – Tripping

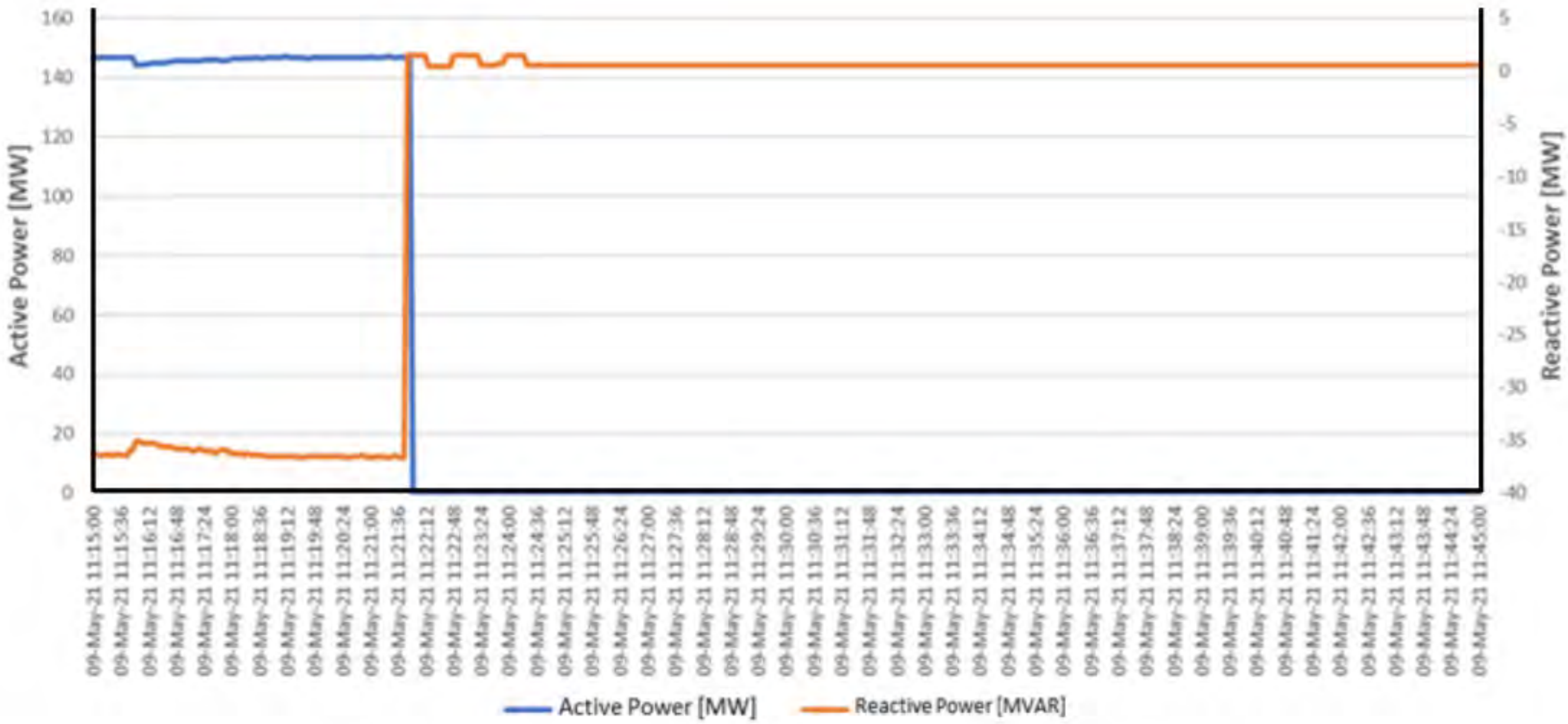


Figure B.14: Plant Active and Reactive Power Output

Root Cause Analysis
POI Oscillography Data to the Rescue

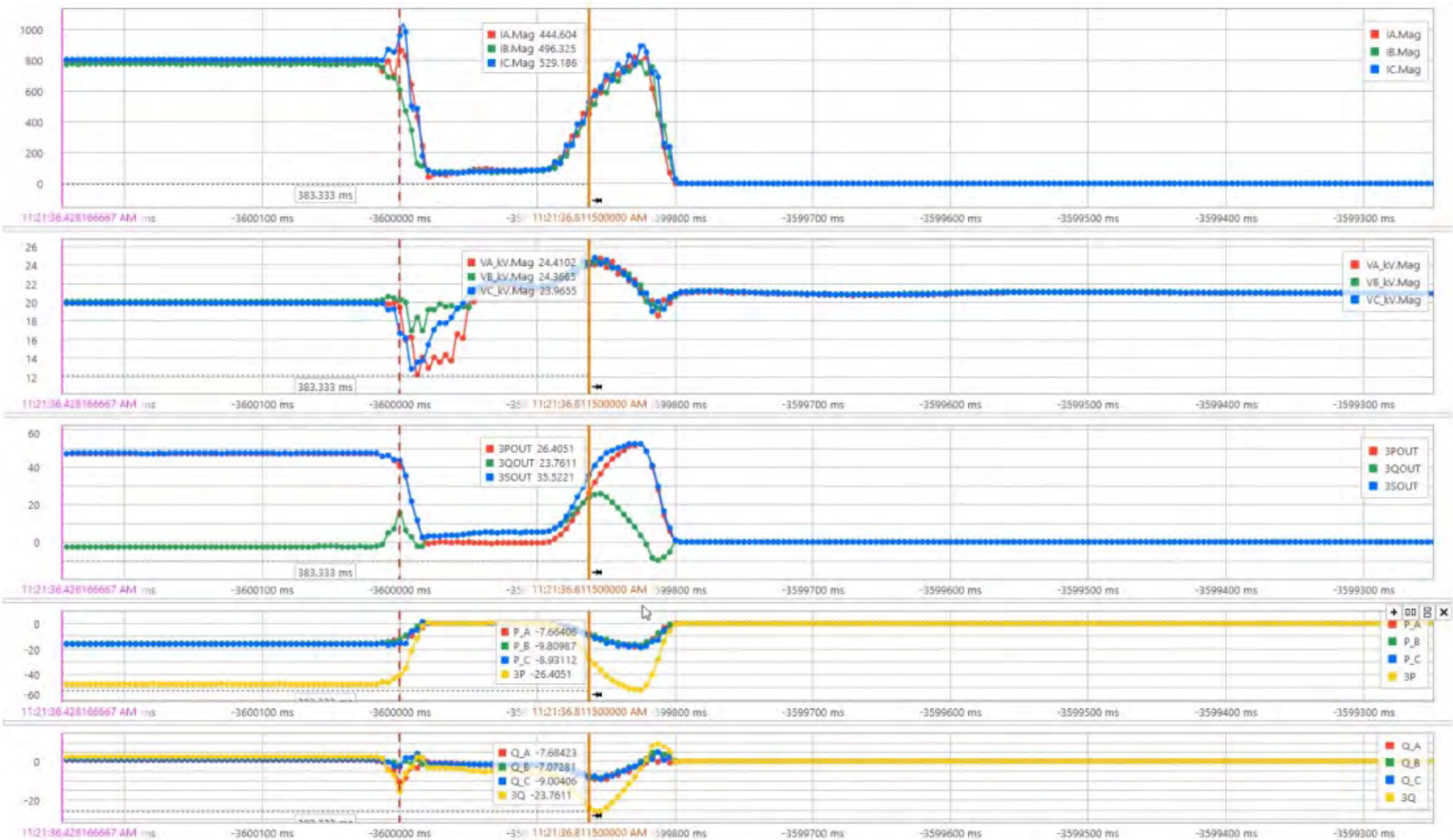


Figure B.13: Current Injection at Time of Trip

Root Cause Analysis Walkthrough

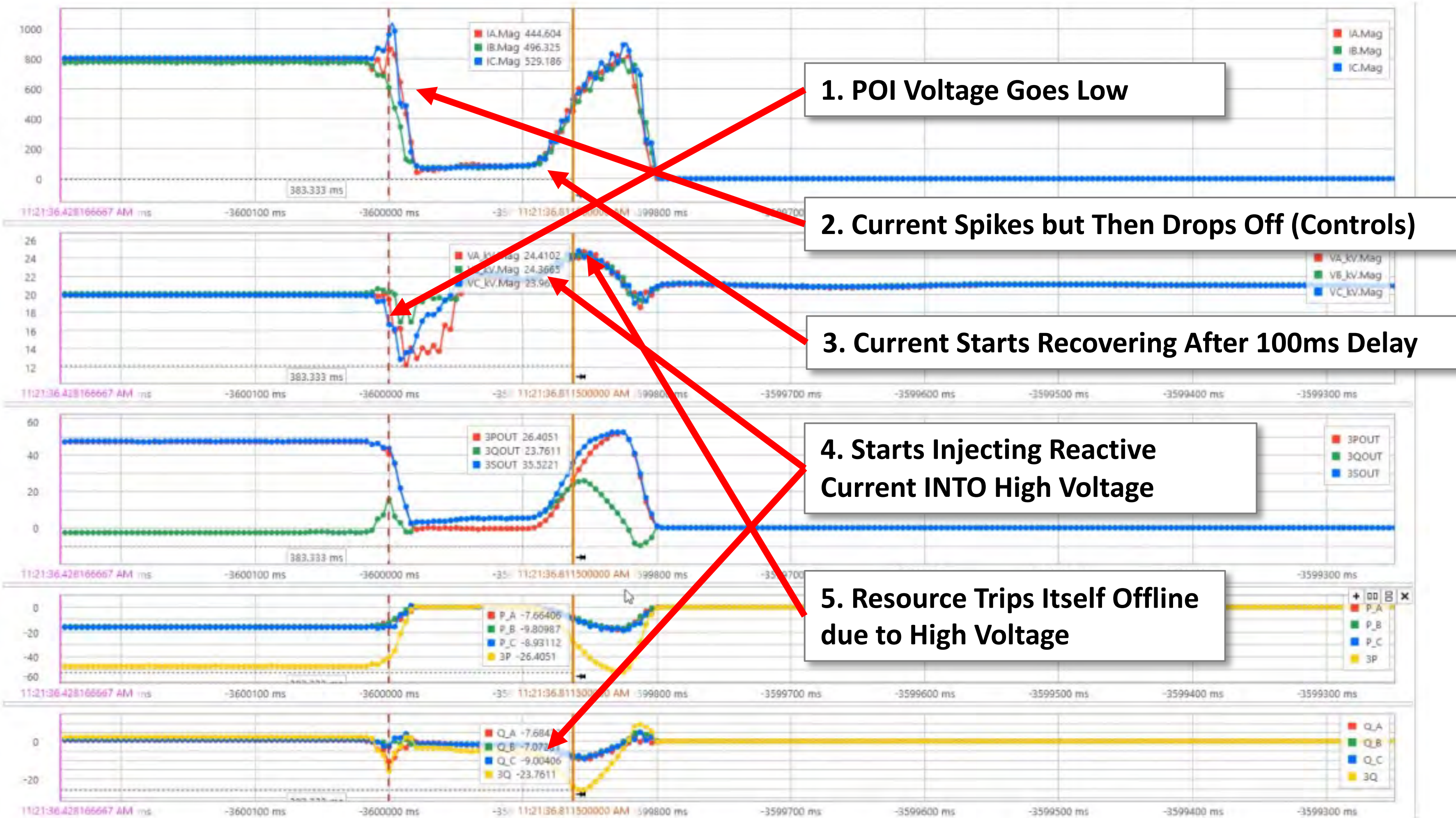
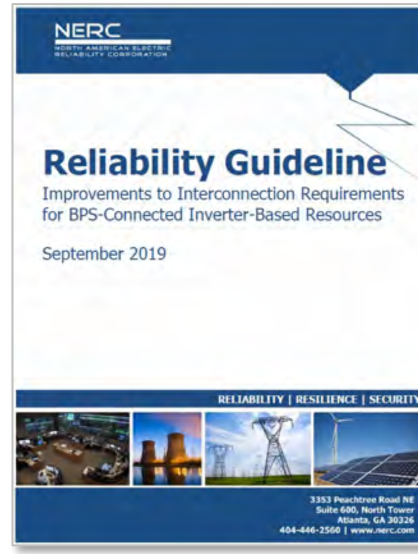
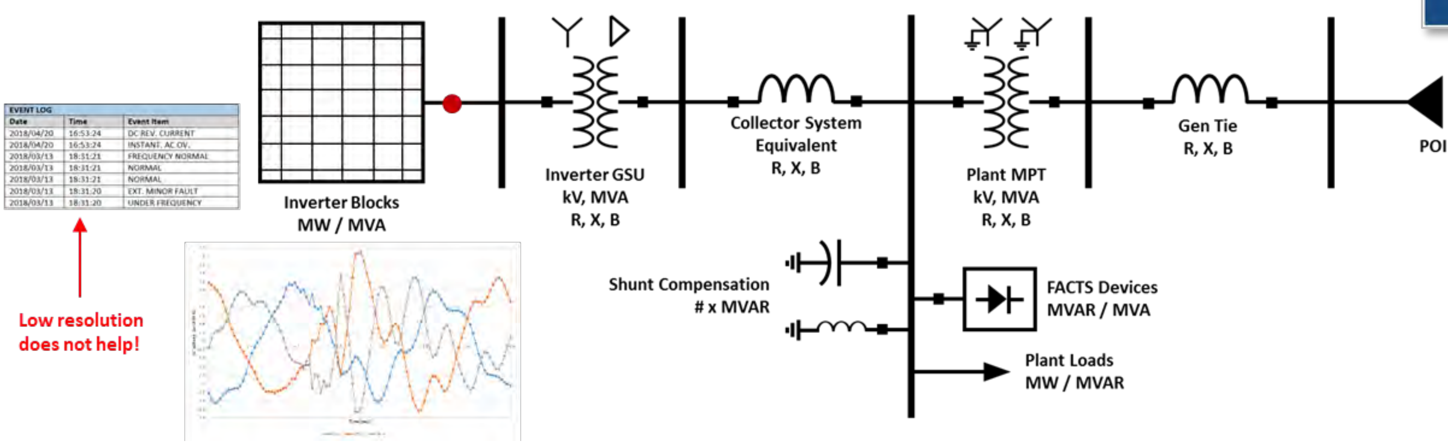


Figure B.13: Current Injection at Time of Trip

Improved Yet Lacking Data

- Plant SCADA – no more than 1 second resolution
- Plant PMU – measurements at POI
- Plant DFR – measurements at POI
- Inverter SER logging – trip and controls
- Inverter oscillography – from some inverters





Make these interconnection requirements!

Questions and Answers

Ryan Quint, PhD, PE
Senior Manager
BPS Security and Grid Transformation
North American Electric Reliability Corporation
Office (202) 400-3015
Cell (202) 809-3079
ryan.quint@nerc.net