The 4th ISM-ZIB-IMI MODAL Workshop on Mathematical Optimization and Data Analysis

Unit Commitment Problem revisited in the course of Electricity Market Reform in Japan

TOSHIBA

Takufumi Yoshida

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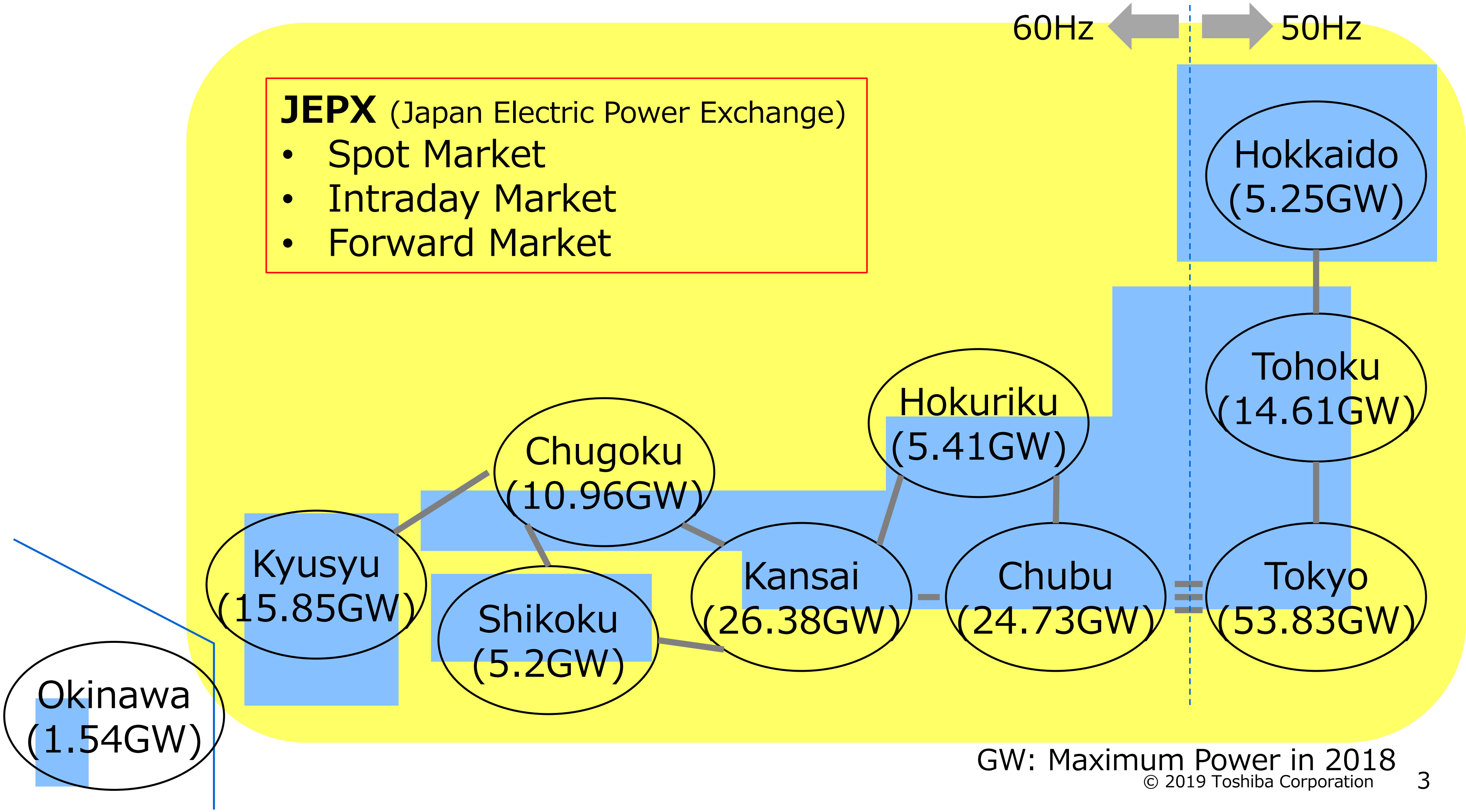
01

Background

Japan’s Electricity Market Overview

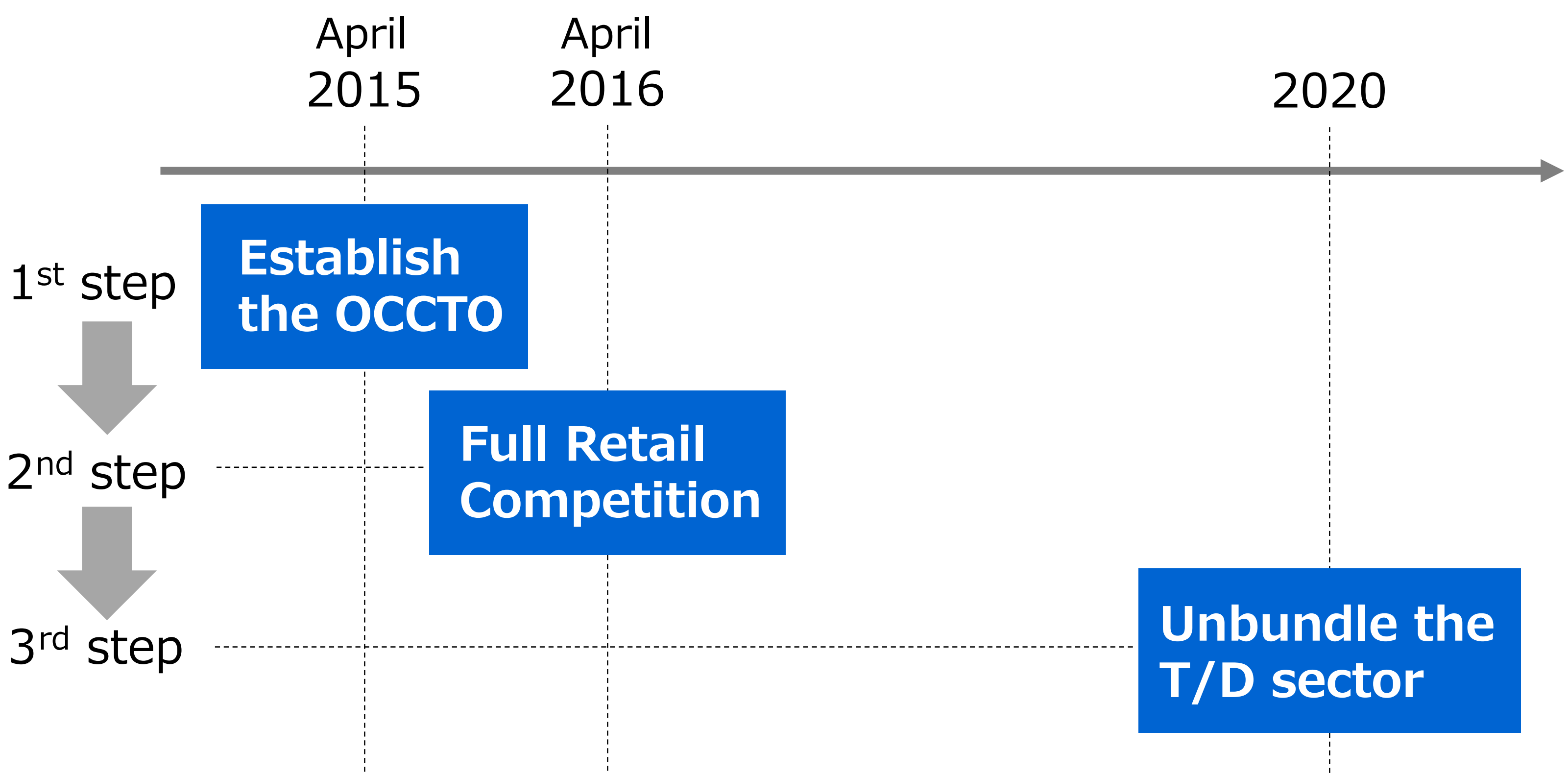
- 10 Electricity Power Companies (EPCOs).
- 2 frequencies, 50Hz (East) and 60Hz (West).
- JEPX is a wholesale market in Japan established in 2003.



GW: Maximum Power in 2018

Electricity Market Reform in Japan: Roadmap

Japan’s Electricity Market Reform is being realized with a three-step approach since 2015.



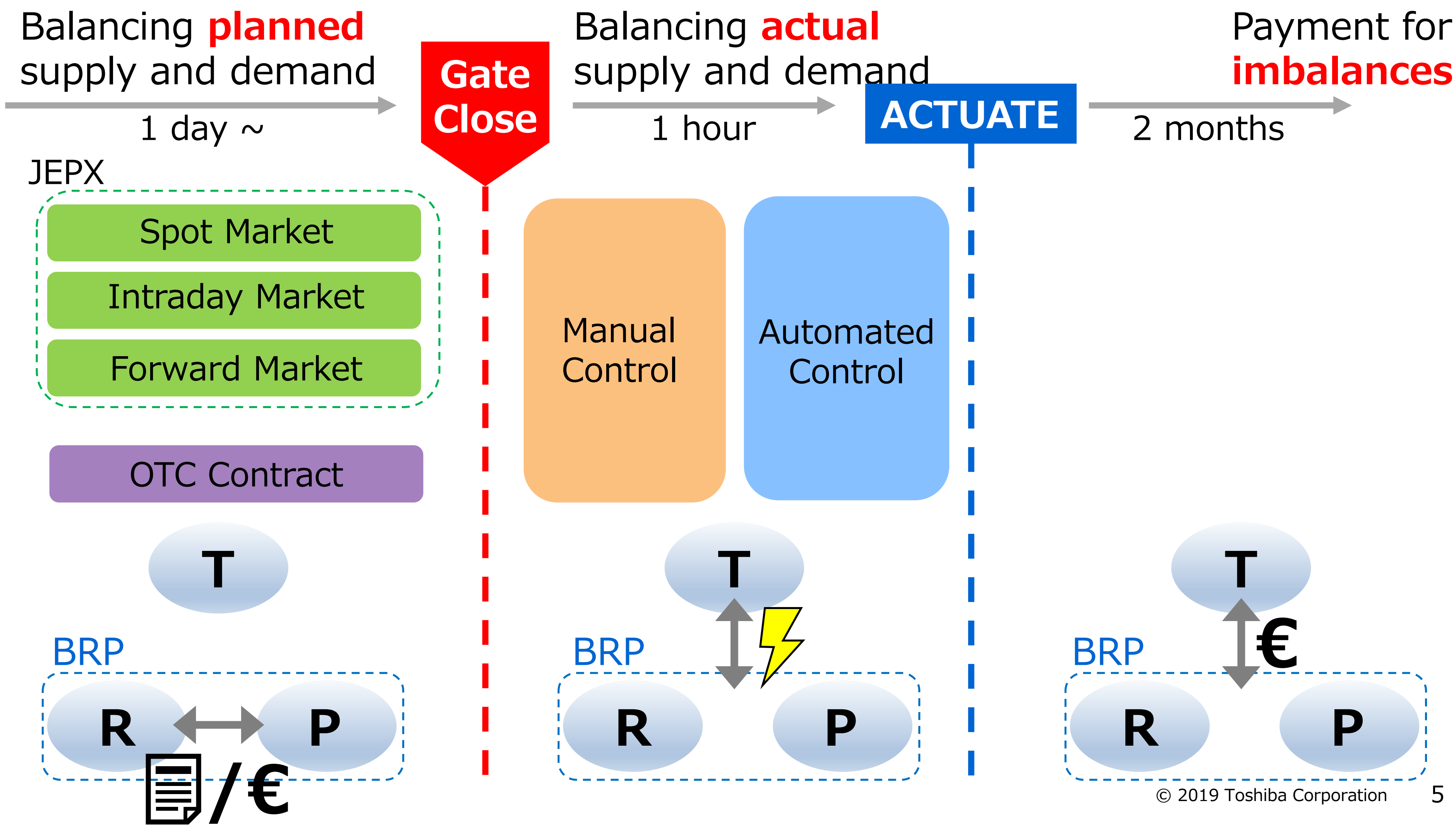
OCCTO:
Organization for Cross-regional Coordination of Transmission Operators

T/D:
Transmission/Distribution

Electricity Market: BRP Model

Balance Responsible Party (**BRP**)
=Retailers and power generation companies who balance planned supply and demand by market transactions

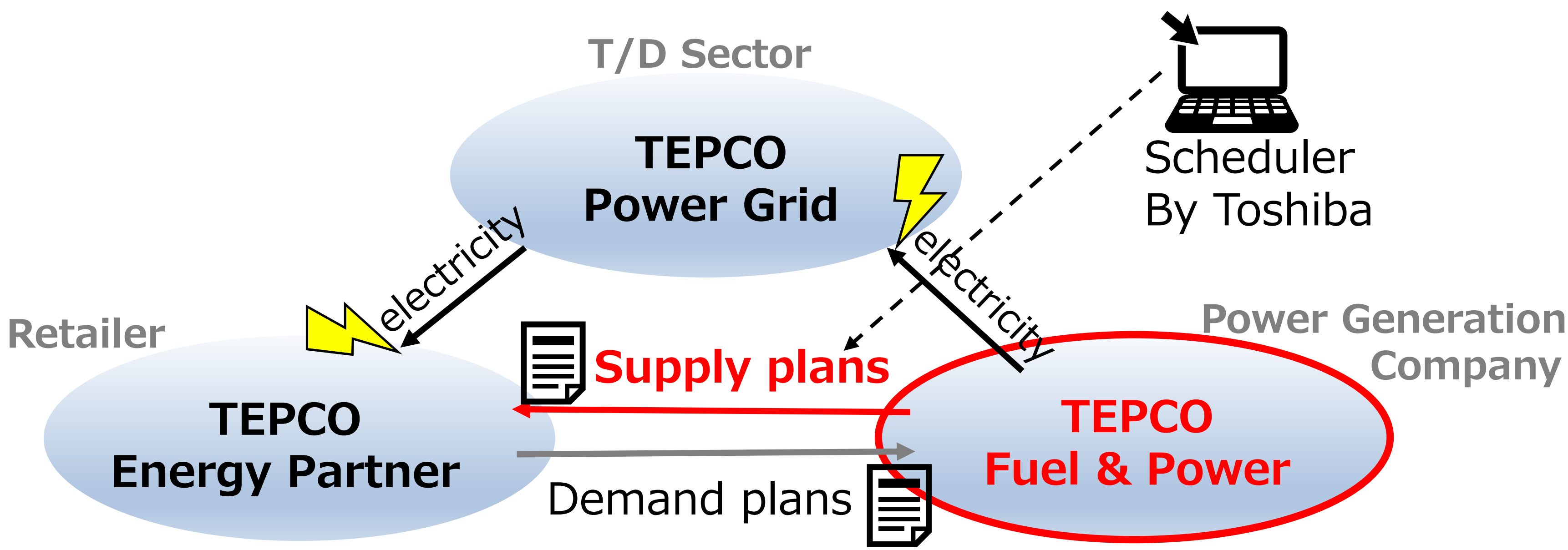
T: T/D Sector
R: Retailer
P: Power Generation Company



TEPCO's Reorganization (April 2016)

- Tokyo Electric Power Company (TEPCO) adopted a holding company system in April 2016 to split into 3 companies.

- Toshiba developed a brand-new power generation scheduling system for TEPCO Fuel & Power.



Brand-new Scheduler for Thermal Power Units

- **Viability**
  - Avoid paying to settle the imbalance, viable schedules with less imbalances are needed.
- **Flexibility**
  - We need to consider flexible operations, such as Daily-start-stop (DSS) and partial-loaded operations, because of increasing amount of renewable energies.
- **Efficiency**
  - To improve profitability as an independent company after April 2016, TEPCO Fuel & Power generates electricity with minimum fuel cost.

02

Model and Algorithm

Unit Commitment Problem (UCP)

variables: $x_{it} \in \mathbb{R}$, MWh of unit #i in period #t (30min)

$y_{it} \in \{0,1\}$ on-off status of unit #i in period #t (30min)

objective:

$$\min_{x,y} \sum_{t=1}^{T} \sum_{i=1}^{n} (a_{it} {x_{it}}^2 + b_{it} x_{it} + c_{it} y_{it})$$

Minimize total operation cost which is convex quadratic function of x and y

constraints:

$$l_{it} y_{it} \le x_{it} \le u_{it} y_{it}$$

online units supply MWh between l and u (note l > 0)

$$\sum_{i=1}^{n} x_{it} = d_t$$

total power supply equals demand at every period

$$(x_{it}, y_{it}) \in \mathcal{F}$$

many other constraints requisite for operation: linear, non-linear(non-convex), if-then rules, etc.

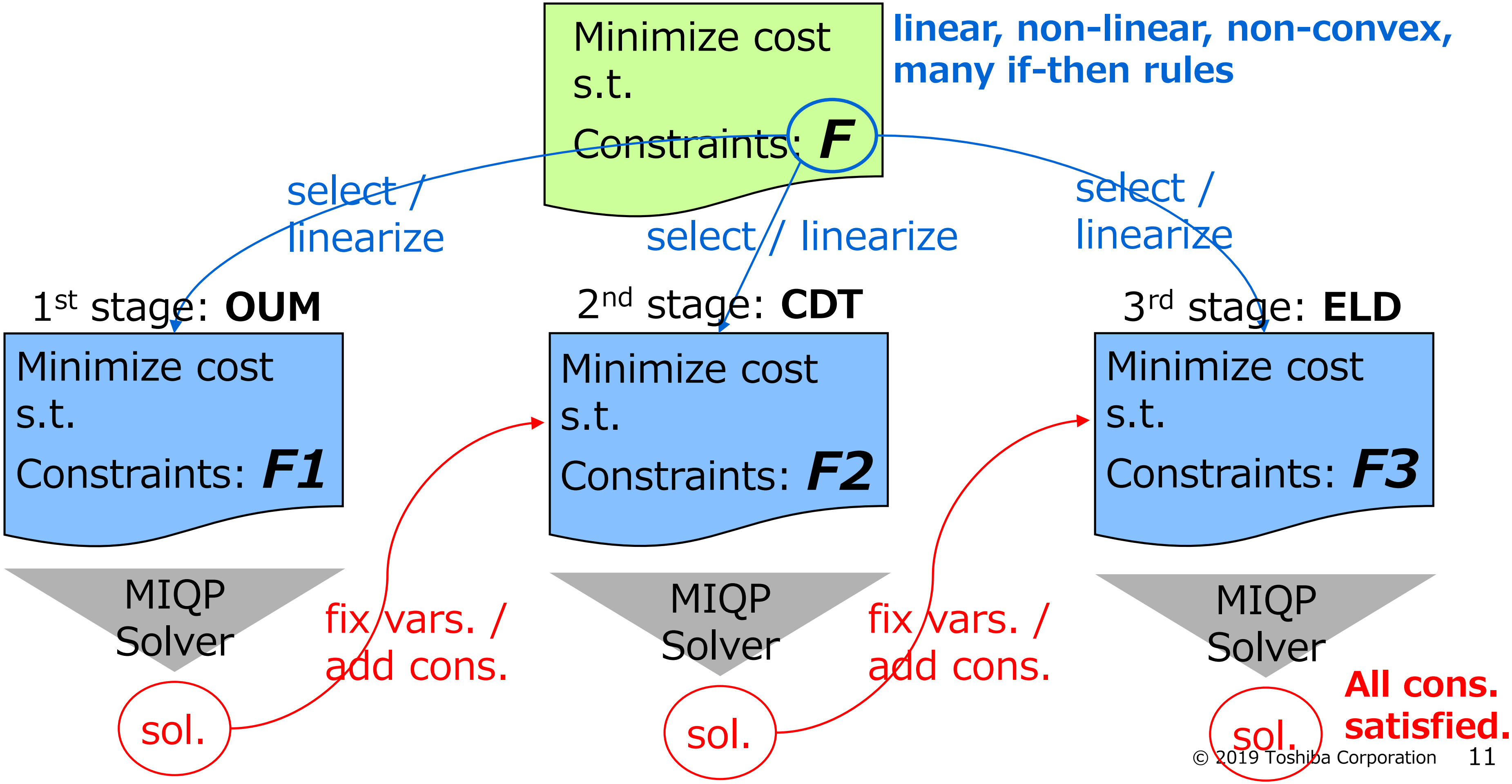
What makes UCP hard to solve

- Without constraints F, UCP would be Mixed Integer Programming Problem (**MIQP**) which is easy to solve even if UCP is large-scale (e.g., 100 units and 1000 periods).

- F includes constraints which make UCP hard to solve, e.g.,
  - Many if-then rules representing conditions on starting/stopping process in DSS operation.
  - Quadratic non-convex constraints representing available range on variation rate of MW during partial-loaded operation.
  - Inequalities including many variables representing long-term cumulative MWh amount that is consistent with LNG supply, considering LNG tank capacity and cargo-ship schedule.

Algorithm: Multi-stage Optimization

- Represent UCP as an approximate three-stage MIQP, reducing F into F1-> F2->F3 by selecting and/or linearizing constraints.



1st stage: OUM (Online Unit Member)

- Output: Online Unit Member (OUM)

variables: $x_i \in \mathbb{R}$,

$y_i \in \{0,1\}$ on-off status of unit #i in period #t

objective:

$$\min_{x,y} \sum_{i=1}^{n} (a_{it} {x_i}^2 + b_{it} x_i + c_{it} y_i)$$

constraints:

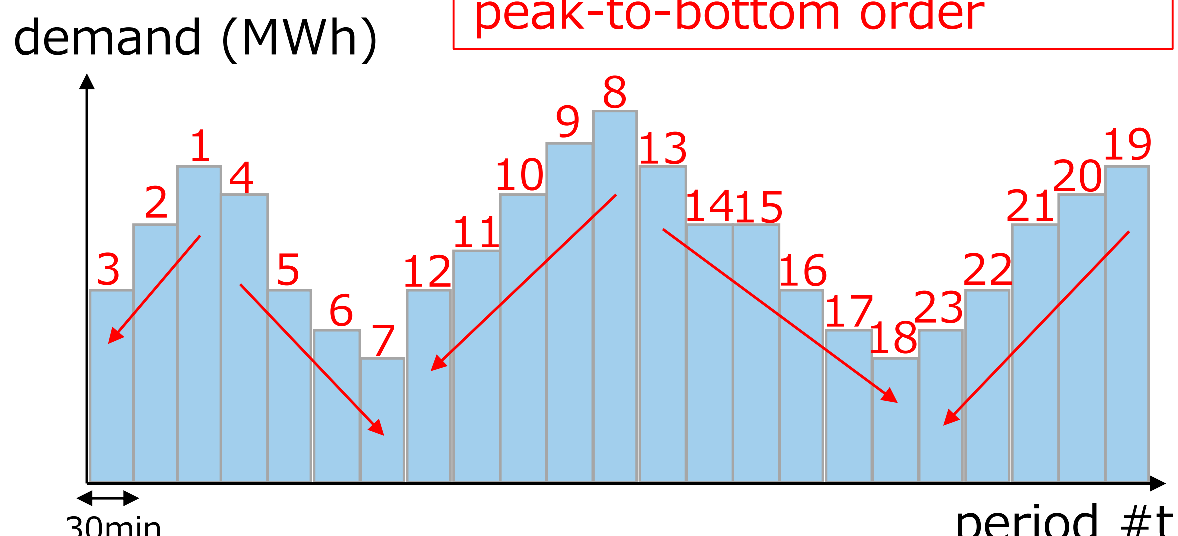
$$l_{it} y_i \leq x_i \leq u_{it} y_i$$

$$\sum_{i=1}^{n} x_i = d_t$$

$$(x_i, y_i) \in \mathcal{F}1_t$$

$$b.c. \sim \#(t \pm 1)$$

Solve MIQP, period by period, peak-to-bottom order



2^{nd} stage: CDT (Commitment/Decommitment Timing)

- Input: online units in time bucket #k
- Output: Commitment/Decommitment Timing (CDT)

variables: $x_{it} \in \mathbb{R}$,

$w_{im} \in \{0,1\}$ operation status of unit #i with different commitment/decommitment timing #m in time bucket #k

objective:

$$\min_{x,w} \sum_{t=T_{k-1}}^{T_k - 1} \sum_{i \in ON} \left(a_{it} {x_{it}}^2 + b_{it} x_{it} + c_{it}\right)$$

constraints:

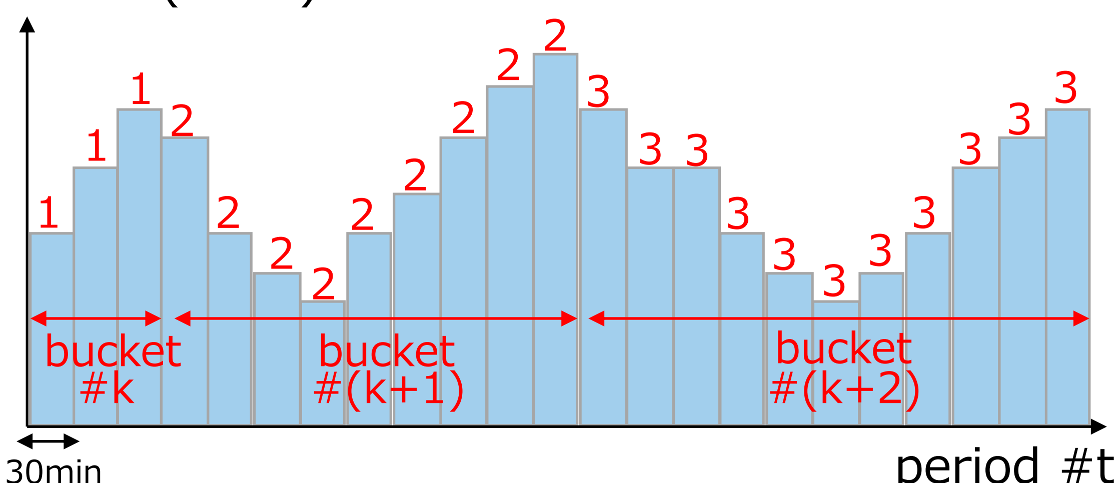
$$l_{it} \leq x_{it} \leq u_{it}$$

$$\sum_{i=1}^{n} x_{it} = d_t$$

$$(x_{it}, w_{im}) \in \mathcal{F}2_k$$

$$b.c. \sim \#(k-1)$$

Solve MIQP, bucket by bucket, chronological order



3rd stage: ELD (Economic Load Dispatch)

- Input: commitment/decommitment period #t
- Output: Economic Load Dispatch (ELD)

variables: $x_i \in \mathbb{R}$,

$z_i \in \{0,1\}$ upward/downward direction of MW of unit #i in period #t

objective:

$$\min_{x,z} \sum_{i \in ON} (a_{it} {x_i}^2 + b_{it} x_i + c_{it})$$

constraints:

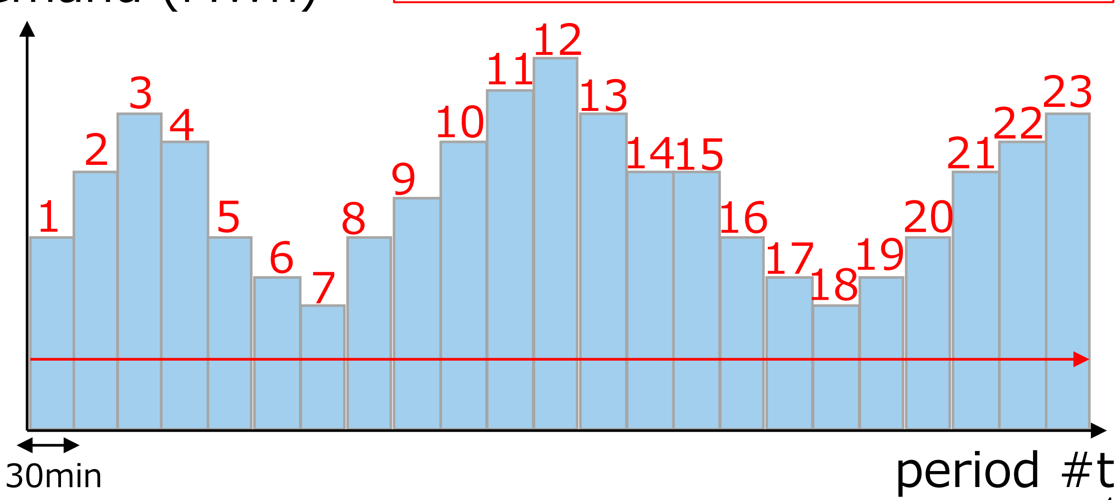
$$l_{it} \le x_i \le u_{it}$$

$$\sum_{i=1}^{n} x_i = d_t$$

$$(x_i, z_i) \in \mathcal{F}3_t$$

$$b.c. \sim \#(t-1)$$

Solve MIQP, period by period, chronological order

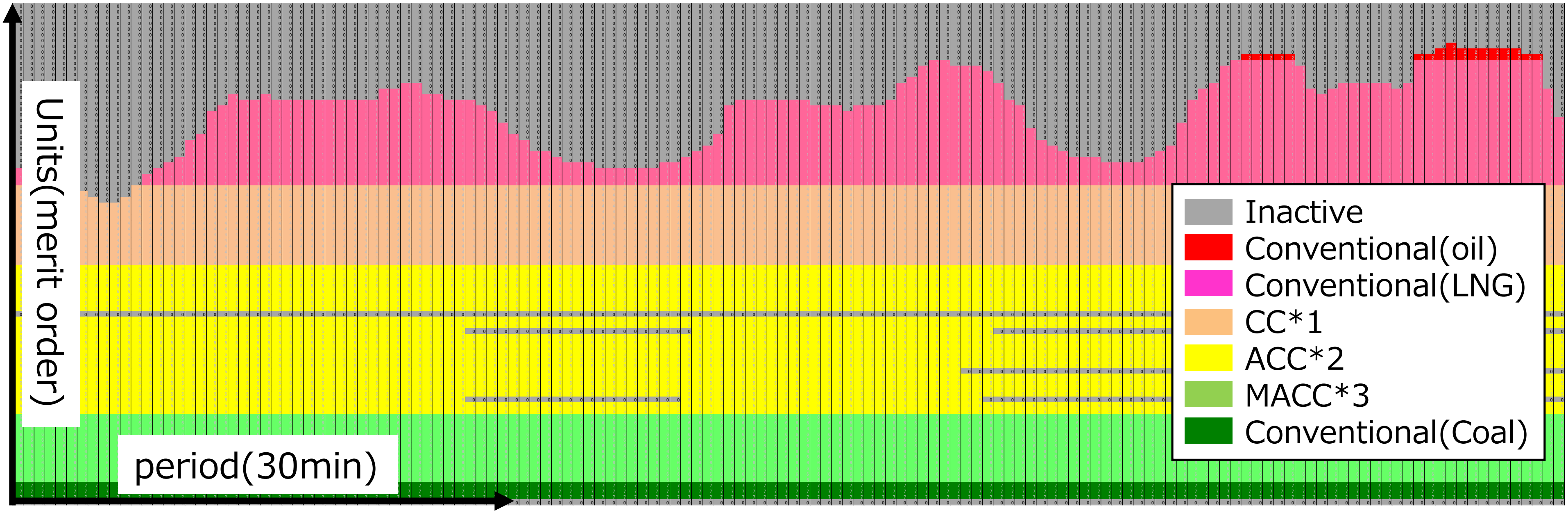


03

Verification and Validation

Verification: Quality of Solution

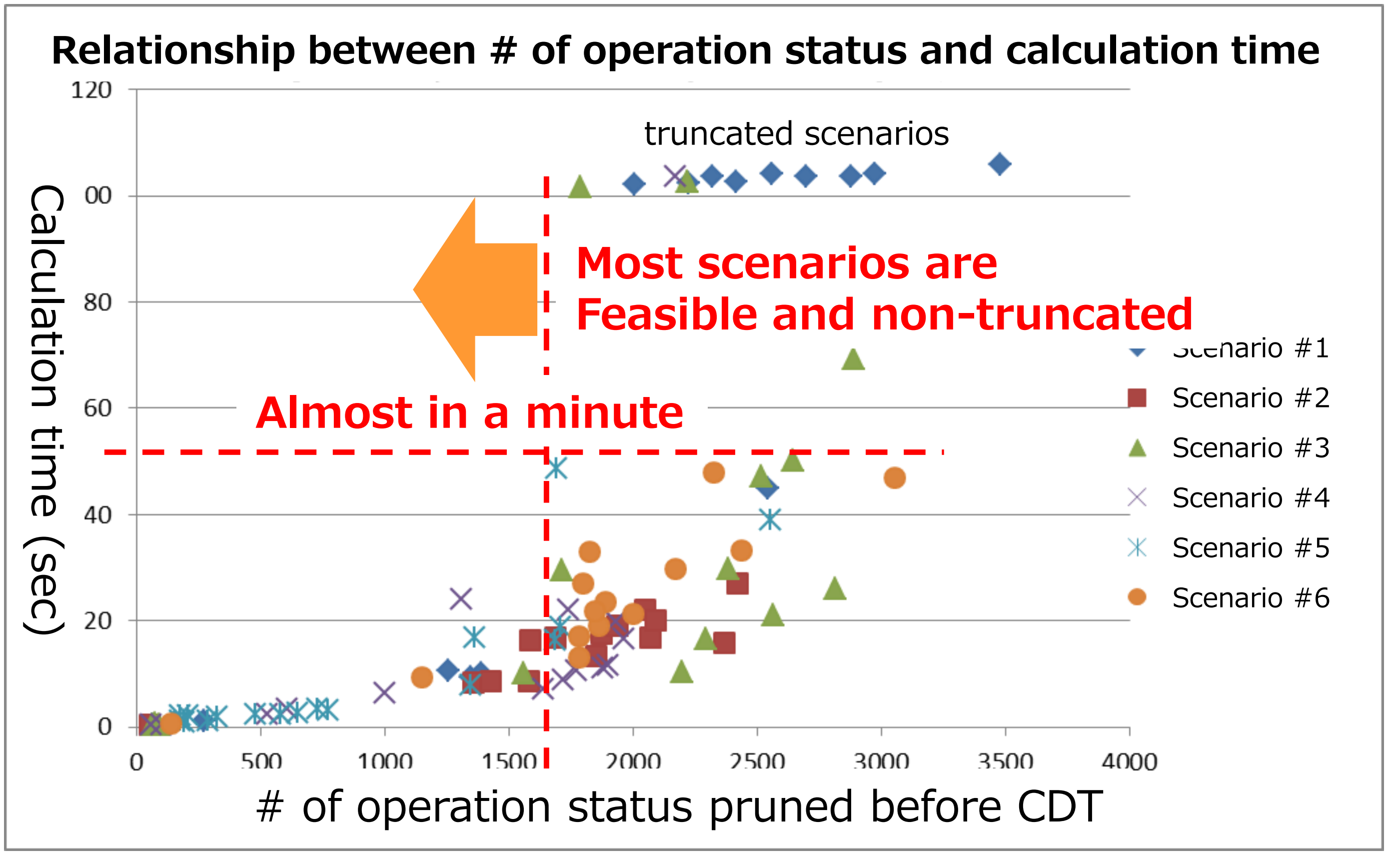
*1: Combined Cycle
*2: Advanced Combined Cycle
*3: More Advanced Combined Cycle



- More than ***500*** scenarios for verification conducted by TEPCO Fuel & Power and Toshiba.
  - Viability: All constraints satisfied? No unusual behaviors of unit?
  - Flexibility: DSS and/or partial-loaded operation fully adopted?
  - Efficiency: Operation cost lowest enough?

Verification: Calculation Time

- Pruning technique is introduced to reduce calculation time.
- Fine tuning to balance calculation time and feasibility is requisite.



Validation

- TEPCO Fuel & Power started "most economical operation" in April 2016:
  - ***24-hour*** constant monitoring and generation planning of over ***90*** thermal units.
  - using a brand-new scheduling system, based on the **multi-stage optimization** algorithm, developed by Toshiba.

- The system provides power generation plans:
  - with high-viability, and operators can fix the plans quickly and easily.
  - in a very short time, e.g., 1-day plan in ***30sec ~ 3min***.
  - more economical than ever, resulting in a fuel cost saving of ***0.48%*** that amounted to ***dozens of €M/year***.

Conclusion

- Toshiba developed a brand-new scheduling system of thermal unit generation planning, based on the multi-stage optimization algorithm, in pursuit for viability, flexibility and efficiency.

- TEPCO Fuel & Power introduced the system and started “most economical operation” in April 2016, in the course of the market reform in Japan.

- Issues to be addressed in the future are:
  - Extension to the power generation system including thermal units and renewable energies.
  - Optimal strategy of operation considering market transactions.

TOSHIBA

Thank you for your attention!!