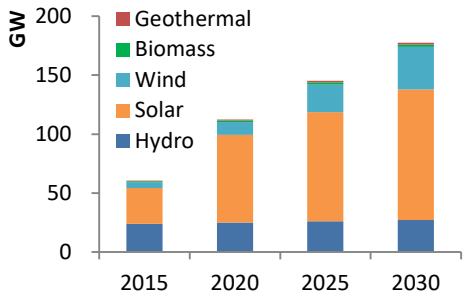
A frequency stability and load flow analysis of the Japanese system in response to high renewables penetration levels

Tatsuya Wakeyama
Senior Research fellow, Renewable Energy Institute
Associate Professor, Kyushu University Platform of Inter/Transdisciplinary Energy Research

Methodology

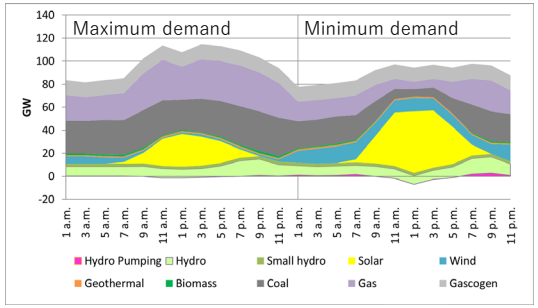
Scenario development

- Database
- Projection of generation capacity
- Estimation of RE output



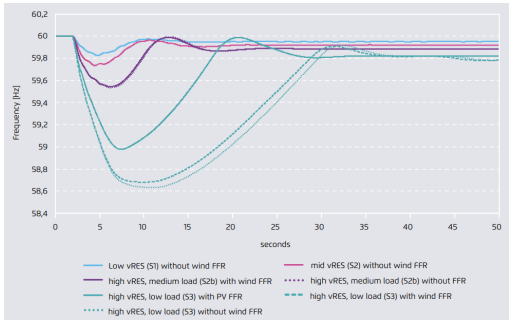
Dispatch modelling

- Evaluation of hourly demand-supply structure
- Selecting snapshot assessed in grid model



Grid modelling

- Evaluation of stability of frequency
- Load flow analysis
- Impact evaluation of higher VRE penetration



Integrated discussion: Issues and countermeasure to expansion of RE capacity

Scenario development

Two scenario in 2030

Government target scenario：long-term energy projection by government（PV:64GW, Wind:10GW）

Higher renewable energy scenario: based on target by RE industrial association（PV:100GW, Wind36GW）＋zero nuclear

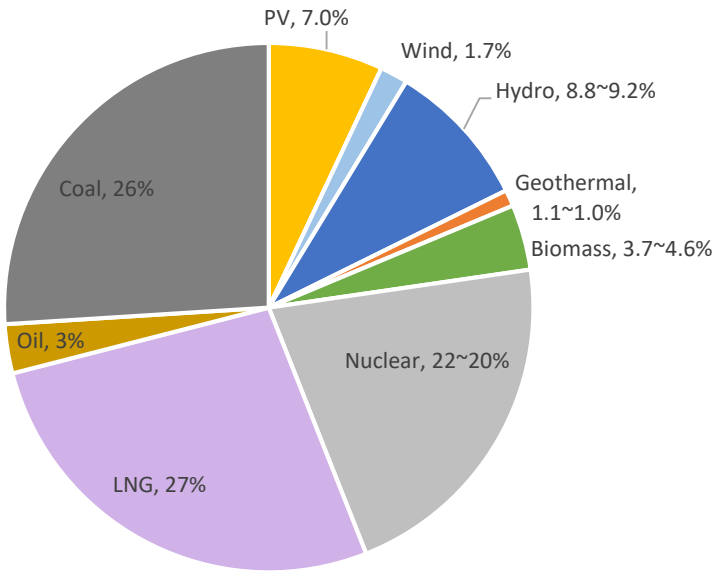
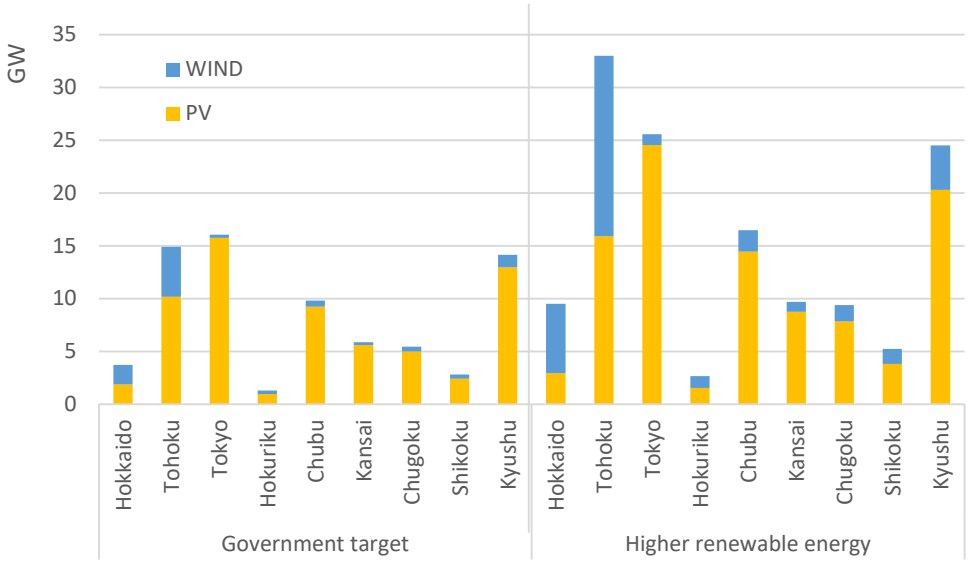


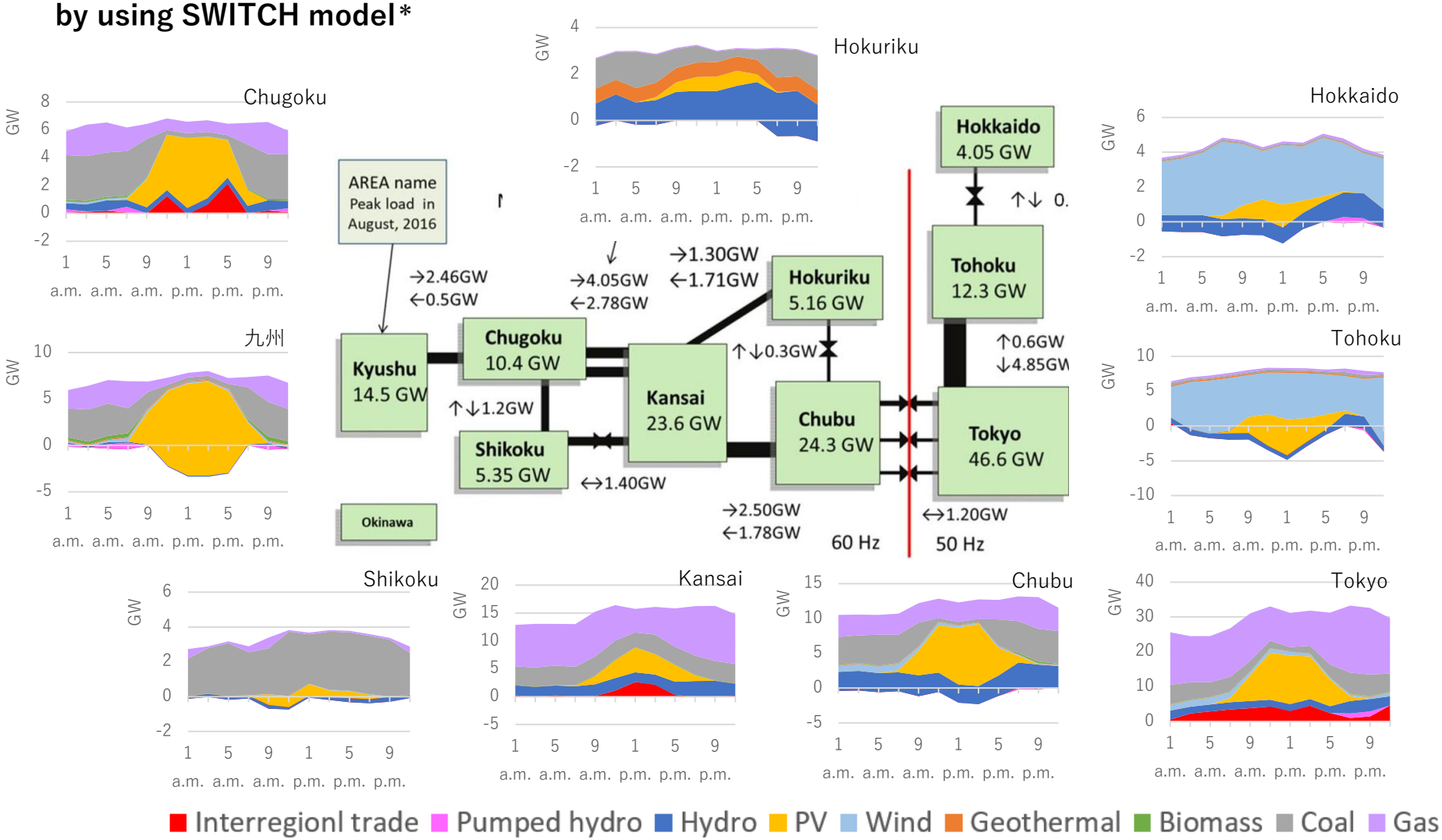
Figure: Energy mix in FY2030 based on long-term energy projection published in 2015



Figure：Distribution of PV and Wind capacity

Dispatch modelling

**Simulate hourly demand-supply in minimum/maximum demand day in each month in 2030 by using SWITCH model*

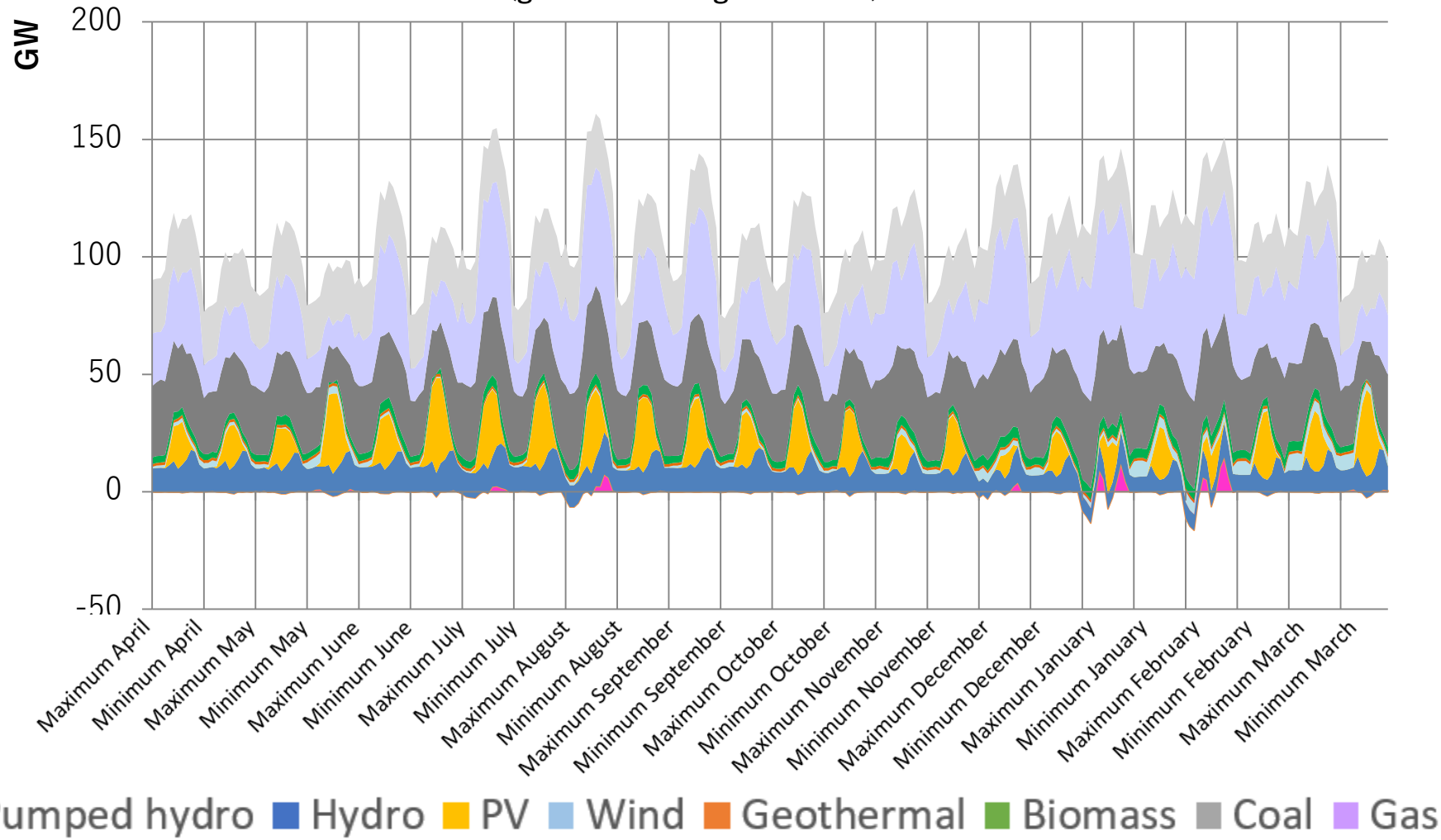


*SWITCH model was distributed capacity expansion model developed by Dr. Fripp Mathiass (Assistant professor @ Hawaii University) and maintained by Renewable & Appropriate Energy Laboratory of UC Berkeley. Hourly supply-demand of each area are simulated to minimize cost considering interregional electricity trade.

Government target scenario/ hourly demand-supply in representative days

Instantaneous VRE penetration reached up to 42%

Figure Hourly demand-supply at maximum/minimum demand day in each month in 2030 (government target scenario)

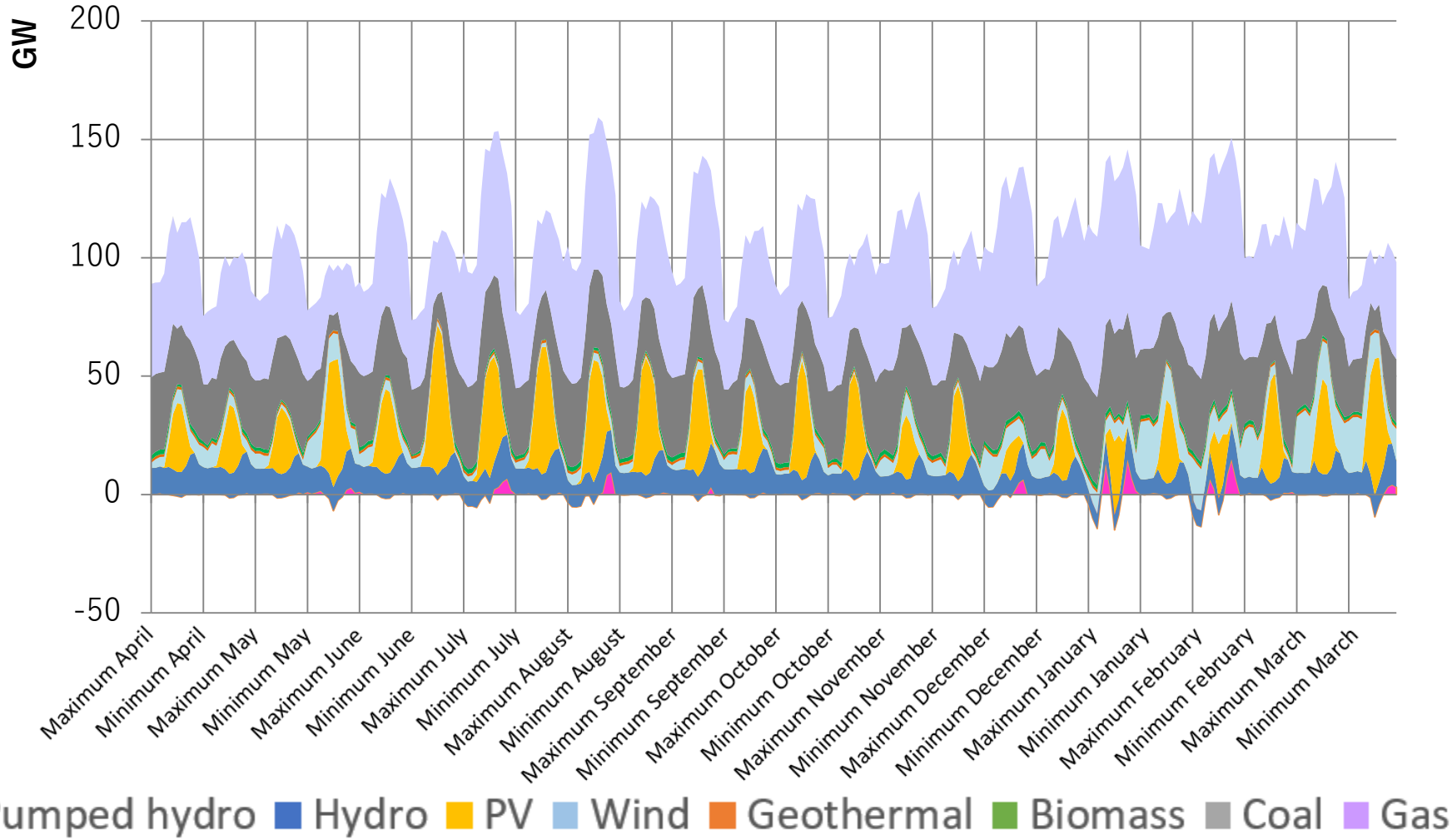


※Negative direction indicates hydro pumping

Higher RE scenario/ hourly demand-supply in representative days

Instantaneous VRE penetration reached up to 72%

Figure Hourly demand-supply at maximum/minimum demand day in each month in 2030 (Higher renewable energy scenario)



※Negative direction indicates hydro pumping

Grid model analysis

Evaluation on impact of increasing instantaneous VRE penetration to frequency stability and load flow

Frequency stability：It is necessary to keep frequency variation caused by an incident on grid within tolerable range

Figure: IEEJ power system model（EAST30）

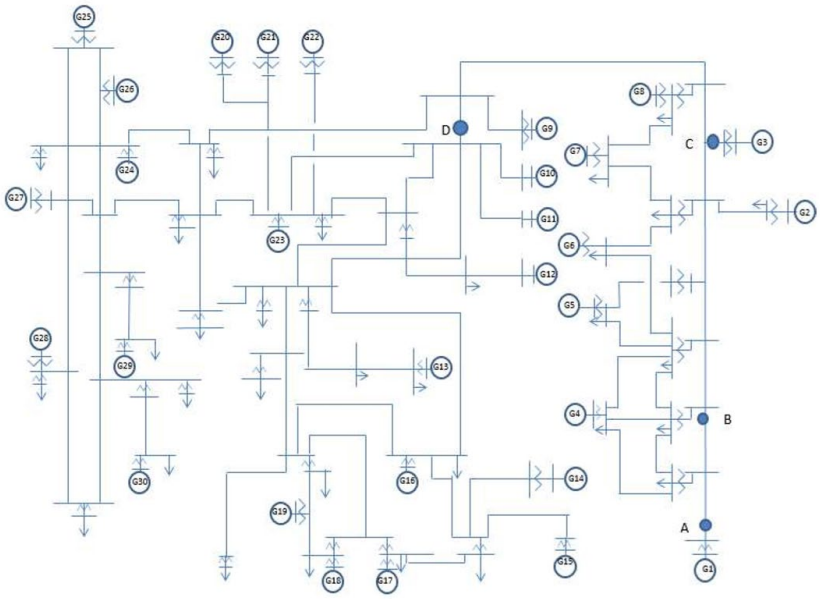
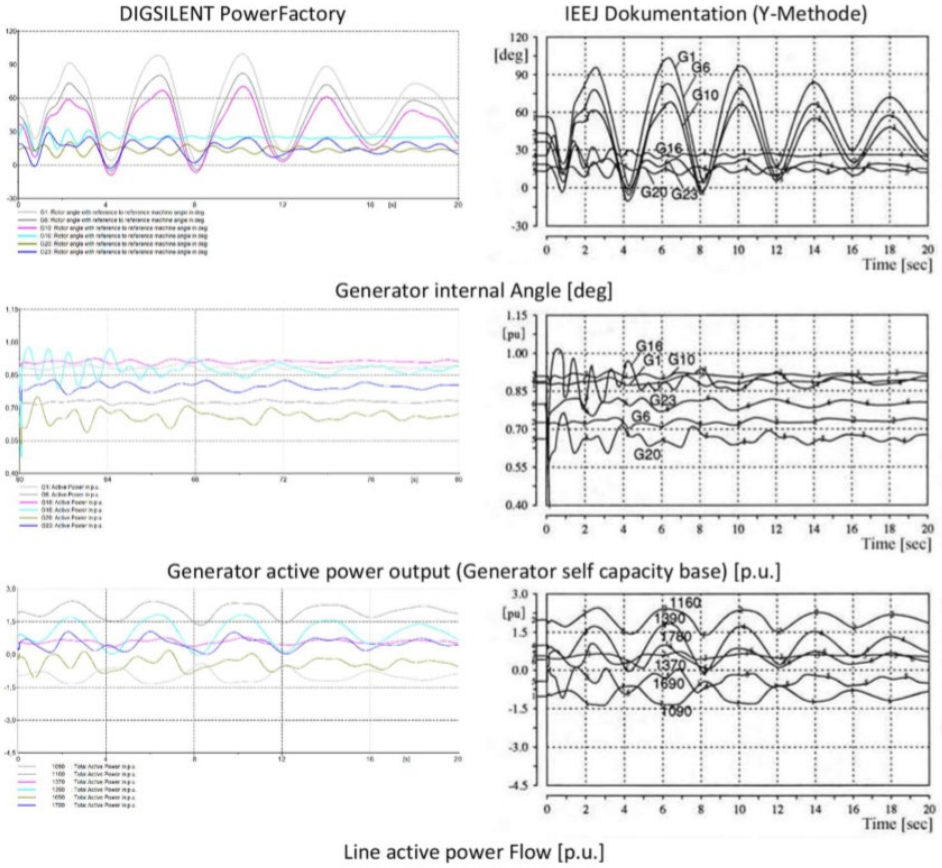


Figure: Example of validation results by Powerfactory



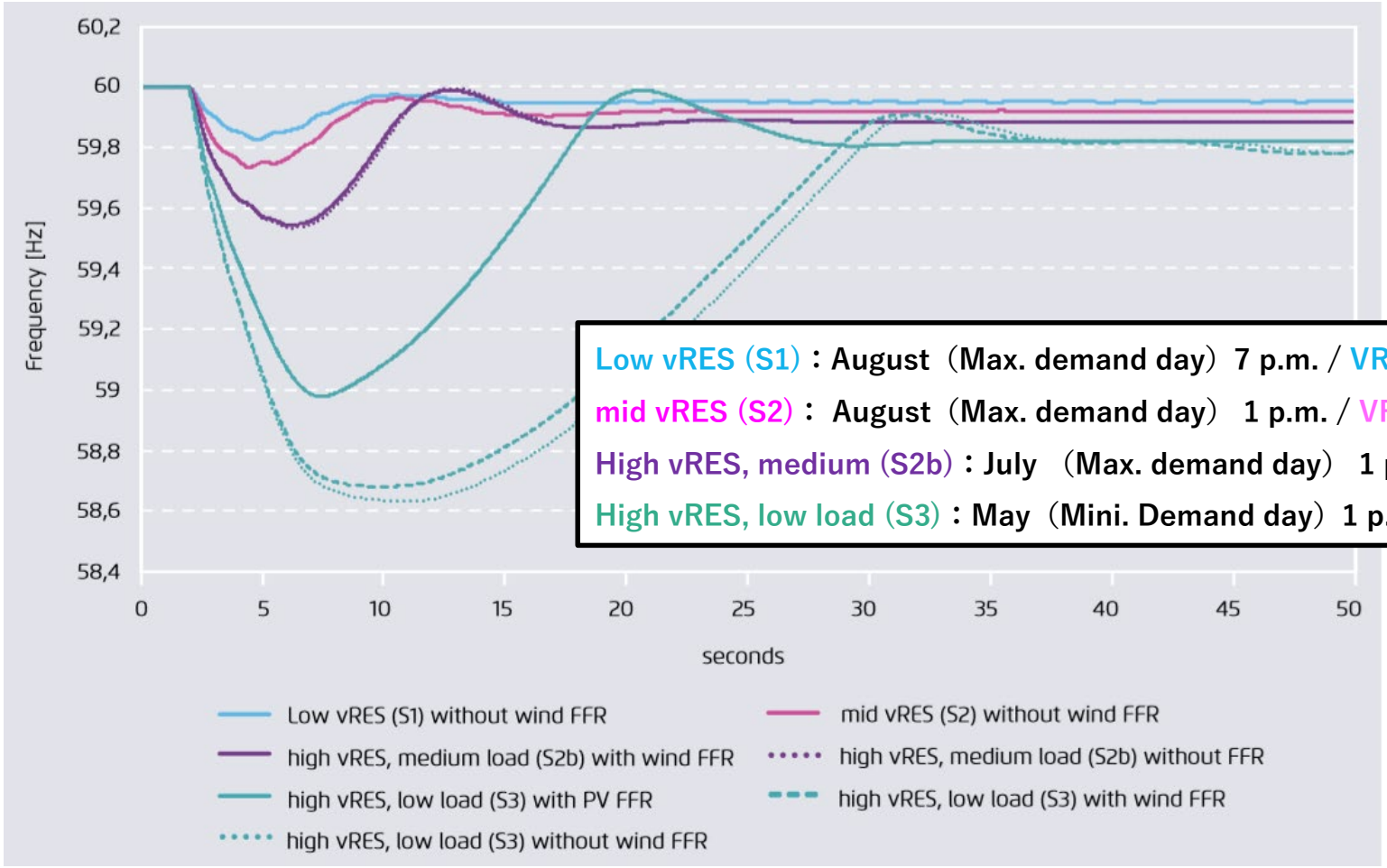
Methodology：

- IEEJ power system model (2001) is reconstructed and validated on Powerfactroy (DIgSILENT) for this analysis.
- The constraint of frequency stability is set to maintain frequency nadir within the range of 0.98 p.u. which equal to the threshold of 58.8Hz for Western grid.

Grid model result ①

Frequency nadir may be increased with increasing instantaneous penetration of VRE. Those frequency nadir can be maintained within tolerable range by using FFR service of VRE.

Figure: frequency response after loss of 1 500 MW for western Japan +RES scenario; with and without wind and solar FFR



Low vRES (S1)：August（Max. demand day）7 p.m. / VRE 9.4%

mid vRES (S2)： August（Max. demand day） 1 p.m. / VRE 44.8%

High vRES, medium (S2b)：July （Max. demand day） 1 p.m. / VRE 49.1%

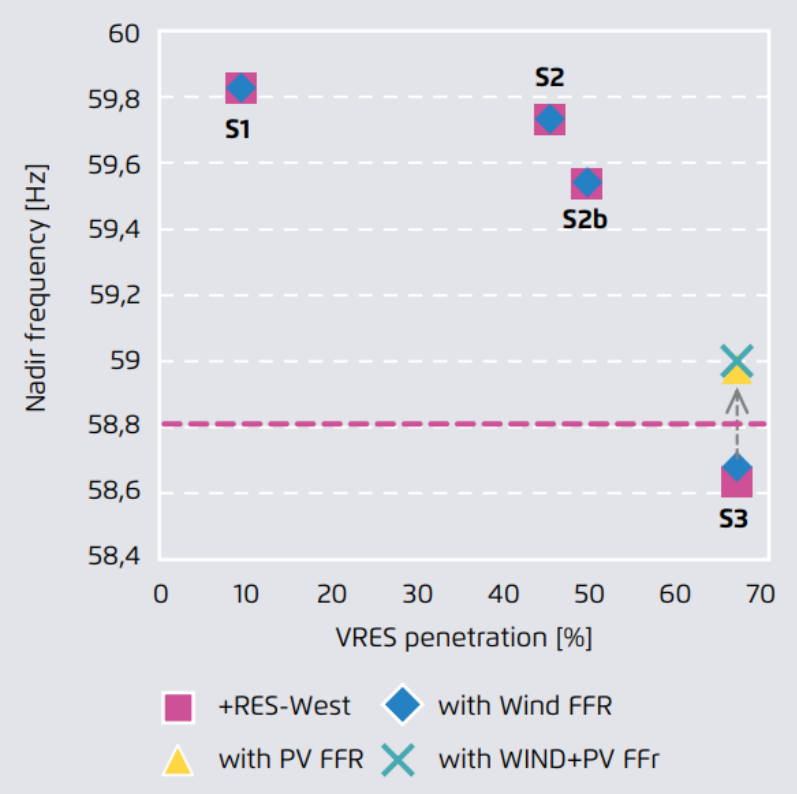
High vRES, low load (S3)：May（Mini. Demand day）1 p.m. / VRE64.9%

出典：EGI, Gridlab

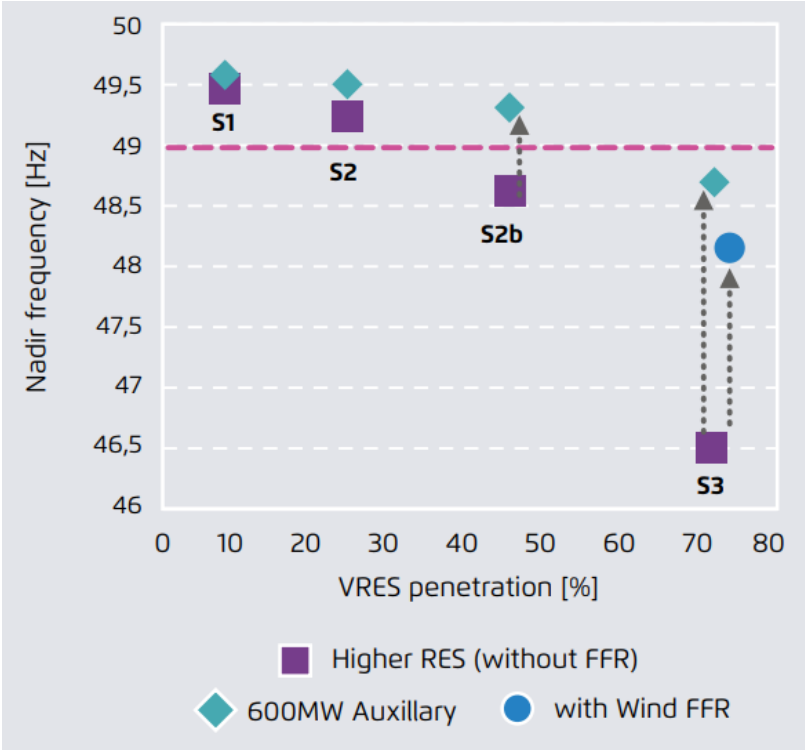
Grid model result ②

Frequency stability can be maintained within tolerable range by using FFR service of VRE when the instantaneous penetration of VRE increased up to 60% for EAST and 70% for WEST.

Left: Evaluation of the frequency nadir for the western synchronous area



Right: Nadir frequency and VRES penetration in eastern Japan with and without the 600MW ancillary service



出典：EGI, Gridlab

議論：変動型自然エネルギーの瞬時供給率と出力抑制

The curtailment can be necessary to maintain frequency stability within tolerable range when the instantaneous penetration of VRE increased over 60% for EAST and 70% for WEST. The curtailment amount is evaluated less than 2% in Higher RE scenario and less than 4% considering more RE expansion up to 40% RE (29% of VRE).

Table Estimation of curtailment amount by setting upper limitation of instantaneous VRE penetration

	Higher RE scenario 33% RES (23% VRES)			More RE expansion 40% RES (29% VRES)		
	JAPAN*2	EAST	WEST	JAPAN*2	EAST	WEST
Annual demand (TWh)	916	412	503	916	412	503
PV(GW)	100	44.7	55.3	125	44.8	80,2
Wind(GW)	36	24.9	11.1	54	37.5	16.5
SNSP limit	-	60%	70%	-	60%	70%
Annual VRES share %	22,1%	28,4%	16,9%	28.9%	34.7%	24.1%
Annual RE incl. hydro share %	33,0%	38,9%	28,3%	39.8%	45.2%	35.5%
Annual VRES curtailment %	1,8%	3%	0%	3.9%	5.1%	2.5%

*1 FY2013 data
*2 Excluding Okinawa area