<Summarized version>

Final Report on the Major Blackout caused by the 2018 Hokkaido Eastern Iburi Earthquake

December 19, 2018

The Investigation Committee
on the Major Blackout by the 2018 Hokkaido Eastern Iburi Earthquake

電力広域的運営推進機関
Organization for Cross-regional Coordination of Transmission Operators, JAPAN
OCCTO

Executive Summary [1]

Sequence of Events from the Occurrence of the Earthquake to the Blackout

1. The blackout mainly occurred due to the composite factors ("N-3" + "N-4") including the shutdown of Units 1, 2, and 4 of the Tomato-atsuma Power Plant and the shutdown of hydro power plants caused by the accident of Karikachi trunk line along with two other lines (4 power transmission lines) as a result of the earthquake.
2. Emergency power transfer was performed to recover the frequency by utilizing the margin Hokkaido-Honshu HVDC Link , but it reached the maximum power interconnected. Hence, the frequency control feature could not function when Unit 1 of the Tomato-atsuma Power Plant tripped, which resulted in the blackout.

Sequence of Events from the Blackout to Ensuring a Certain Supply Capacity (Approx. 3,000 MW)

1. Restoration by the first black start was appropriately performed according to the procedural manual. However, when power was transmitted to the main transformer of the Tomari Power Plant, the shunt reactors of Minamihayakita/Kitashintoku Substations shut down due to abnormal electric current.
2. There was no major issue on the second recovery process. It took approximately 45 hours from the blackout to restore the supply for almost the entire Hokkaido area.
3. It was extremely difficult to predict the shutdown of shunt reactors. Even if the restoration were performed in an optimal manner without troubles in the first black start, only a few hours of black start operation could have been shortened at maximum.

We did not observe any issues within the operation or system structure of Hokkaido Electric Power Company. Nonetheless, we have summarized the short-term measures (for winter 2018/19) considering the negative impact a blackout could bring to the society

Short-term recurrence prevention measures (winter 2018/19)

1. Add load shedding of 350 MW through Under Frequency Relay (UFR) (when demand is for 3,090 MW)
2. Operate 3 units of the Tomato-atsuma Power Plant including Units 1, 2, and 4 based on the premise of Units 1 and 2 of the Kyogoku Power Plant operating
3. If one of the Units 1 or 2 of the Kyogoku Power Plant shuts down, curtail the output of Unit 1 of the Tomato-atsuma Power Plant to 200 MW or secure thermal power equipment that can supply 200 MW in approx. 10 min.
4. Even if the frequency drops to 46.0 to 47.0Hz, secure supply of at least 30% to 35% of the demand that can be continually operated
5. Take additional measures in case one of the units 1 or 2 of Kyogoku Power Plant shuts down, and perform monitoring by OCCTO

Not only the Investigation Committee but also other various stakeholders are preparing operational/system-related medium-to-long-term measures, in the Hokkaido area taking into account that Ishikariwan-shinko Power Plant Unit 1 and the new Hokkaido-Honshu HVDC Link will start operating at the end of FY 2018

Executive Summary [2]

Mid-to-long term operational measures (Including points to note)

The mid-to-long term operational measures must be reviewed properly at the right time hereafter due to major changes in the power supply composition and demand-supply balance in the Hokkaido area. If the Tomari Power Plant trips after resuming operations, it is indispensable to perform simulation again when the schedule of restart becomes clear, as well as to examine and conduct necessary actions.

○After commercial operations of the Ishikariwan-shinko Power Plant and new Hokkaido-Honshu HVDC Link

<The Under Frequency Relay (UFR) setting in the Hokkaido area>

- ■ Review the UFR settings promptly so that the lowest point of frequency can be raised to 47.0Hz or higher (increase the share of UFR with df / dt function from 10% to 20%).

<Operations of the largest capacity generators>

- ■ Presuming that automatic frequency control (AFC) reserves can be secured with the Hokkaido-Honshu/ new Hokkaido-Honshu HVDC, set aside the condition “operation of Units 1 and 2 of the Kyogoku Power Plant are available” for operating the three generators of the Units 1, 2, and 4 of the Tomato-atsuma Power Plant stated in the measures for winter 2018/19.
- ■ If the frequency is expected to drop even lower than the most severe scenarios assumed here, simulate the tripping of the largest site in advance, make sure that the situation does not lead to a blackout, and take the required measures as and when necessary.

<Re-evaluation of the governor-free system, AFC function, and interconnection facility margin>

- ■ Not necessary at present.

○After resuming operations at Tomari Power Plant

<The UFR setting in the Hokkaido area>

- ■ Review of UFR settings (application of frequency variance rate element (df/dt)) and taking measures using a stabilization device to activate high-speed load shedding are essential.

<Re-evaluation of the governor-free system, AFC function, and interconnection facility margin>

- ■ Not necessary at present.

Mid-to-long term measures for facility formation (Further reinforcement of the Hokkaido-Honshu HVDC Link)

- ■ The Government shall examine how the cost allocation should be placed if further reinforcement of the line is needed. On its part, OCCTO shall determine the feasibility of switching the existing Hokkaido-Honshu HVDC interconnection line to a self commutation type or further reinforcing the Link.
- ■ It goes without saying that further reinforcement will be technically advantageous in order to prevent a blackout according to Government policy, the Government and OCCTO must conduct simulations to confirm the effectiveness of switching the existing Hokkaido-Honshu HVDC Link to a self commutation type or further reinforcing the Link, and then propose drafts, including the routes and the scale of reinforcement, until next spring.

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I. Objectives and Overview of the Investigation Committee

I. Objectives and Overview of the Investigation Committee

- On September 11, 2018, Hiroshige Seko, the Minister of Economy, Trade and Industry, issued an order to Hokkaido Electric Power Company and OCCTO to start the investigation for the cause, etc. of this major blackout. The Interim Report was requested to be submitted by the end of October.

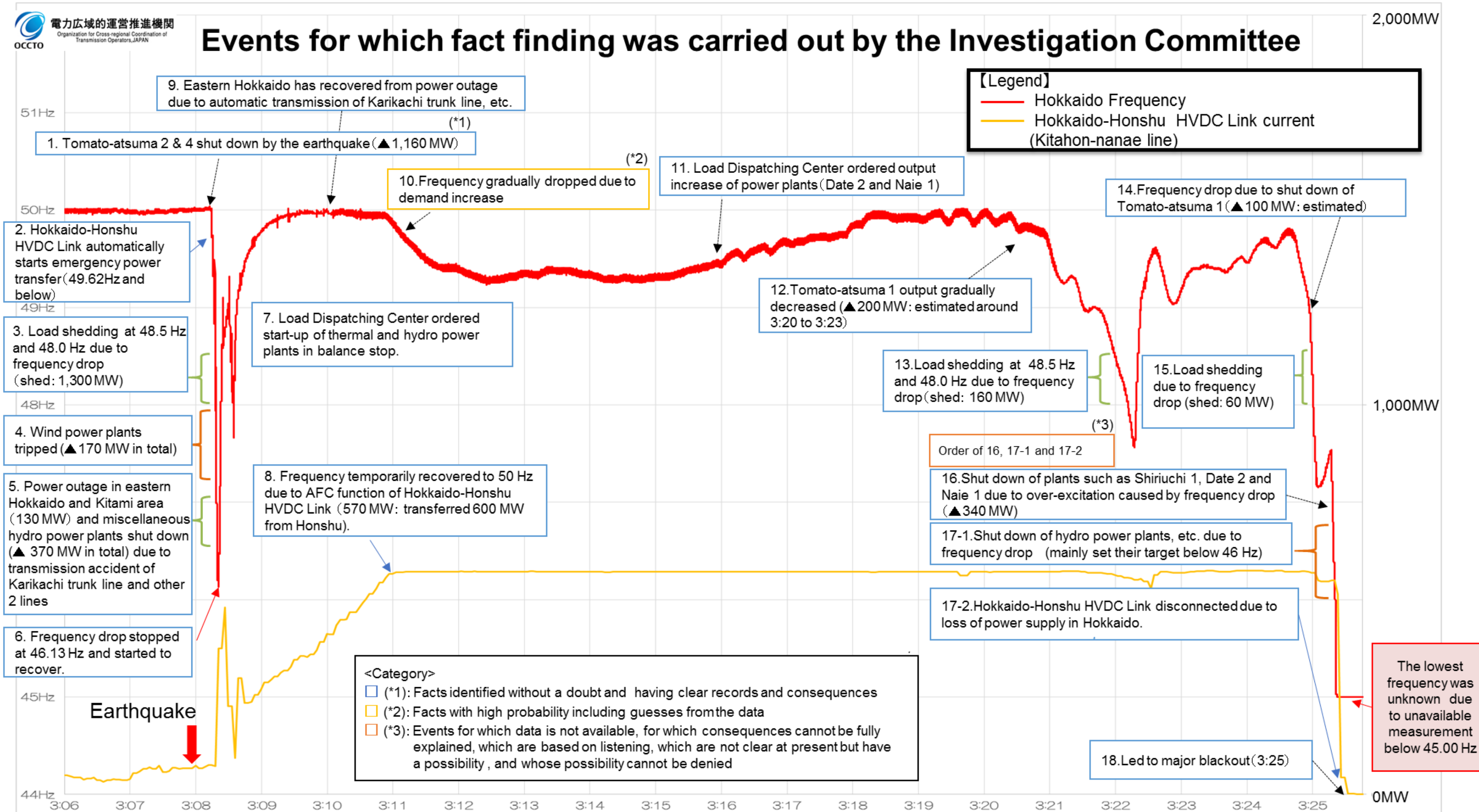
- Following this order, “The Investigation Committee on the Major Blackout by the 2018 Hokkaido Eastern Iburi Earthquake” was established by OCCTO to ensure that highly-transparent and impartial investigations are performed involving third parties based on objective data from a neutral /fair position. The consultation topics are as follows.
  - ① Analysis of the cause of the major blackout affecting the entire Hokkaido area (from the occurrence of the earthquake at 3:07 am to the major blackout at 3:25 am on September 6)
  - ② Technical investigations (black start generator operation , etc.) regarding the process (September 6 and 7) before securing a certain level of power supply (approx. 3,000 MW) after the major blackout
  - ③ Consideration of recurrence prevention measures, etc. (including blackout scale control measures) to be taken in the Hokkaido area, etc.

<Overview of The Investigation Committee>

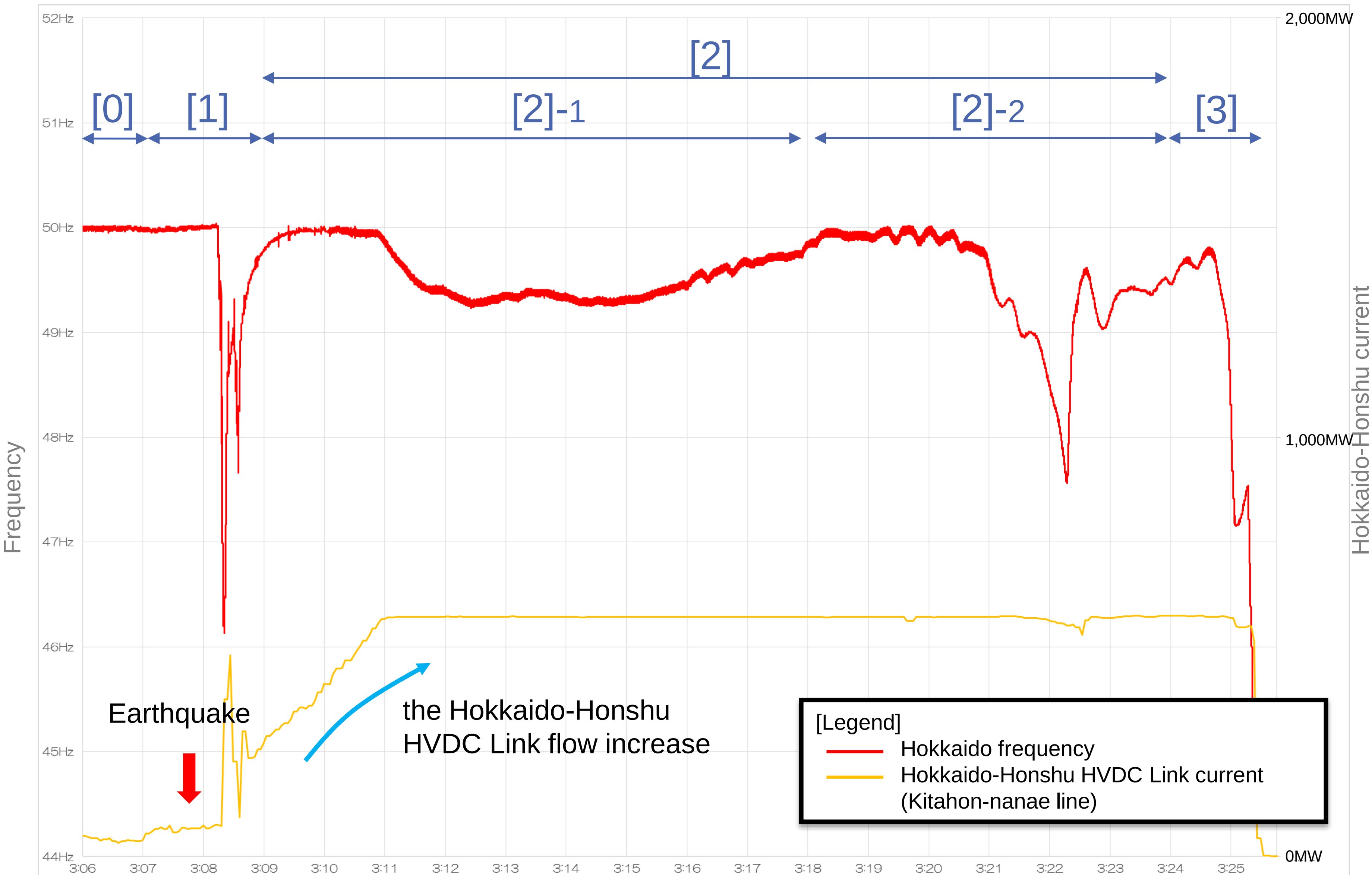
Committee members	Meeting dates
● **Chair** Akihiko Yokoyama — Professor of the Graduate School of Frontier Sciences, University of Tokyo ● **Committee members** Toshio Inoue — Director, System Engineering Research Laboratory, Central Research Institute of Electric Power Industry Yumiko Iwafune — Project Professor of the Institute of Industrial Science, University of Tokyo Takao Tsuji — Associate Professor of the Faculty of Engineering, Yokohama National University ● **Observers** ・Electric Power Safety Division, Ministry of Economy, Trade and Industry ・Electricity infrastructure Division, Agency for Natural Resources and Energy ・The Federation of Electric Power Companies of Japan ・Hokkaido Electric Power Company	**1st meeting (September 21, 2018)** ◊ Investigation on the sequence of events leading to the major blackout caused by 2018 Hokkaido Eastern Iburi Earthquake, etc. **2nd meeting (October 9, 2018)** ◊ Sequence of events from the black start to securing a certain level of supply ◊ Organizing the discussion points with the aim of preventing recurrence, etc. **3rd meeting (October 23, 2018)** ◊ Short-term recurrence prevention measures (winter 2018/19) ◊ Interim Report proposal, etc. **4th(final) meeting (December 12, 2018)** ◊ Mid-to-long term operational measures ◊ Final Report proposal, etc.

II. Sequence of Events from the Occurrence of the Earthquake to the Blackout

- Graph below clarifies the sequence of events from the occurrence of the earthquake to the blackout and explains the frequency fluctuations.
- Almost all events have been factually confirmed including some assumptions. The series of events can be explained with frequency fluctuations caused by the imbalance between demand and supply.

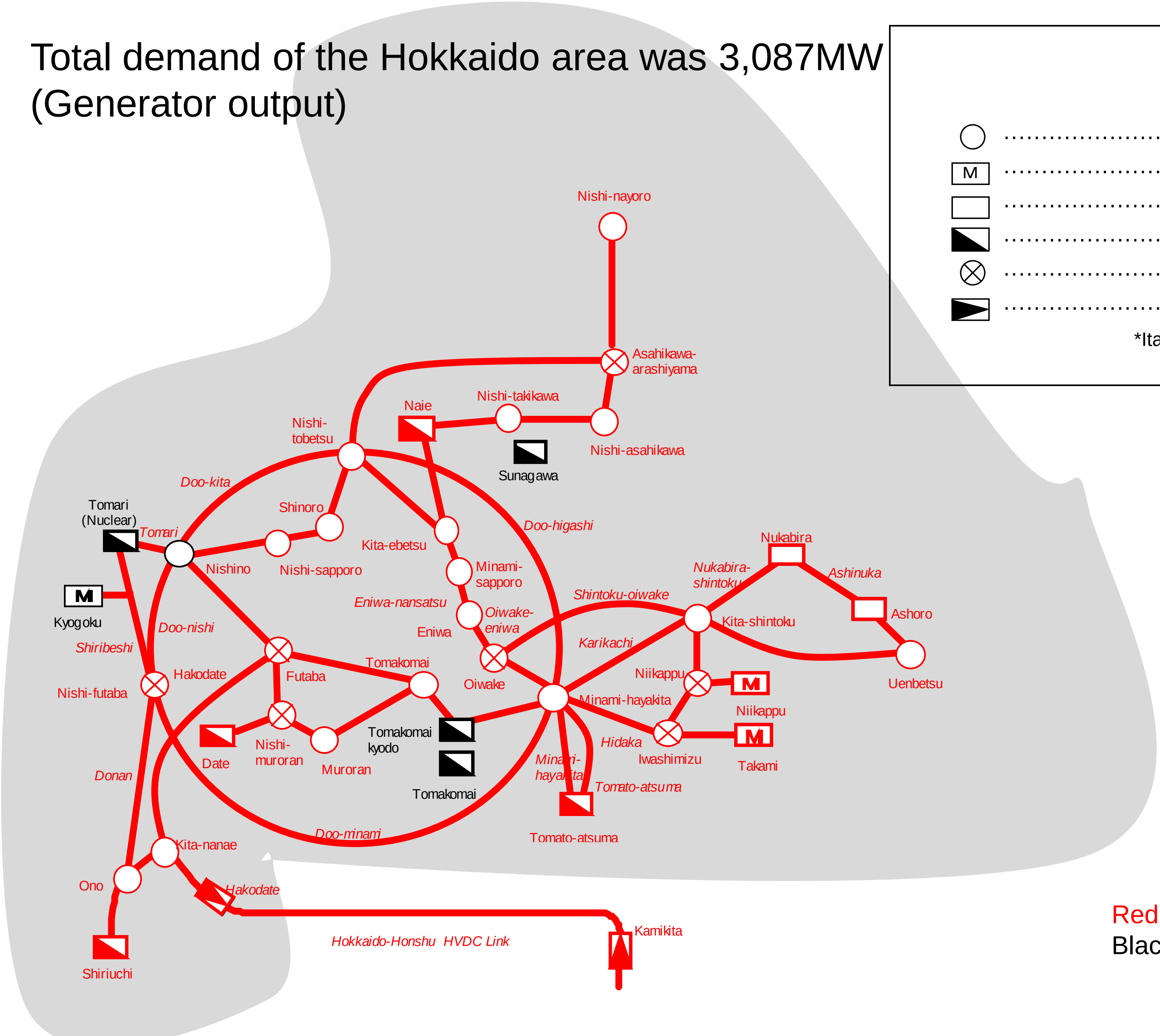


■ Clarifying the each events ([1]~[3]) where the frequency significantly fluctuated.



Grid status immediately before the earthquake [0]

Total demand of the Hokkaido area was 3,087MW
(Generator output)



Legend

- Substation
- Pumped-storage hydro power plant
- Hydro power plant (Excluding pumped-storage hydro-power plants)
- Thermal/Gas/Nuclear power plant
- Switching station
- AC/DC converter station

*Italics are transmission line names

Red: Operating
Black: Shut down

II. Sequence of Events from the Occurrence of the Earthquake to the Blackout
Grid status immediately before the earthquake [0]

- Generators' operational status was as shown in the right table.
- Since some thermal power plants had been shut down due to lower demand during late night, and they require some time to restart, the operation plan to meet the demand curve of the following day was;
  - start Sunagawa Units 3/4 and Naie Unit 2 respectively
  - keep Date Unit 1 and Onbetsu Units 1/2 shut down
- Thermal power plants were operated in merit order. For this, Tomato-atsuma was operated with high output, and other thermal power generators operated with minimum output.

Supply capacity				Rated (MW)	Output (MW)	Operation plan
Thermal	Sunagawa	Unit 3	Coal	125	0	Parallel in scheduled at 11:00
		Unit 4		125	0	Parallel in scheduled at 14:00
	Naie	Unit 1	Coal	175	61	In operation
		Unit 2		175	0	Parallel in scheduled at 5:30
	Tomakomai	Unit 1	Heavy crude oil/ natural gas	250	0	Planned Outage *1
	Tomakomai kyodo	Unit 3	Heavy oil	250	0	Planned Outage
	Date	Unit 1	Heavy oil	350	0	Balance stop *2
		Unit 2		350	76	In operation
	Tomato-atsuma	Unit 1	Coal	350	338	In operation
		Unit 2		600	556	In operation
		Unit 4		700	598	In operation
	Shiriuchi	Unit 1	Heavy oil	350	96	In operation
		Unit 2		350	0	Planned Outage
	Onbetsu	Units 1/2	Gas oil	148	0	Balance stop
Hydro*3	Niikappu Units 1/2, Takami Unit 1, Nukabira Unit 1, Ashoro Units 1/2			361	69	In operation
	Kyogoku Units 1/2, Takami Unit 2, Nukabira Unit 2			521	0	Planned Outage
	Other hydro			–	711	In operation
Major wind powers*3				319	166	In operation
Other *4				–	344	In operation
Hokkaido-Honshu HVDC Link (Maximum power reception on the Hokkaido side)				600 (Approx. 570)	72	In operation
Demand				–	3,087	

(Supplemental note for the table)

*1: "Planned Outage" refers to when the generator is shut down for regular inspection, etc.

*2: "Balance stop" refers to when the generator operation is stopped due to demand balance

*3: Hydro/wind generators for which the Load Dispatching Center is receiving telemeter (remote measurement) information

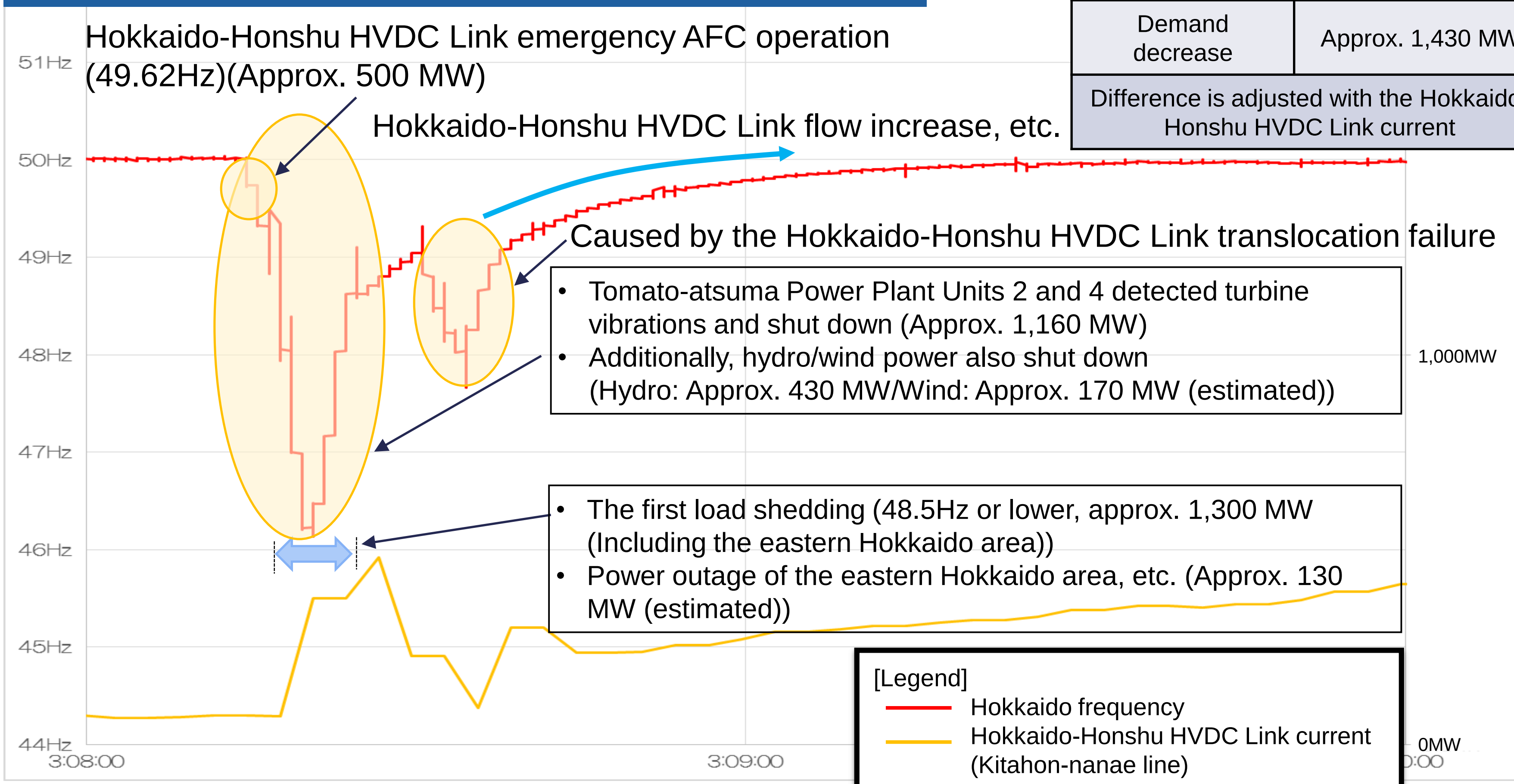
*4: "Other" is includes the non-utility generation, etc. obtained by subtracting the sum of the thermal/hydro/major wind powers/ Hokkaido-Honshu HVDC Link from the demand

2018/9/6 AM3:08 - 3:09

- Tomato-atsuma Units 2 and 4 detected turbine vibrations and shut down, which led to frequency drop. However, the frequency recovered due to the emergency power transfer from the Hokkaido-Honshu HVDC Link and load shedding that only operates during emergency accidents.
- The Karikachi trunk line along with 2 other lines shut down due to ground faults, and the eastern Hokkaido area had a power outage.

Frequency fluctuation and response status

Output curtailed	Approx. 1,760 MW
Demand decrease	Approx. 1,430 MW
Difference is adjusted with the Hokkaido-Honshu HVDC Link current	

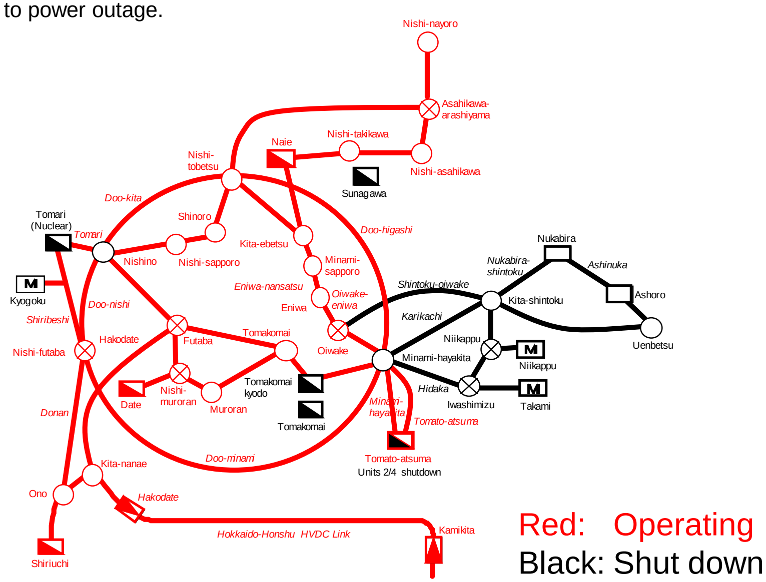


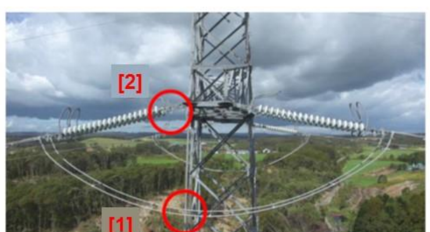
Immediately after the earthquake[1] (Earthquake – frequency recovery)

- In terms of the events leading to the blackout, we were able to confirm the accident points of transmission lines and therefore have confirmed that it was caused by composite factors of mainly the shutdown of Tomato-atsuma Power Plant Units 1, 2, and 4 (N-3 accident) as well as the accident of 4 transmission lines (N-4 accident) (and shutdown of eastern Hokkaido hydro power plants due to this) caused by earthquake vibrations. As a result of simulation, it is considered that it was highly likely that it would not have led to blackout if hydro power plants shutdown (N-4) had not occurred.

Eastern Hokkaido route disconnection due to the transmission line accident

3 lines leading to the eastern Hokkaido/Kitami areas, to which many hydro power plants are connected, shut down due to the earthquake. After the eastern Hokkaido area grid became -isolated, the hydro power plant shut down, leading to power outage.

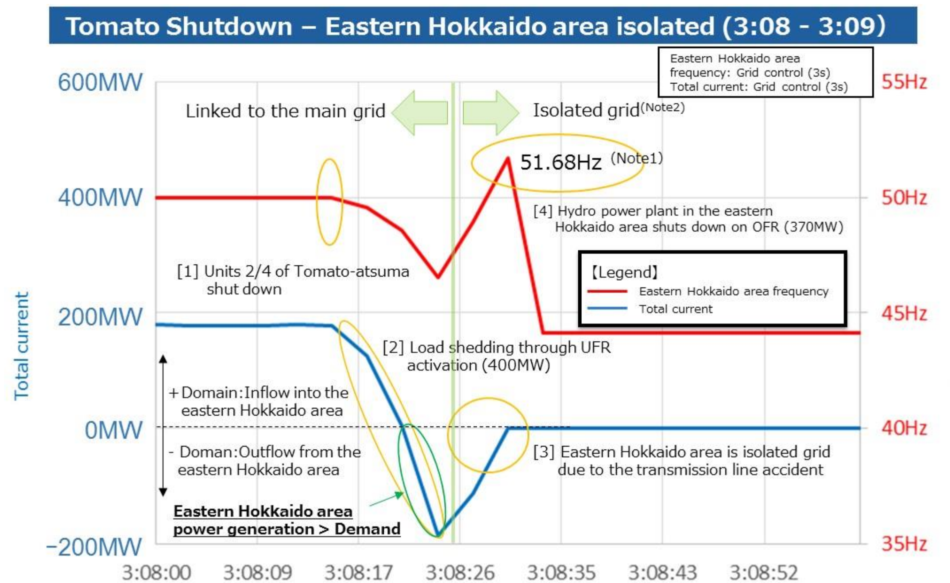




Earthquake vibrations caused the [1] jumper wire to come in contact with the [2] tower body

Eastern Hokkaido hydro power plant trip due to the transmission line accident

The eastern Hokkaido area's power supply became greater than the demand due to the load shedding of the first UFR operation. After the eastern Hokkaido area grid became isolated, the eastern Hokkaido area frequency rose, and the hydro power plants shut down due to over frequency relay (OFR).



(Note 1) Although the measured value was 51.68Hz, we assume that it was at least 52.0Hz for at least 0.5 seconds due to the facts that the measurement was made every 3 seconds and that the OFR (operating value: 52.0Hz 0.5 seconds) of the hydro power plant was working. However, the hydro power plant whose OFR operating value was 52.0Hz 2.0 seconds did not shut down. (Refer to the next sheet)
(Note 2) Due to the fact that the measurement was taken every 3 seconds and due to delayed transmission, etc., we have not been able to chronologically synchronize the eastern Hokkaido area frequency and the total current.

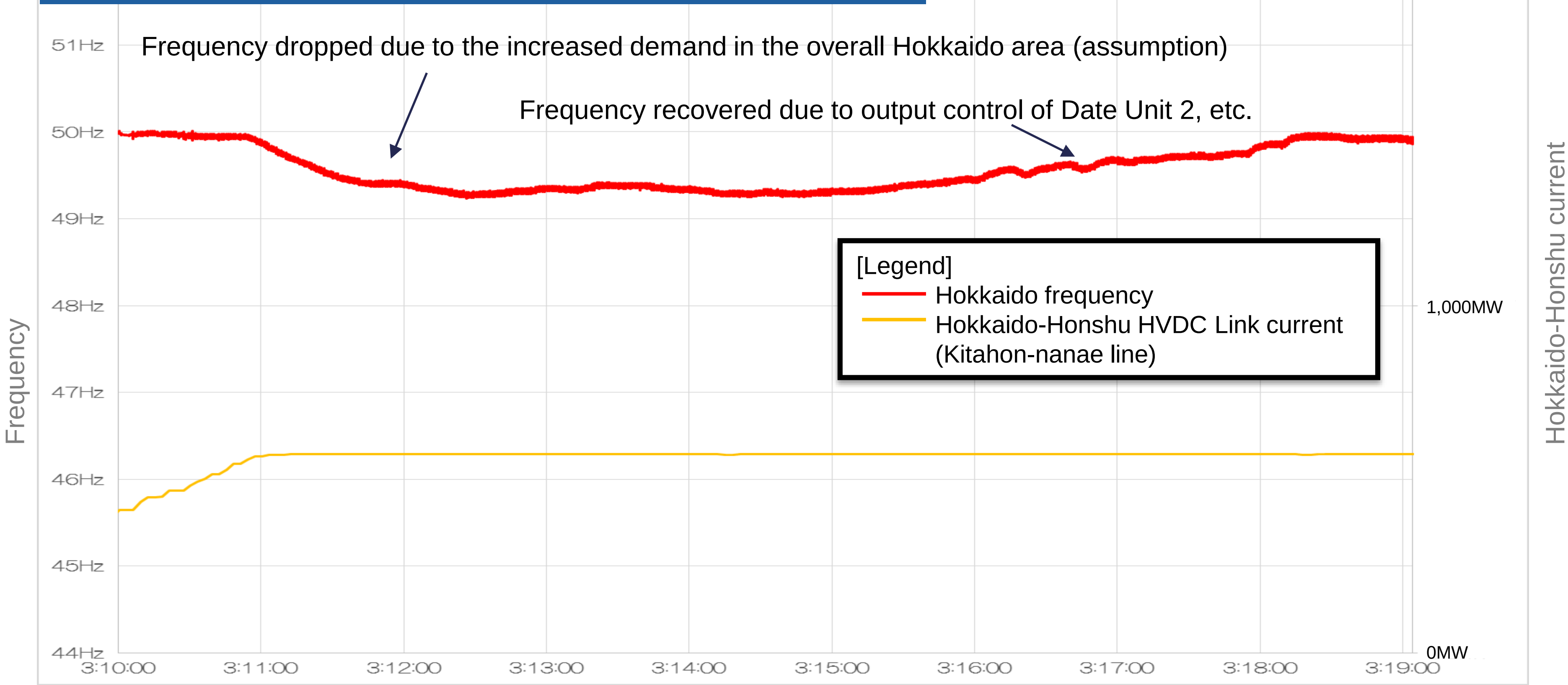
Immediately after the earthquake [2]-1 Overview (Frequency recovery – decrease of Tomato-atsuma Unit 1 output)

2018/9/6 AM3:09 - 3:19

- After the frequency recovery, the frequency gradually decreased due to the increased demand (such as lighting/TV watching for searching information. We expect that the load increase due to the grid voltage rise after the load shedding also contributed)*
- The Load Dispatching Center automatically instructed/controlled thermal power generators to increase the output level, and the frequency started to recover.

*Due to the reduced grid size caused by the earthquake, the impact of demand fluctuations on frequency increased.

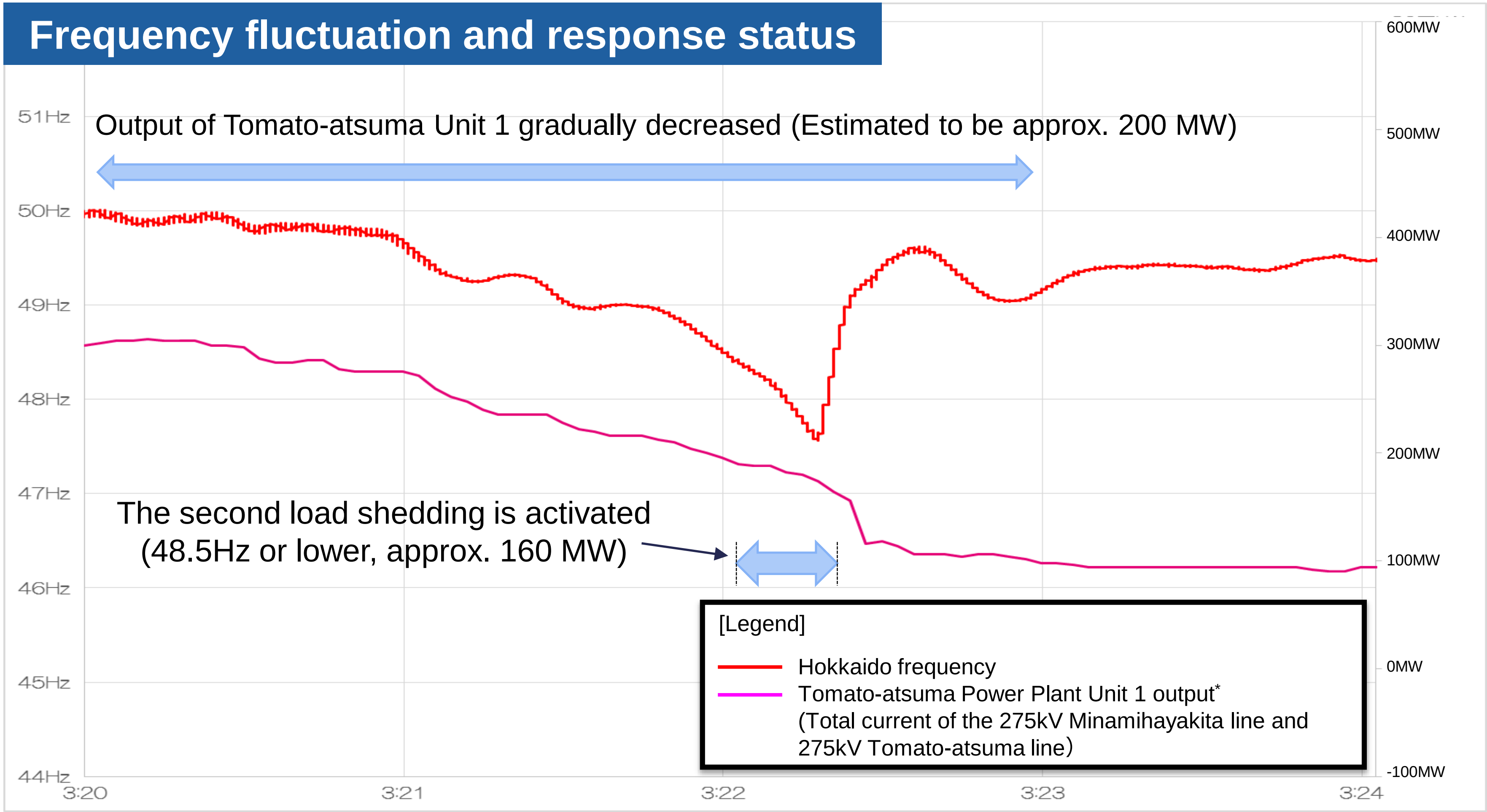
Frequency fluctuation and response status



Immediately after the earthquake [2]-2 Overview (Tomato-atsuma Unit 1 output decrease – second load shedding)

2018/9/6 AM3:20 - 3:24

- The output of Unit 1 of the Tomato-atsuma Power Plant did not stabilize, and the output gradually decreased, causing the frequency drop.
- After second load shedding (automatically activated), the frequency started to recover but not stabilized.



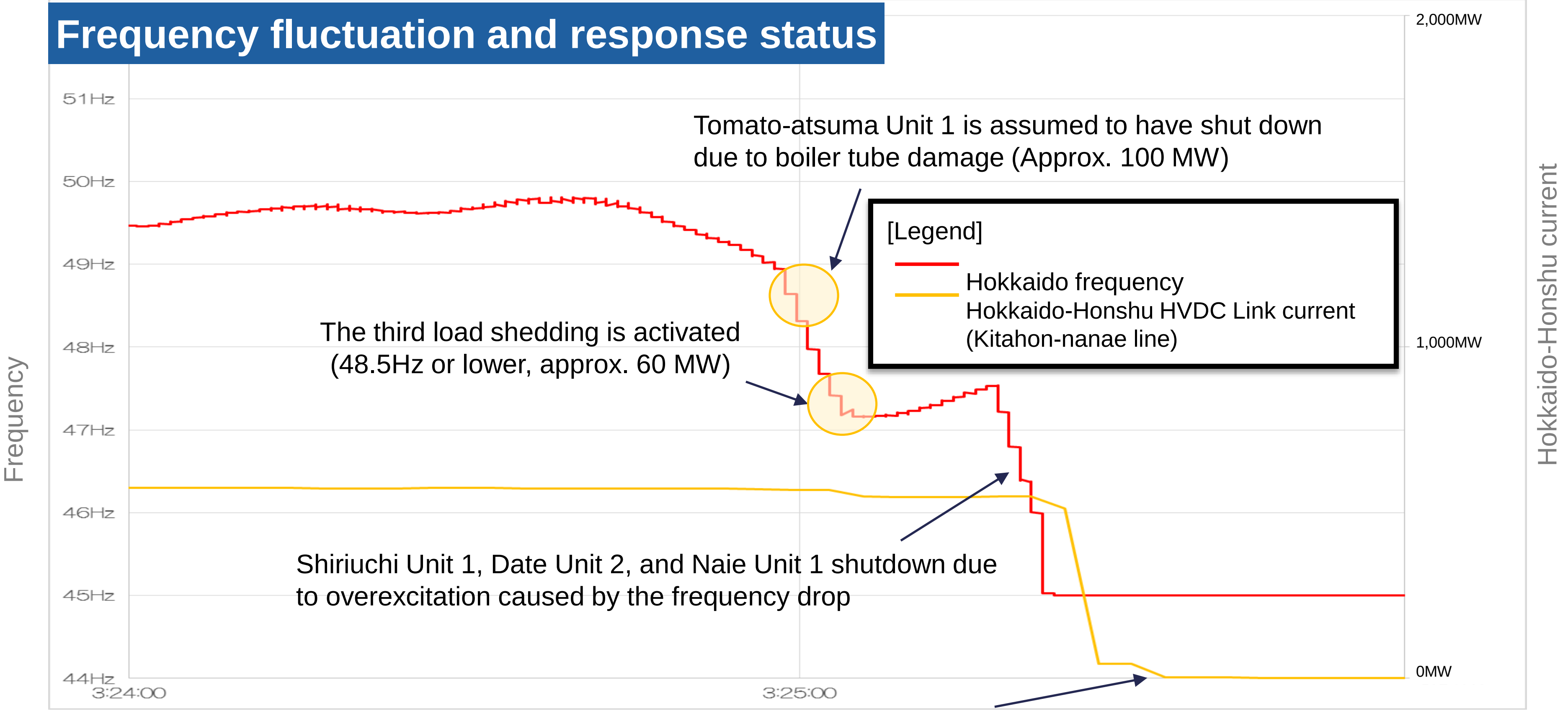
* The transmission line current (Minamihayakita line + Tomato-atsuma line) value was almost twice as much as the generating-end output of Tomato 1G, starting around 3:08. Since it may have been caused by measurement abnormality of the generator, we used the transmission line current value.

Up to the Blackout [3] Overview

2018/9/6 AM3:24 - 3:25

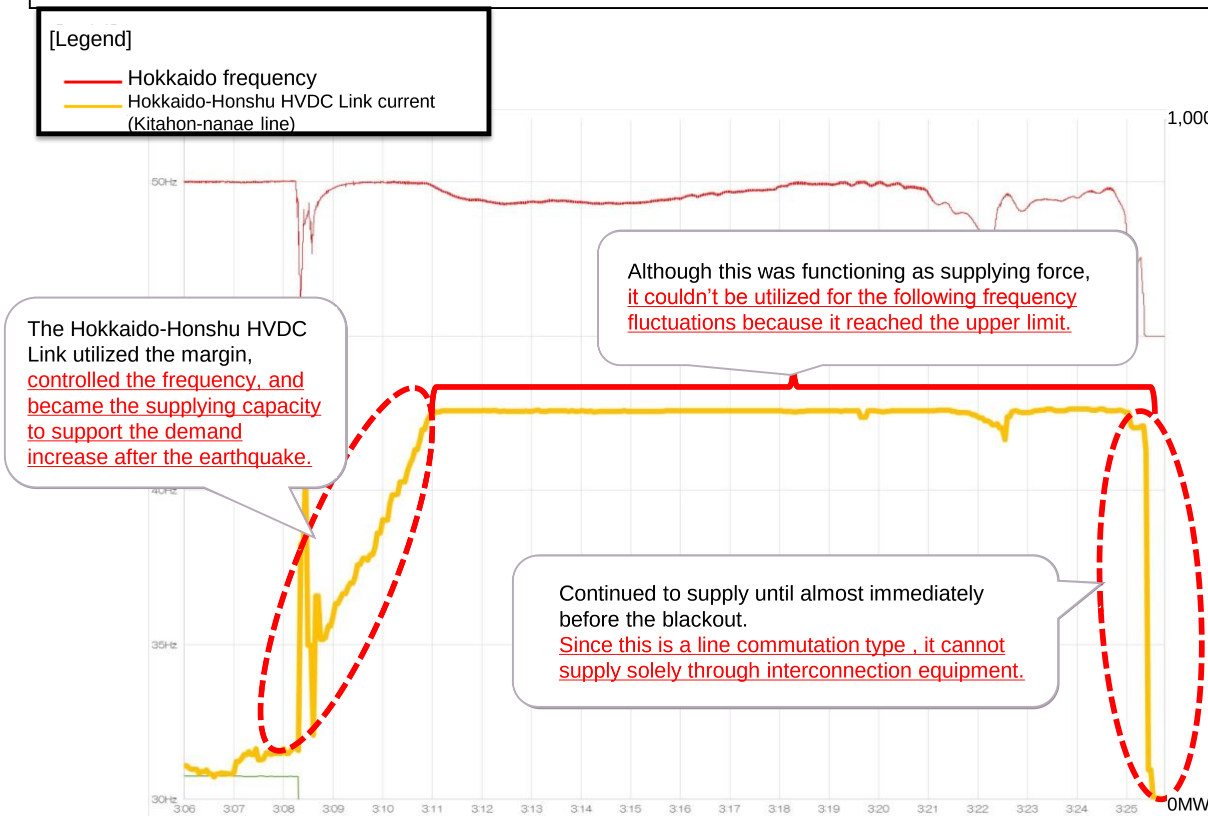
- Unit 1 of the Tomato-atsuma Power Plant shut down and the frequency dropped again.
- Third load shedding was automatically activated. However, since the remaining capacity of the shedding was only 60 MW and not sufficient to recover the frequency.
- The frequency drop caused other thermal/hydro power, etc. to shut down to protect themselves and the Hokkaido-Honshu HVDC Link to become disconnected.
- The above mentioned events caused loss of the power supply, ultimately leading to blackout.

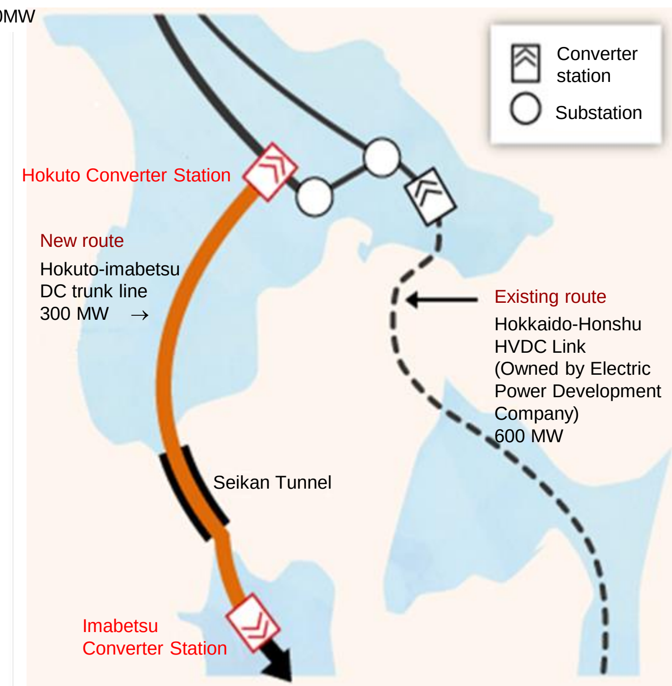
Frequency fluctuation and response status



Hokkaido-Honshu HVDC Link disconnected (caused by frequency drop)

- Expected emergency power transfer was worked with the Hokkaido-Honshu HVDC Link by utilizing the transmission margin.
- However, the power interconnected capacity was at its maximum for the Hokkaido-Honshu HVDC Link, and it was unable to control sudden fluctuations as expected.
- Considering these events, it would have been impossible to support the power supply with the secured transmission margin capacity.
- A new Hokkaido-Honshu HVDC Link, which will run through the Hokuto-imabetsu Direct Current Trunk Line, is under construction. The line is scheduled to be in operation in March of 2019.





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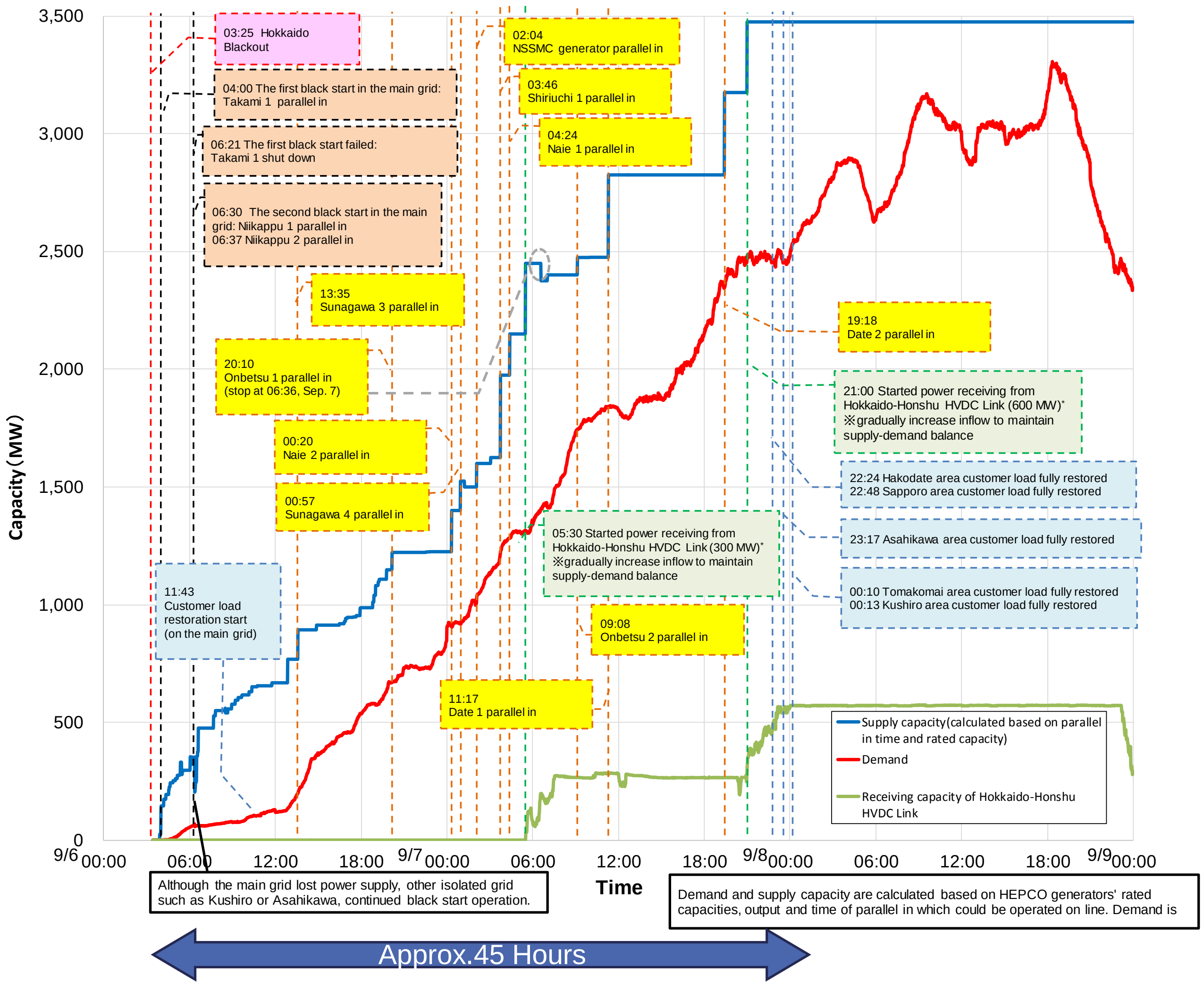
III. Sequence of Events from the Blackout to Securing a Certain Level of Supply

III. Sequence of Events from the Blackout to Securing a Certain Level of Supply

- We have investigated the operation from the blackout to restore supply to customer load (equivalent to securing approx. 3,000 MW).
- Although the restoration was appropriately performed according to the procedure stipulated in the manual, it took approximately 45 hours to supply power to nearly the entire area after the blackout.

Time Series Incidents after Blackout to Power Restoration Investigated and Fact-verified by the Investigation Committee



■ Black start operation was conducted as per the manual without obvious human errors. We have confirmed that there is a limit to the shortening of recovery time since generators could only gradually start beginning with small grids.

Summary of the manual

- Speculating the condition of generators equipped with black start capability at the time of blackout, different patterns of black start operation is designed (7 patterns in total)

  In order to stabilize the grid, the first generators to be started are 2 of the pumped storage plants in most of the patterns

- Clarifying prioritization of the order of grid restoration area after black start

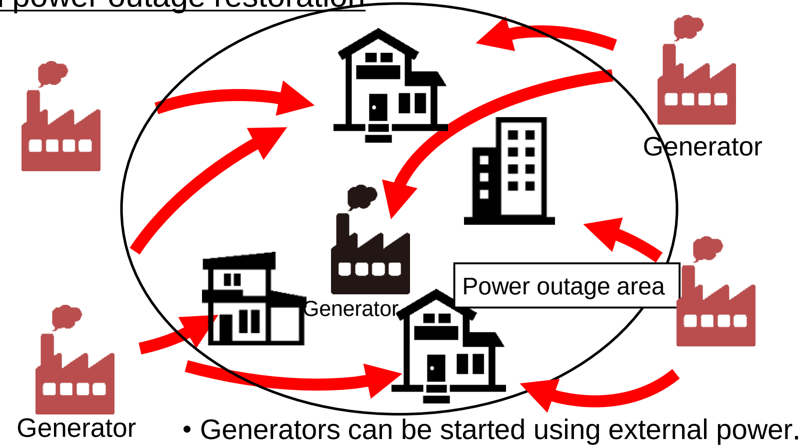
  Starts with 275 kV grid, which requires fewer operational steps, to ensure supply to internal power required for maintenance of thermal/nuclear power plants as well as to promptly parallel in.

etc.

Load supply

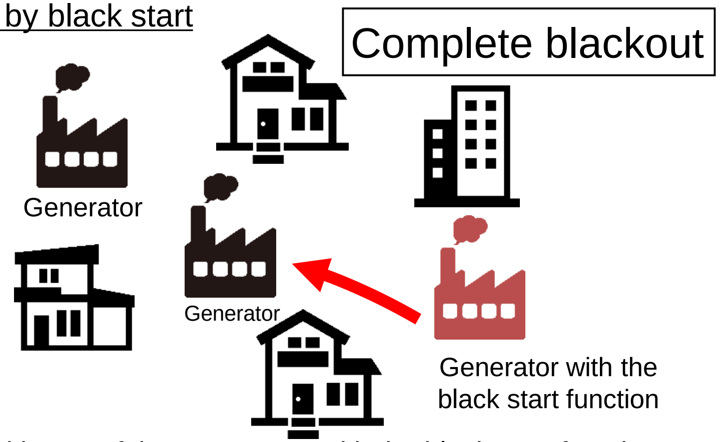
- The Load Dispatching Center calculates the supply level based on the situation of generator parallel in and commands grid controls to restore supply.
- Controls transmission by approximately 3 MW increment based on the frequency/voltage changes caused by the black start grid load supply

Normal power outage restoration



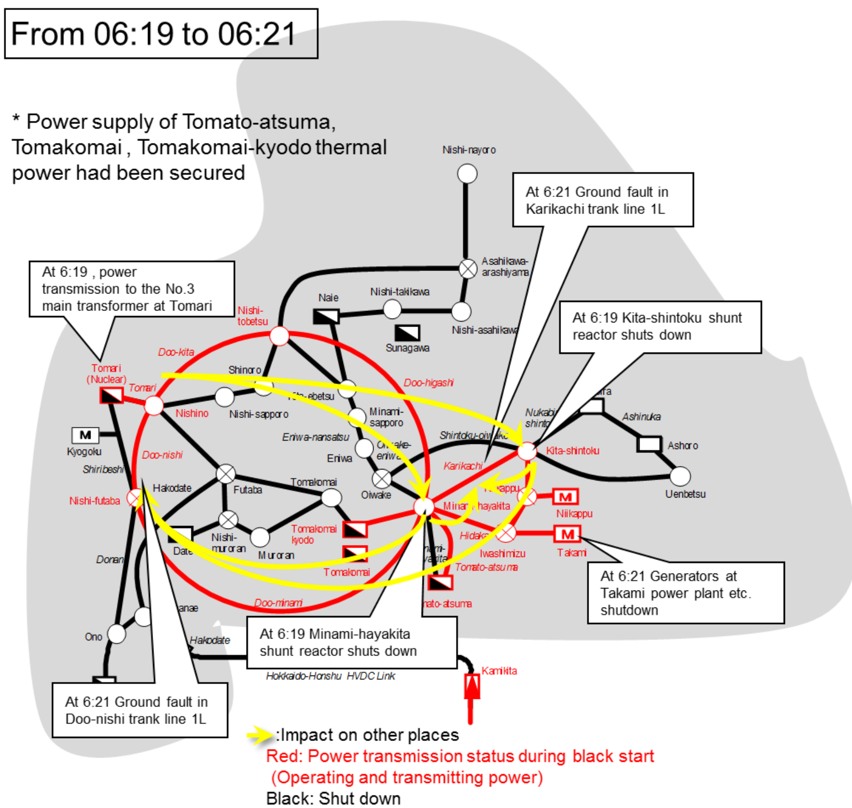
- Generators can be started using external power.
- Grid is supported externally to achieve stable restoration.

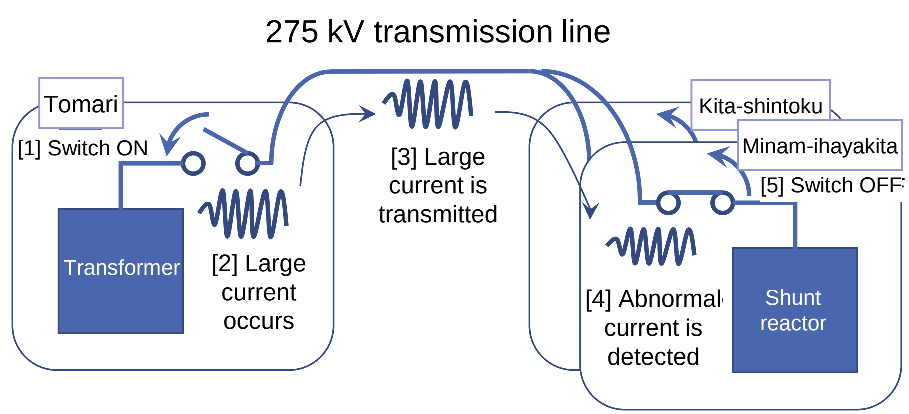
Restoration by black start



- Starting with part of the generators with the black start function, and the neighbor generators are gradually started.
- Grids are extremely small, and thus greatly fluctuate with the smallest changes and thus are unstable.

- During the first black start process, as per the manual, Hokkaido Electric Power Company aimed to first supply to thermal and nuclear power plants to secure electricity for security purpose and internal equipment to start the generators. When power was transmitted to the main transformer 3 of Tomari Power Plant, a large amount of electrical current was flowed. Due to the abnormal electrical current, which is believed to be from this electrical current, the shunt reactor shut down in Minami Hayakita/Kitashintoku substations.
- Due to the voltage increase after the shunt reactor shutdown, ground fault occurred in the Doo-nishi Trunk Line and Karikachi Trunk Line. At the same time, Takami Pumped-storage Power Plant and other plants detected abnormal electrical current, and generators shut down.
- In the second black start, internal power was supplied solely with spare transformers without using the main transformer, in which the large current occurred. The grid was appropriately expanded afterwards, securing the supply level.

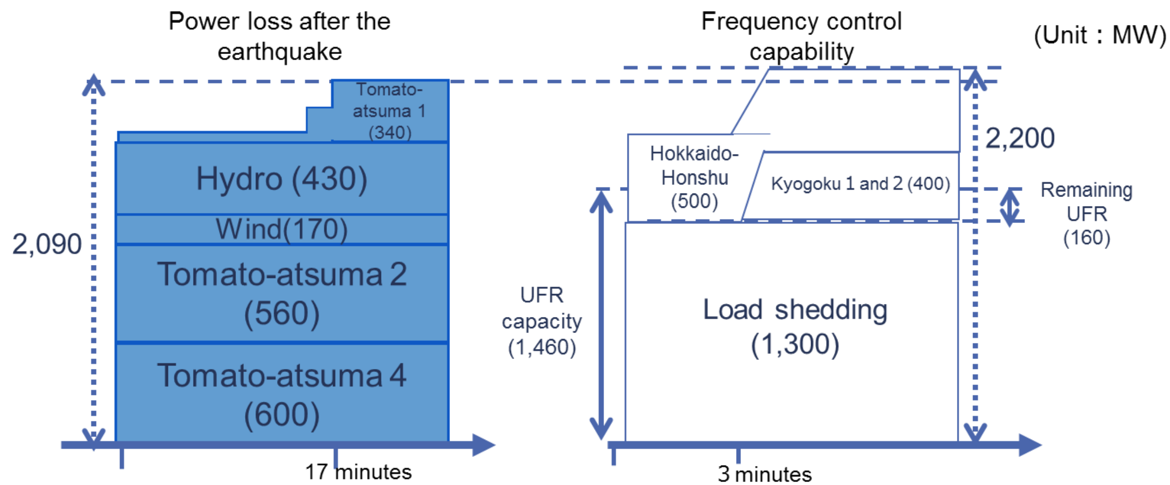




IV. Recurrence Prevention Measures
(1) Short-term measures on operation winter 2018/19

Evaluation of the Operation (Preparation against risks with rare occurrence)

- We have confirmed through simulations that **if Kyogoku Units 1 and 2 (200 MW x 2) were in operation it is highly likely that it would not have led to blackout, even if all of the units on Tomato-atsuma tripped**.
- Moreover, even if two large-scale pumped storage units (Kyogoku Units 1 and 2) also stopped, **it would not have led to blackout as long as hydro power plant trip (N-4) had not occurred**.



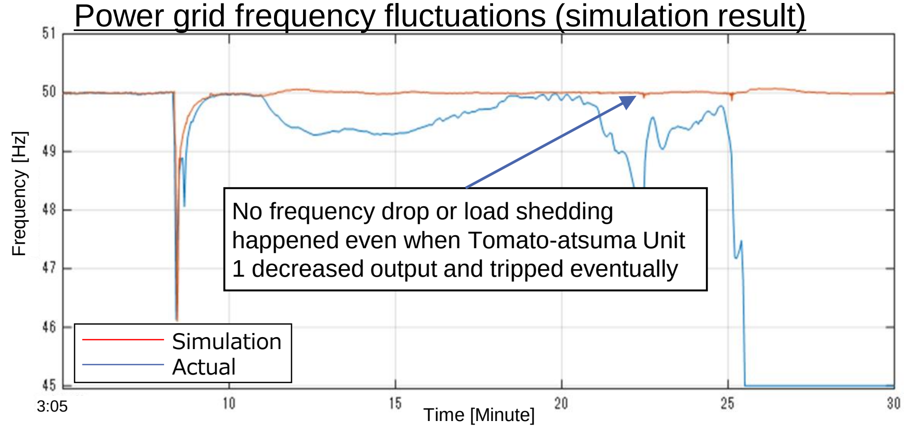
Assumption at the occurrence of the earthquake

Simulation case: Recreation of the earthquake

Tomato-atsuma 2 units trip + 1 unit delayed trip (N-2 + N-1)
Trip by frequency relay (wind power generator, etc.)
Eastern Hokkaido hydro power plant trip due to the transmission line accident (N-4)

Emergency start of Kyogoku 2 units

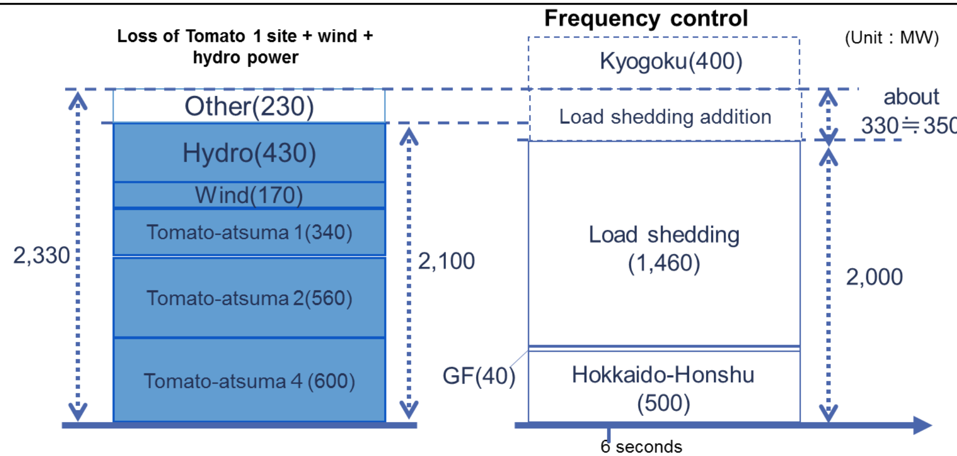
Power grid frequency fluctuations (simulation result)



Simulation result	
Blackout avoidance possibility	○
Lowest frequency point immediately after the earthquake (Hz)	46.10
UFR operation (MW)	1288.0
Remaining UFR (MW)	158.3
Hokkaido-Honshu current final value (MW)	-398.1
Period remaining at 49Hz or less (s)	8.3

Evaluation of the Operation (Load shedding expansion through UFR)

- As a measure to avoid another blackout in the near term, we have **evaluated the required load shedding capacity to control frequency by assuming more severe conditions**. The conditions used were simultaneous trips of all of the units on Tomato-atsuma + wind + hydro power as well as simultaneous trip of approximately 230 MW of other power sources*.
- In this case, the capacity of Hokkaido-Honshu HVDC Link, load shedding and others combined would be 2,000 MW against the simultaneous trip of 2,330 MW. Therefore, the required addition of UFR capacity would be approximately 350 MW, which is also confirmed through simulation.
- 350 MW of additional capacity must be secured by UFR since it is operationally difficult to secure 350 MW of capacity from Kyogoku since it is a pumped-storage hydro power plant. Also, **additional amount of UFR must be set at a level that will not affect the operation of the existing Hokkaido-Honshu HVDC Link**.



* "Other": Value gained by subtracting 110 MW*, which did not trip, from the 340 MW power.

Assumption at the occurrence of the earthquake

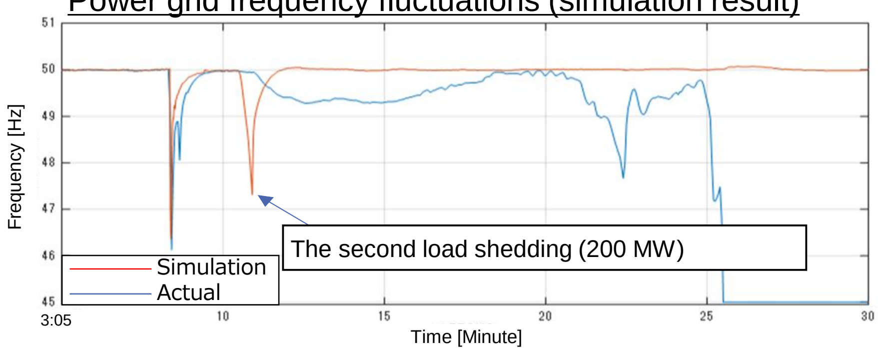
Simulation case: (more severe case)

Entire Tomato-atsuma 3 units trip simultaneously (N-3)
Trip by frequency relay (wind power generator, etc.)
Eastern Hokkaido hydro power plant trip due to the transmission line accident (N-4)

UFR expansion

Emergency start of Kyogoku 2 units

Power grid frequency fluctuations (simulation result)



Simulation result	
Blackout avoidance possibility	○
Lowest frequency point immediately after the earthquake (Hz)	46.37
UFR operation (MW)	1611
Remaining UFR (MW)	199
Hokkaido-Honshu current final value (MW)	-75.6
Period remaining at 49Hz or less (s)	6.7

Short-term measures on operation in the Hokkaido area (winter 2018/19)

Short-term measures for winter 2018/19 in Hokkaido are as follows. OCCTO shall continue monitoring the implementation status.

1. Add load shedding by UFR by approximately 350 MW (against demand of 3,090 MW), to be dispatched in an emergency situation.
2. On condition that operation of Units 1 and 2 of the Kyogoku Power Plant are available, operate the 3 units of the Tomato-atsuma Power Plant including units 1, 2, and 4.
3. However, in order to secure some margin in case one of the Units 1 or 2 of the Kyogoku Power Plant shuts down, curtail the output of Unit 1 of the Tomato-atsuma Power Plant by approximately 200 MW (equivalent of one Kyogoku unit capacity). However, during a high-demand period, instead of regulating the output, thermal power plants could be operated to increase the 200 MW of output within 10 minutes timeframe.
4. Approximately 30% to 35% of the total demand shall be supplied from generators such as thermal power plants that can continue operation even when frequency is dropped .
5. Do not take supply capacity of Units 1, 2 and 4 of Tomato-atsuma Power Plant into account when calculating the short-circuit capacity required to operate the Hokkaido-Honshu HVDC Link.
6. Thoroughly consider the available reserve capacities when performing balance stop. Make sure that thermal power plants secure reserved capacities to supply power within a few minutes to several hours according to the demand changes for the time being.
7. When measures are taken in case one of the Units 1 or 2 of the Kyogoku Power Plant shuts down, OCCTO shall monitor the operation to make sure that the measures taken are appropriate.

Comprehensive inspections of generator equipment and transmission equipment in the Hokkaido area

We expect that the Government must perform comprehensive inspections on the conformity of generator facilities and transmission facilities within the Hokkaido Electric Power Company area with relevant regulations from the perspective of network resilience reinforcement as short-term measures for winter 2018/19 to prevent another blackout.

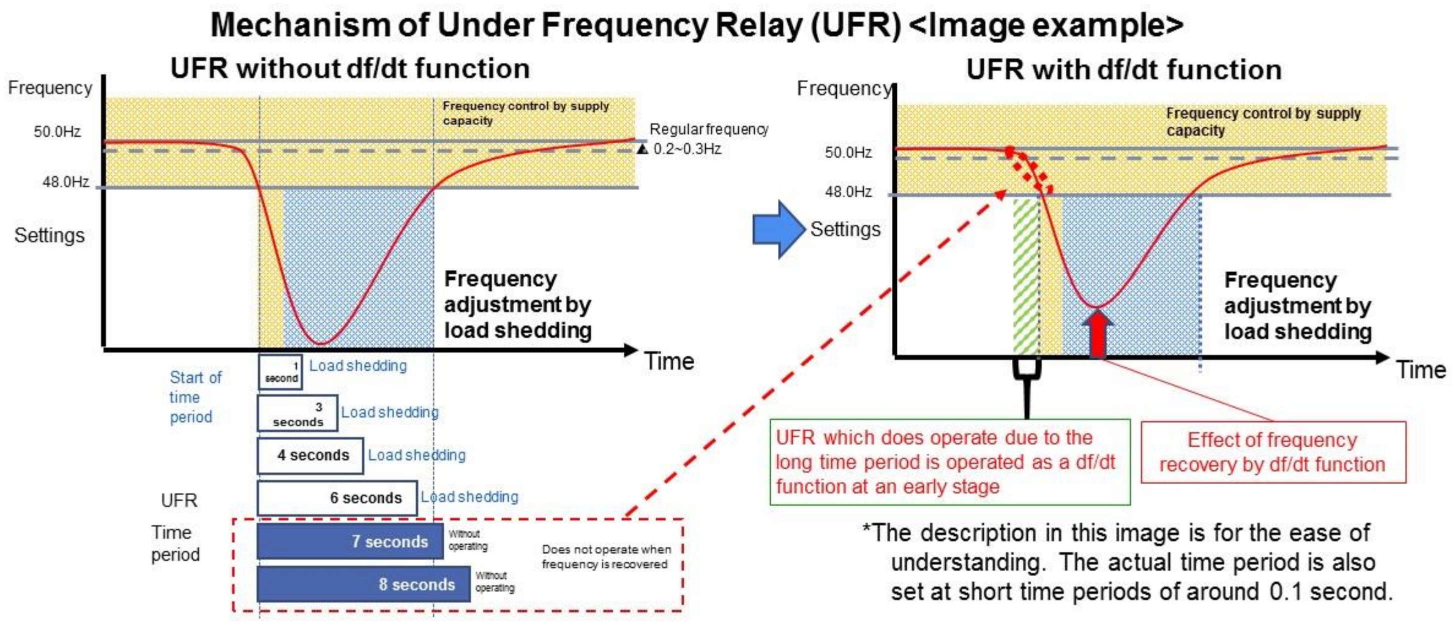
IV. Recurrence Prevention Measures

(2) Simulations for examining mid-to-long term measures

Simulation conditions for mid-to-long term measures

- In connection with the final report, the situation of the **largest site tripping in the most severe scenarios** that can be presumed at present was **simulated** for the two scenarios - “**[1]After the commercial of operations of the Ishikariwan-shinko Power Plant and new Hokkaido-Honshu HVDC Link ” and “[2]After the resuming operations at Tomari Power Plant”**, and study was conducted for the following items proposed in the interim report:
  - The Under Frequency Relay (UFR) setting in the Hokkaido area
  - Operations of the largest capacity generators
  - Re-evaluation of the frequency control functions, such as governor-free system, Automatic Frequency Control (AFC) function, and interconnection facility margin
- We identified “**late night demand when frequency drop has a severe impact**” and “**demand for high-output renewable energy for which massive tripping due to frequency drop is a concern**” as the most severe scenarios, and selected the **scenarios taking into account availability of pumped-storage operations and Hokkaido-Honshu HVDC Link current**.
- The UFR terminal device, which is being sequentially upgraded by the Hokkaido Electric Power Company, is equipped* with a function (df/dt function) to detect the frequency fluctuations rate element in case the frequency drops abruptly and activate load shedding, and this device has also been incorporated.

* At present, about 20% of total UFR has been installed, and of this, values have been set for about 10% of total UFR



IV. Recurrence Prevention Measures (2) Simulations for examining mid-to-long term measures

[1] After the commercial operations of the Ishikariwan-shinko Power Plant and new Hokkaido-Honshu HVDC Link

- The simulation results for “[1] After the commercial operations of the Ishikariwan-shinko Power Plant and new Hokkaido-Honshu HVDC Link ” are as follows and for the three most severe scenarios that can be assumed at present (late night demand, light load and high-output renewable energy, late night demand and no pumped-storage operation), we confirmed that tripping of the Tomato-atsuma Power Plant site will not lead to a blackout.

Unit：MW

Case No.			[1]-1	[1]-2	[1]-3
Scenario			Tomato-atsuma 3 units full output		
			Late-night demand	Light load and maximum renewable energy	Late-night demand and no pumped storage
Demand		Demand	2564	2811	2792
		Pumped-storage power	183	460	0
		Hokkaido-Honshu (Power transmission to Hokkaido is regular)	53	-301	55
Supply capacity	Generators simulated to be tripped	Tomato-atsuma	1598	1598	1598
		Other renewable energy	268	1168	264
		Subtotal	1866	2766	1862
	Generators simulated not to be tripped	Shiriuchi Unit 2	110	110	110
		Ishikariwan-shinko Unit 1	155	142	189
		Other	563	554	576
		Subtotal	828	806	875
Simulation result		Result	O	O	O*
		Lowest frequency point (Hz)	47.46	47.87	*2 46.95
		UFR operation (MW)	1071	636	1166
		Remaining UFR	476	1060	519
		Maximum AFC operating capacity of Hokkaido-Honshu HVDC link (MW)*1	802 (546)	963 (531)	800 (532)
		Hokkaido-Honshu current final value	558	533	652

* 1 () indicates margin (Tripping of largest single unit)

* 2 Though it is below 47 Hz, the situation does not lead to a blackout as there was no UFR load shedding at the thermal power plant (47 Hz-10 seconds). The case is judged not to be led to a blackout with condition, stated as “ O* "

[2] After the resuming operations at Tomari Power Plant

■The simulation results for "[2] After the resuming operations at Tomari Power Plant" are as follows and for the four most severe scenarios* that can be assumed at present (late night demand/ no pumped-storage operation/ Hokkaido-Honshu north flow, 3 Tomari generators, the same/ 2 Tomari generators, high-output renewable energy/ pumped-storage operation/ 3 Tomari generators/ Hokkaido-Honshu south flow, the same/ Hokkaido-Honshu 0MW), we confirmed that additional measures are required only for case [2]-1 in the event that the Tomari Power Plant site trips.

* If the actual demand value is used as in cases[1]-1, 2, the Hokkaido-Honshu and new Hokkaido-Honshu HVDC Link current will increase towards Honshu in addition to the increase in pumping water operations due to the demand and supply balance, and is not considered to be the most severe scenario

Unit: MW

Case No.			[2]-1	[2]-2	[2]-3	[2]-4
Scenario			Late night zone scenario		Scenario of high output renewable energy	
			Tomari 3 units in operation	Tomari 2 units in operation	Tomari 3 units in operation	
Demand		Demand	3123	2507	2793	3438
		Pumped storage power	0	0	422	422
		Hokkaido-Honshu (Power transmission to Hokkaido is regular)	175	138	-645	0
Supply capacity	Generators simulated to be tripped	Tomari	2070	1491	2070	2070
		Other renewable energy	30	30	942	942
		Subtotal	2100	1521	3012	3012
	Generators simulated not to be tripped	Shiriuchi Unit 2	110	110	110	110
		Ishikariwan-shinko Unit 1	142	142	142	142
		Other	596	596	596	596
		Subtotal	848	848	848	848
Simulation result		Result	Measures are required (Note)	O	O	O
		Lowest frequency point (Hz)	45 or less	47.41	47.68	47.44
		UFR operation	1305	1047	726	1436
		Remaining UFR	580	466	960	639
		Maximum AFC operating capacity of Hokkaido-Honshu HVDC link *1	680	717 (762)	1317 (744)	855 (706)
		Hokkaido-Honshu current final value	855	547	672	631

(Note) Consider the blackout workaround separately.

*1 () indicates margin (Tripping of largest single unit)

[2] After the resuming operations at Tomari Power Plant

- We examined additional measures for case [2]-1 (simultaneous tripping of 3 Tomari generators (no pumped-storage operations)).
- Accordingly, we confirmed that both the measures (UFR settings applying the df/dt function, stabilization device) will not lead to blackout in the event that the Tomari Power Plant site trips.

Unit: MW

Case No.		[2]-1-a1	[2]-1-a2	[2]-1-b1	[2]-1-b2
Recurrence prevention measures		UFR settings using df/dt		Stabilization device	
		UFR settings rate 20%	After the update of entire UFR	Load shedding 1980MW	Load shedding 1390MW
Simulation results	Results	○*	○	○	○
	Lowest frequency point (Hz)	*2 46.65	47.26	48.65	48.52
	UFR operation	1836	1732	188	188
	Remaining UFR	49	152	1697	1697
	Maximum AFC operating capacity of Hokkaido-Honshu HVDC link (MW) *1	680 (725)	680 (725)	615 (725)	673 (725)
	Hokkaido-Honshu current final value	357	451	2	586

*1 () indicates margin (Tripping of largest single unit)

2 Though it is below 47Hz, the situation does not lead to a blackout as the duration is less than the UFR load shedding at the power plant (47 Hz-10 seconds). The case is judged not to be led to a blackout with condition, stated as “ ○ "

IV. Recurrence Prevention Measures
(3) mid-to-long Term Operational Measures

<The UFR settings in the Hokkaido area>

- If the frequency significantly drops due to the factor such as the tripping of the largest site without water pumping of pumped storage hydro plant , the lowest point of frequency might fall below 47.0Hz, and cause cascading trip of renewable energy. Therefore, **review the UFR settings promptly so that the lowest point of frequency can be raised to 47.0Hz or higher** (Increase the UFR with df / dt function from 10% to 20%).

<Operations of the largest capacity generators>

- **Presuming that AFC reserves can be secured with the Hokkaido-Honshu/ new Hokkaido-Honshu HVDC Link, set aside the condition "operations of Units 1 and 2 of the Kyogoku Power Plant are available" for operating the three generators of the Units 1, 2, and 4 of the Tomato-atsuma Power Plant stated in the measures for winter 2018/19.**
- With the three generators of the Tomato-atsuma Power Plant equivalent to being fully operational, **if the demand-supply scenario is such that the frequency is expected to drop even more than the most severe scenarios assumed here,** the Hokkaido Electric Power Company shall **simulate the tripping of the largest site in advance, make sure that the situation does not lead to a blackout, and take the required measures as and when necessary.**

<Re-evaluation of the governor-free system and AFC function>

- Simulation confirmed that even if the largest site tripped, the governor-free systems could secure 2% by utilizing generators simulated not to be tripped and AFC function retained a frequency control margin due to the Hokkaido-Honshu and new Hokkaido-Honshu HVDC Link, therefore, the re-evaluation of the **governor-free system and AFC function are not necessary at present**.

<Re-evaluation of the interconnection facility margin>

- The cases of a maximum north flow current in the minimum demand scenario, and Tomato-atsuma Power Plant in full output are believed to be extremely rare. If such cases are presumed, conduct simulations beforehand and **if the blackout risk is recognized, measures such as curtailing the output of the Tomato-atsuma Power Plant or water pumping of pumped-storage hydro plant can be taken. Therefore, with respect to the margin oriented towards Hokkaido or in the opposite direction of Hokkaido-Honshu and new Hokkaido-Honshu HVDC Link , the current approach assuming maximum tripping of a single generator are not necessary be reviewed at present.**

[2] After the resuming operations of Tomari Power Plant

For a situation wherein the Tomari Power Plant, which is currently under long-term shutdown, trips after resuming operations, it is indispensable that simulation be performed again when the prospect of resuming operations at the Tomari Power Plant is actually near, the necessary measures be examined and taken.

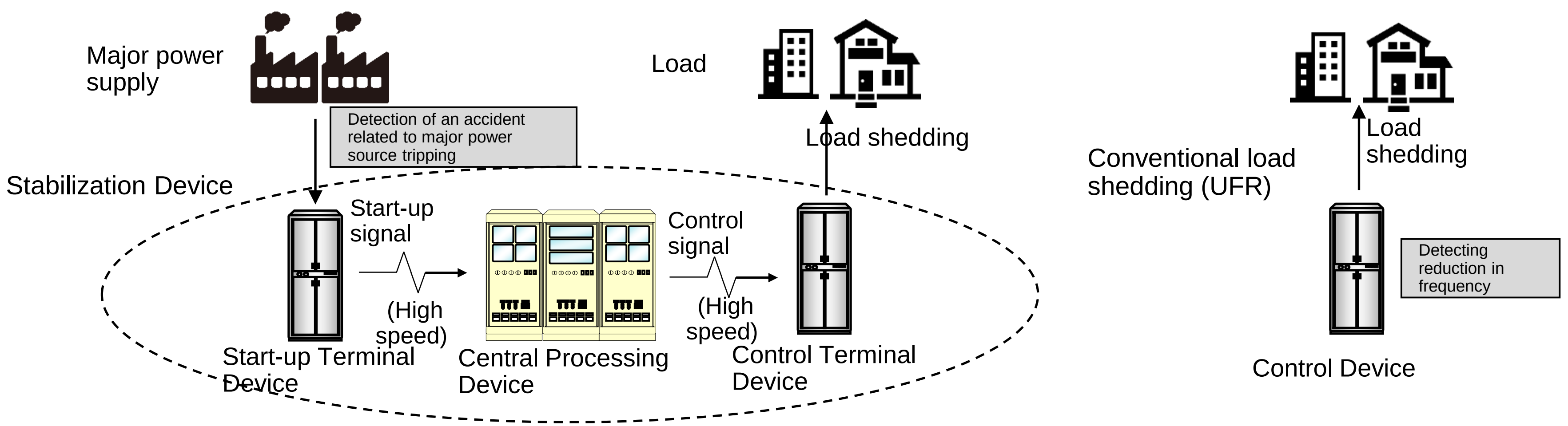
<The UFR settings in the Hokkaido area>

- Application of frequency fluctuations rate element (df/dt) of UFR (review of settings) and measures using a stabilization device activating high-speed load shedding are essential.

<Re-evaluation of the frequency control functions, such as governor-free system, AFC function, and interconnection facility margin>

- Just as in the case of “[1] After the commercial operations of the Ishikariwan-shinko Power Plant and new Hokkaido-Honshu HVDC Link ”, re-evaluation of **these functions are not necessary at present.**

(Reference) Difference between Stabilization device and conventional load shedding (UFR)



Activate load shedding speedily by detecting major generator tripping and without waiting for frequency drop

Activation of load shedding takes time for waiting frequency drop

IV. Recurrence Prevention Measures
(4) mid-to-long Term Measures for Facility Formation

IV. Recurrence Prevention Measures (Equipment Measures)

Further reinforcement of Hokkaido-Honshu HVDC Link

- The Government shall promptly examine how the cost allocation should be placed if, after the completion of the new Hokkaido-Honshu HVDC Link , further reinforcement of the Hokkaido-Honshu HVDC Link is needed. On its part, OCCTO shall promptly examine the feasibility of switching the existing Hokkaido-Honshu HVDC Link to self commutation type and further reinforcing the Hokkaido-Honshu HVDC Link after the new Hokkaido-Honshu HVDC Link is completed.
- It goes without saying that in order to prevent a blackout, further reinforcement of the Hokkaido-Honshu HVDC Link will be technically advantageous from the viewpoint of securing a stable supply, according to Government policy (Government's response policy consolidated for the cabinet meeting on emergency inspection of important infrastructure, Interim Summary of the Working Group on Electricity Resilience), the Government and OCCTO shall conduct simulations to confirm the effectiveness of further reinforcing the existing interconnection line after the completion of the new Hokkaido-Honshu HVDC Link (after total interconnection capacity is reinforced from 600 MW to 900 MW), and the feasibility of switching the existing Hokkaido-Honshu HVDC Link to self commutation type, and then work towards proposing the drafts, including the routes and the scale of reinforcement, until next spring.