ECC Workshop 2016

An outage work planning under the weather uncertainties

(不確定条件下での作業系統計画について)

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Table of Contents

- Overview of the current research (Hiroshima Univ.)
  - Our research works
- Outage works
  - What is the outage work?
- Problems to be appeared under uncertainties
  - Difficulties against weather conditions
- A solution for supporting system (IEEJ paper)
    - Formulation
    - Simulation studies
- Summary

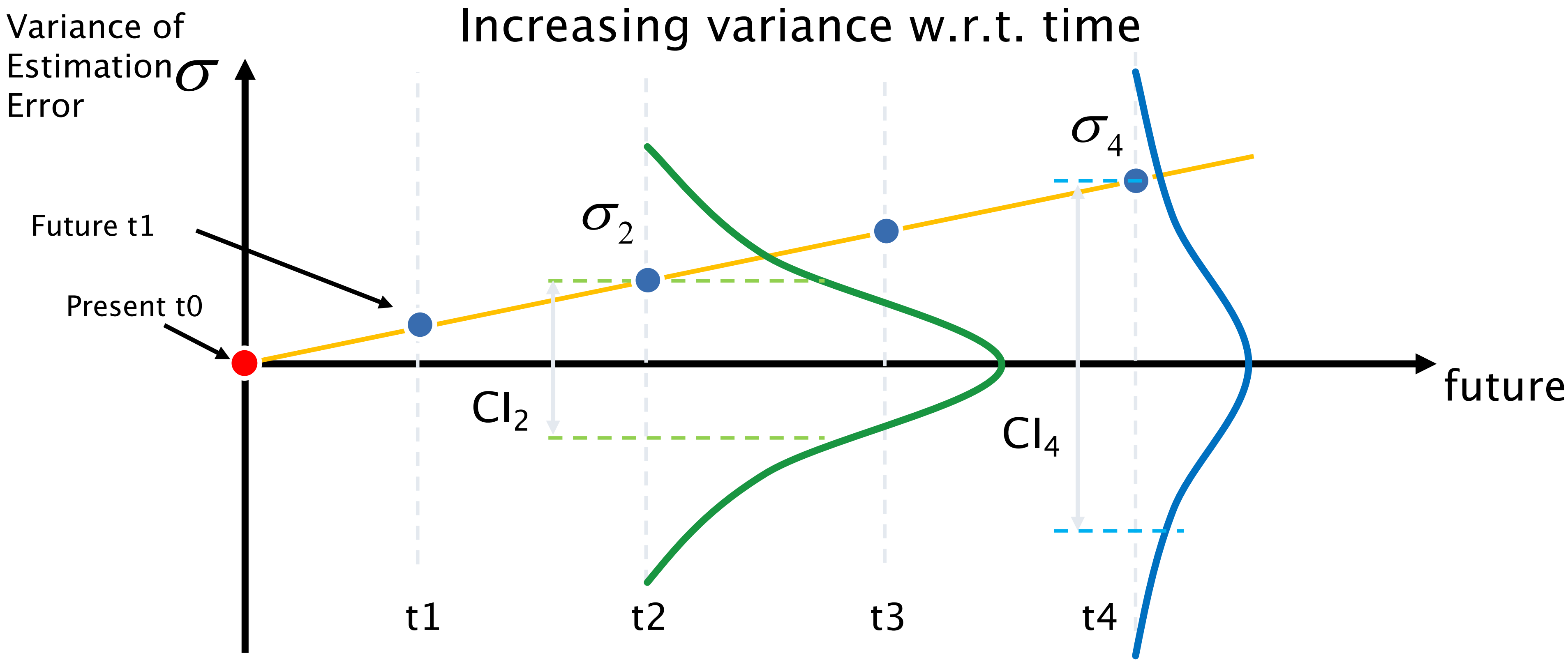
Overview of the current research
(Hiroshima Univ. Team)

Outline of Research Themes (HU)

Fields	Groups	Themes/Keywords
Analysis, Evaluation	Reliability analysis, evaluation (Y, S)	Robust stability & security, Feasible region, Uncertainty, PV + Battery
	Transient stability analysis (Y, S)	Critical Trajectory, Computation efficiency, unbalanced fault
	Reactive power evaluation (Y, S)	Deregulation, "Q" pricing, OPF
	EV/PHEV (Z)	Frequency control, Uncertainty, Economic value evaluation
	Frequency control analysis (Y)	Performance indices for LFC
Operation, Control	Load forecasting (Z) Renewable-energy forecasting (Y, S)	Min/Max Load forecast, continuous-updating regression PV/WT output prediction, Uncertainty
	Dynamic ELD / Stochastic OPF (Y, S)	Dynamic Economic Load Dispatch including PV/WT, Uncertainty
	System stabilizing control (Z)	PSS, Robust control (Uncertainty), Support Vector Machine
	Microgrid operation, control (Y, Z, S)	Demand-Supply Control, Plug-and-Play, Stabilization, Uncertainty
	Autonomous distributed control (Y, Z)	Voltage control for distribution systems, PV, Multi-agent system, Uncertainty
	Power electronics application (Y, Z, S) Inverter Design (Y, S) FACTS Controller Design (Y)	Quasi-synchronizing power invertors, FACTS design
Planning, Optimization	OPF (O, Y) Optimal FACTS allocation (Y)	OPF for distribution system, Security-constrained OPF (SCOPF) Cost minimization, Load shedding, Voltage stability and Security
	Outage-work planning (Z, O)	PV, Support system, Uncertainty
	Unit Commitment with RE (Y, S) Operation Planning	Including batteries, PV, forecast error, Uncertainty

(Y): Yorino, (Z): Zoka, (S): Sasaki, (O): Outside

Treatment of Uncertainty



Power System Security Analysis, Planning, Operation and Control

Co-variance Matrix → Stochastic Power Flow

Confidence Intervals (CI) → Robust Power System Security

Subject (1)

1. Robust Power System Security (RPSS)

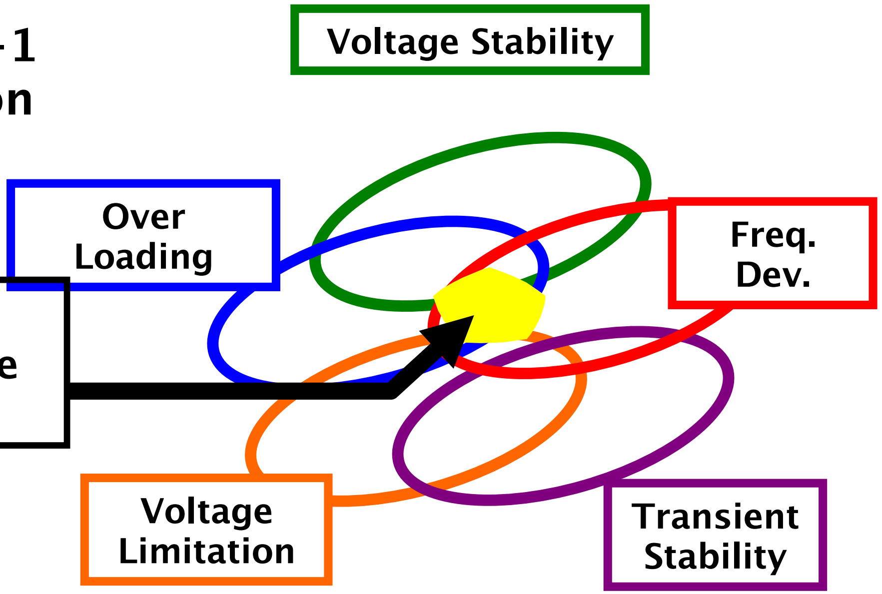
> Robust stability under N-1 contingencies inside CI

Definition of RPSS

Security Analysis with Uncertainty

Conventional N-1 Security Criterion

System must be stable for all single contingencies.



Robust N-1 Security (More strict concept)
where uncertain parameters are allowed to vary in Confidence Intervals

Robust Static Security Region (RSS)

The Worst Case Max & Min inside RSS Region with Uncertainties

Measure of RSS Region

Objective function

Upper bound $\overline{\alpha}_{RSS} = \min_{u,p}\{\max_{u} c^T u\}$

Lower bound $\underline{\alpha}_{RSS} = \max_{u,p}\{\min_{u} c^T u\}$

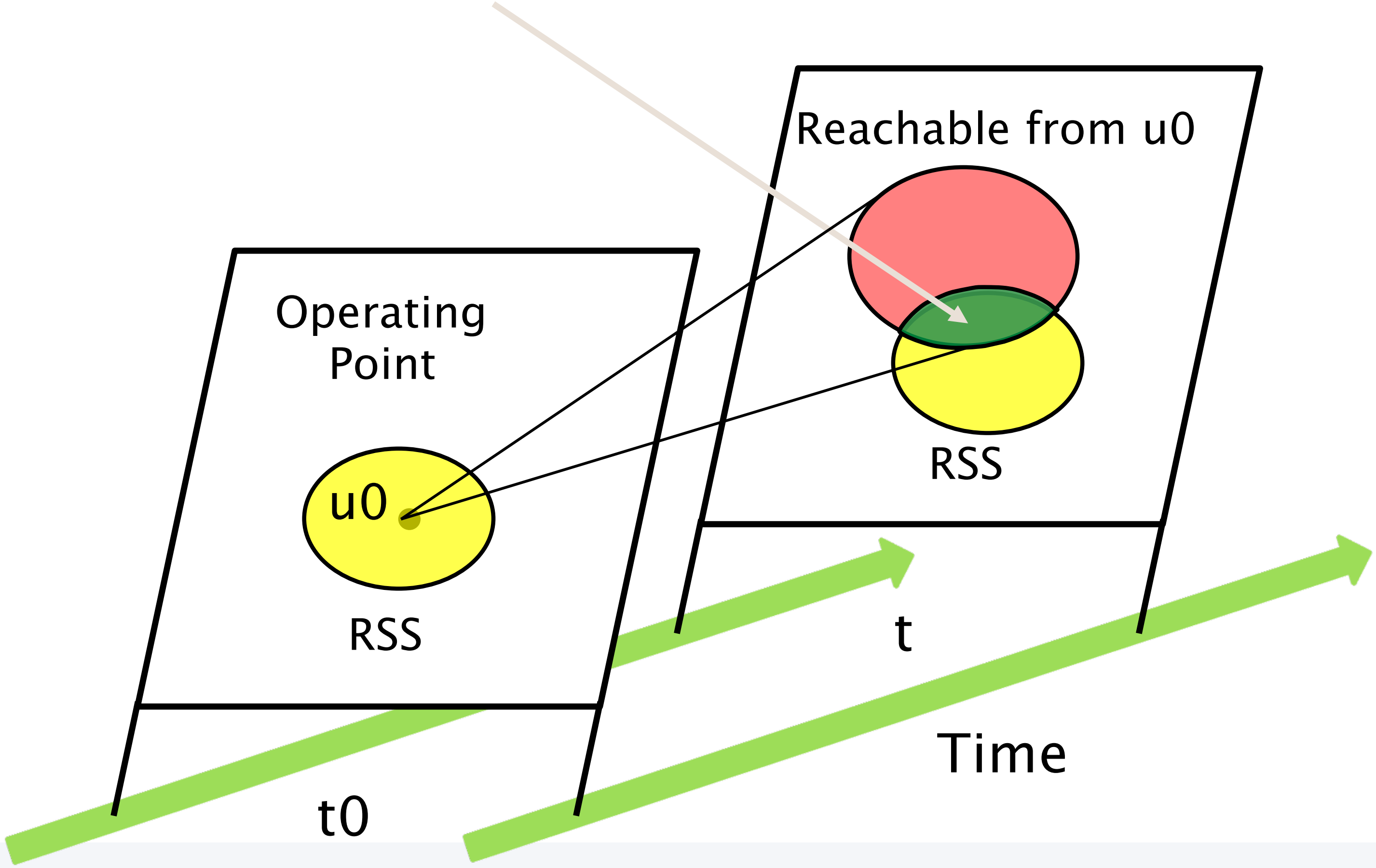
Constraints

- ✓ Power Flow Equations $F^{(n)}(u,p)=0$
- ✓ Constraints $G^{(n)}(u,p) \le 0, \quad n = 0,1,\cdots,N$
- ✓ Control Variables $\underline{u} \le u \le \overline{u}$
- ✓ Uncertainties in CI $\underline{p} \le p \le \overline{p}$

Definition of RRS

Robust Static Security region (RSS)

Robust Dynamically Reachable Security region (RRS)
RRS : (RSS) + (Ramp Rate Constraints of u)

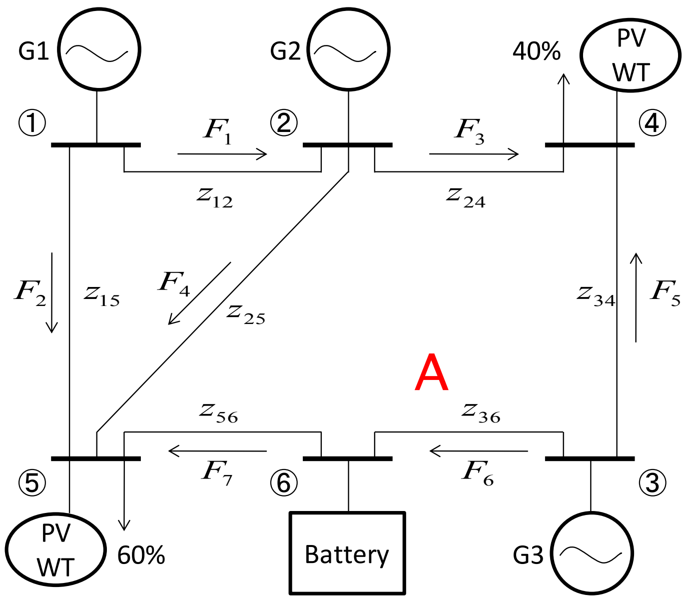


Robust Dynamic Analysis Example

- Controllable parameter
  - Generator outputs u=[G1, G2, G3, S]'
- Uncertainties
  - CI for RE generations p=[RE1, RE2]'
- Constraints for RRS : Linear
  - Demand and supply balance
  - Generator output limits
  - Power flow equation (DC power flow)
  - Security limits of line flows
  - Generator Ramp Rate Constraints
  - Initial Operating Point at t=t0
- Contingency
  - 1 of 2 Lines Trip at A

- Objective function

$\alpha = c^T u$: Total Generation



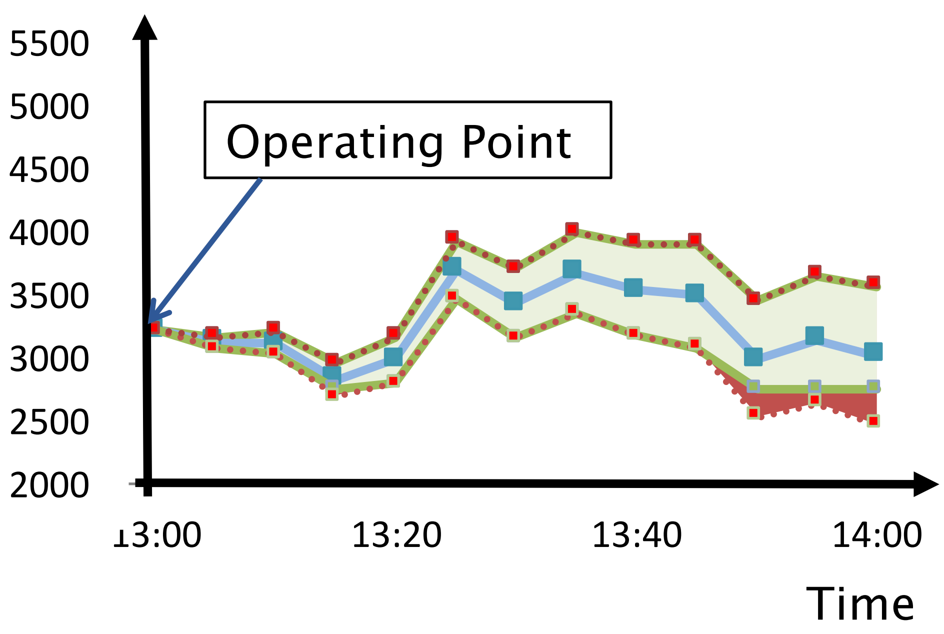
Test System

Results of RRS Evaluations

RRS analysis at 13:00 for 1 hour ahead

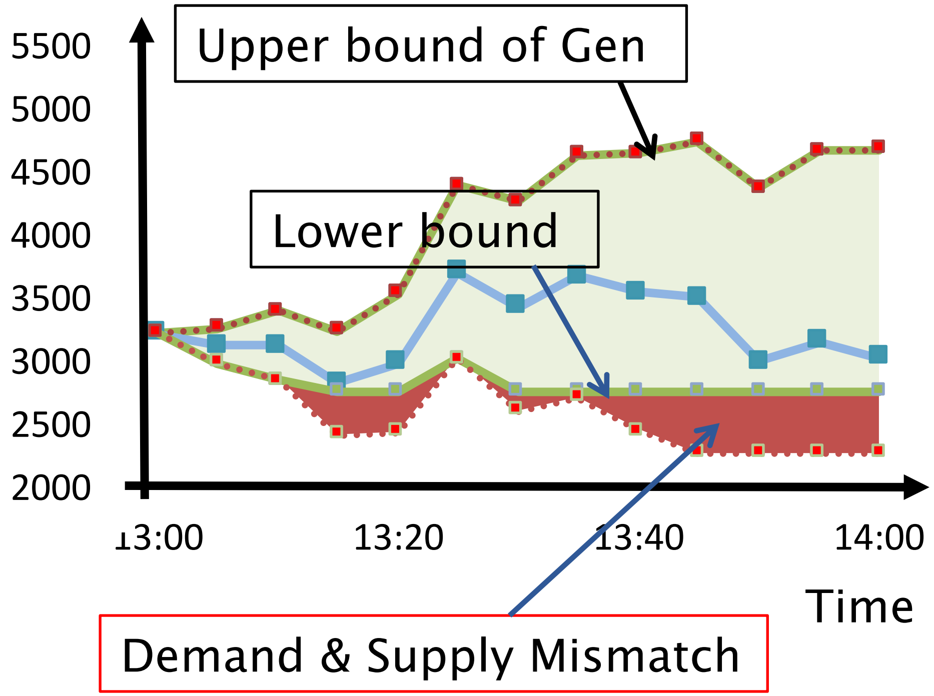
$c^T = [\ 1\ 1\ \ldots 1]$
$c^T u = Total\ Generation$

Total Thermal Generation



Case 1

Total Thermal Generation



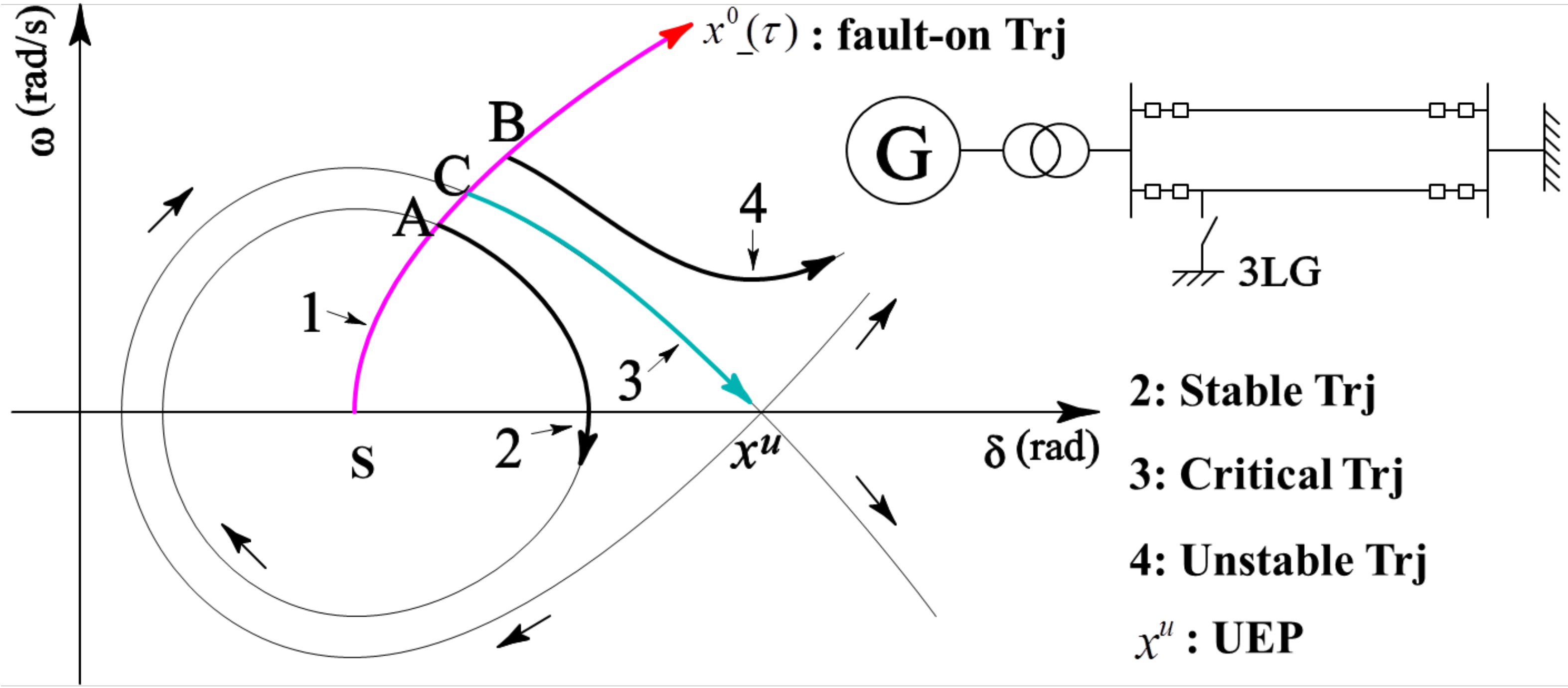
Case 2

Subject (2)

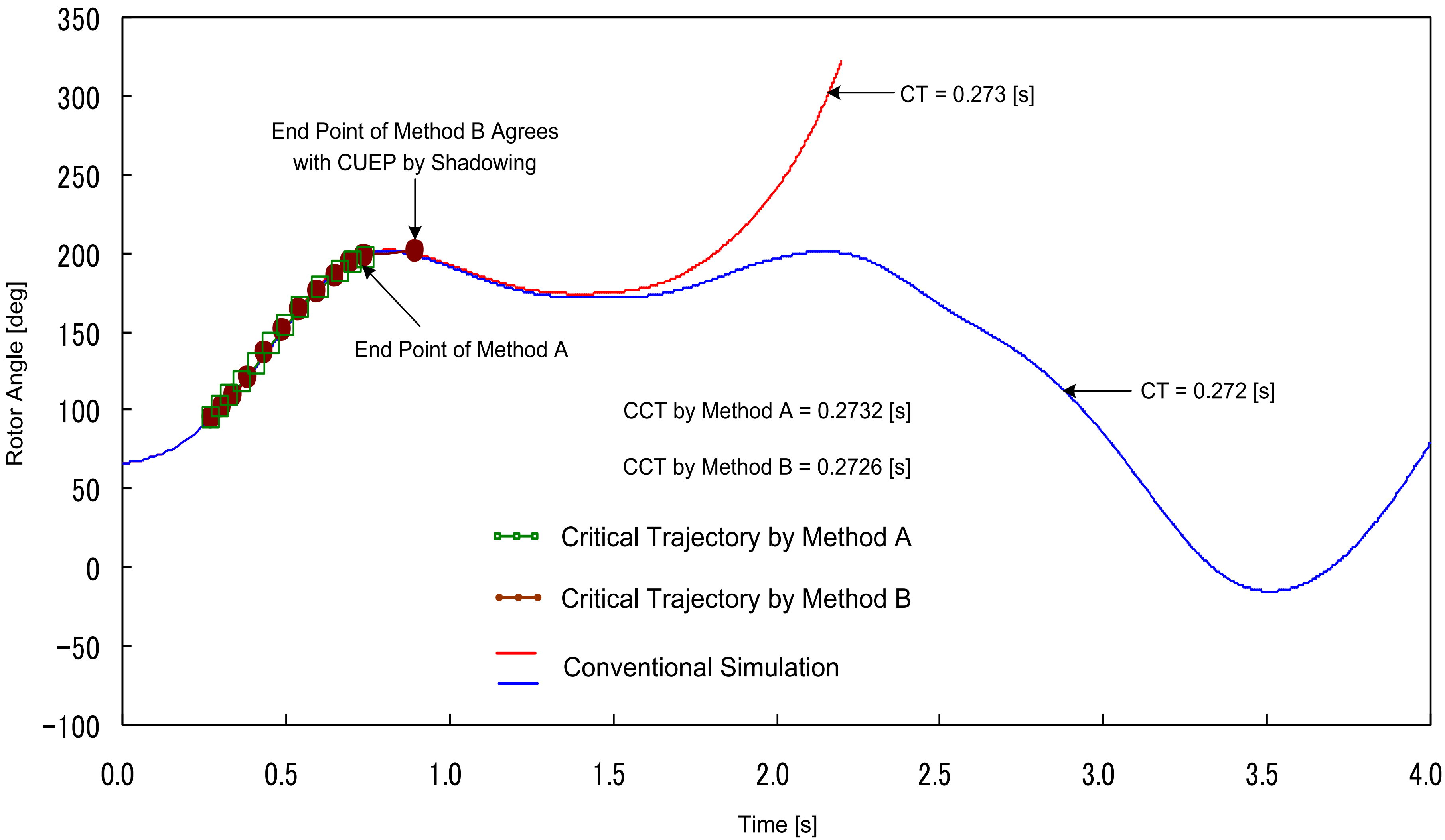
Transient Stability Analysis

- Critical Trajectory Method

Fast Stability Analysis

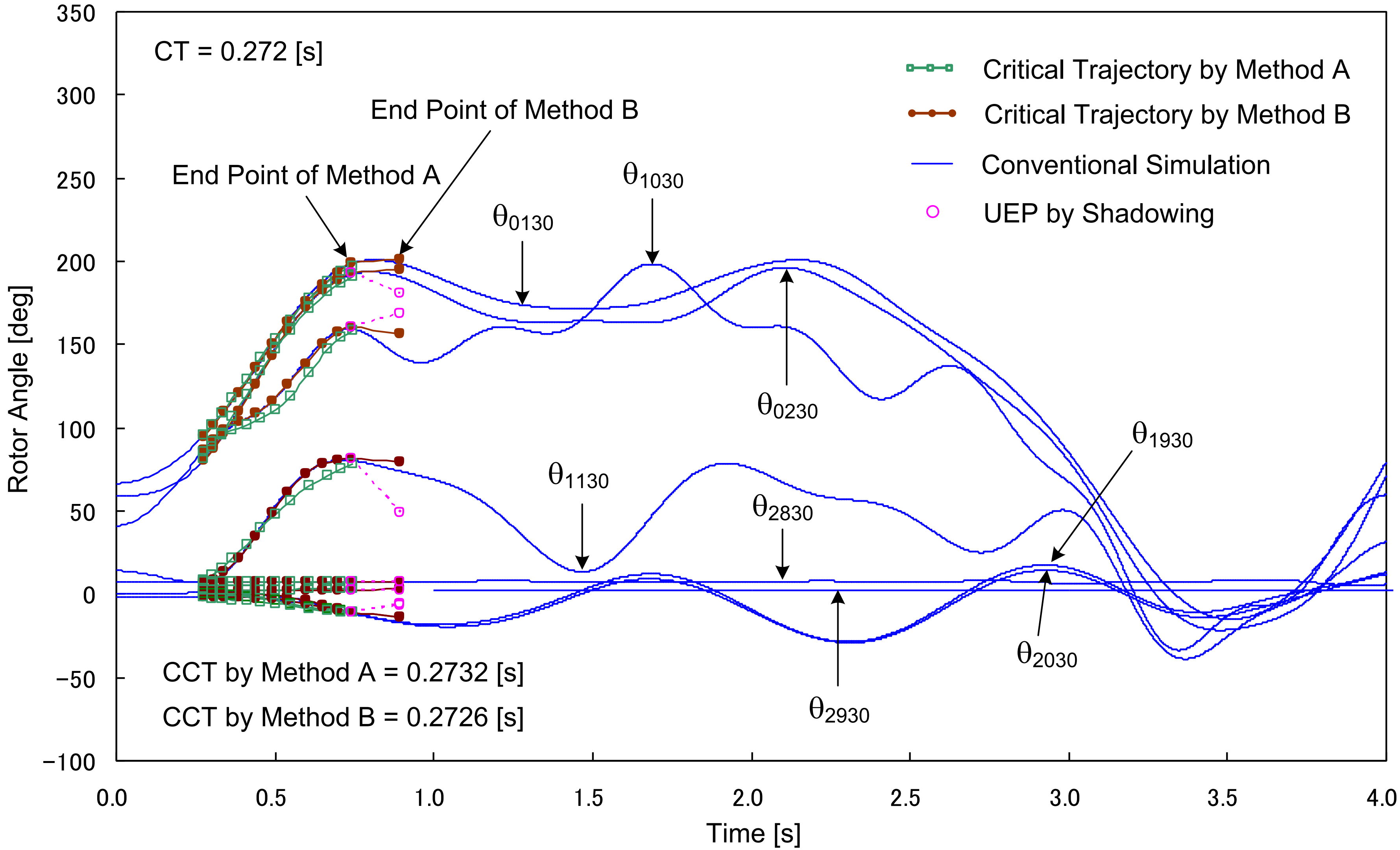


Critical waveform by methods A & B compared with conventional simulation method



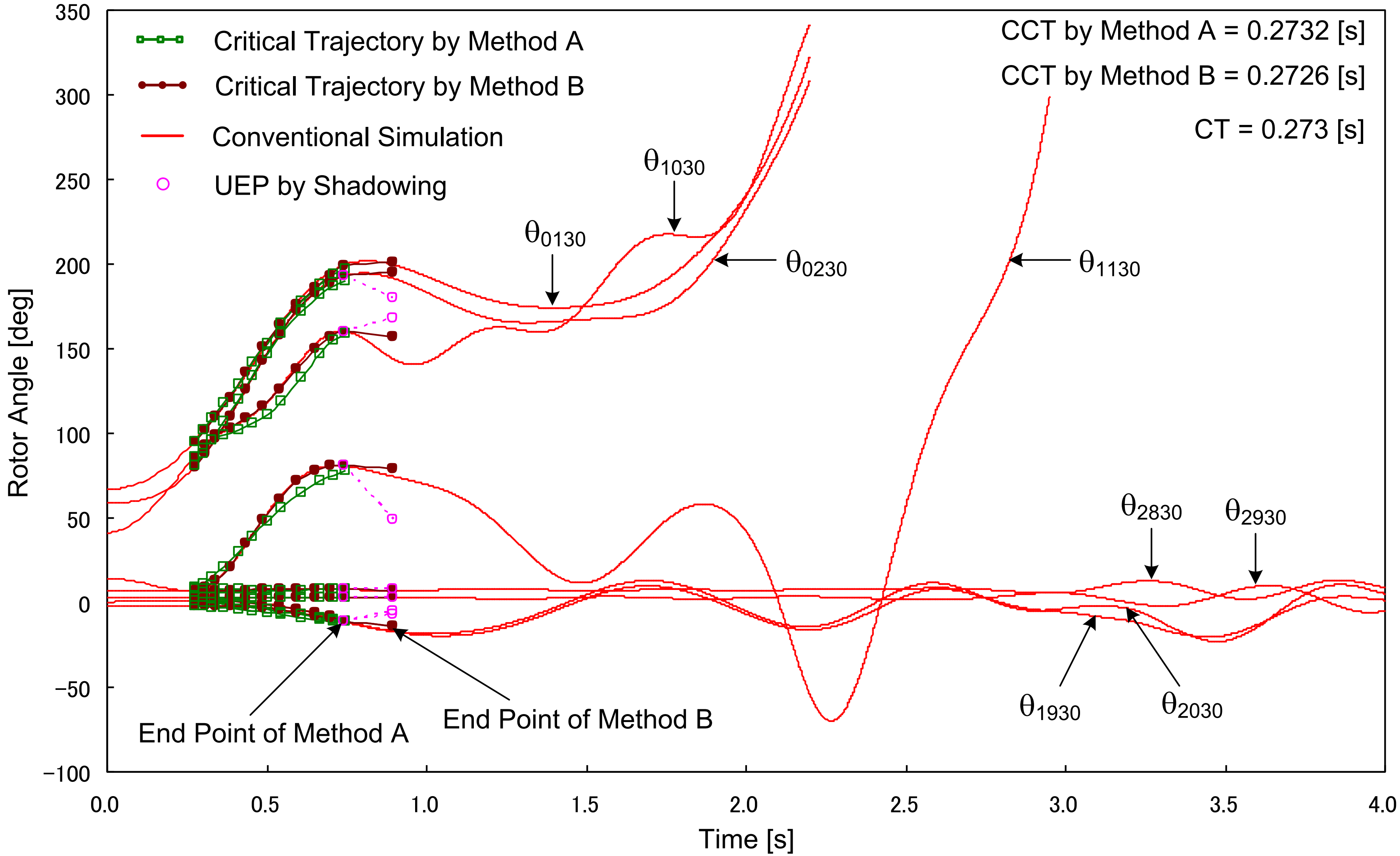
Rotor angle of generator 1 for fault at point G

Critical waveform by methods A & B compared with conventional simulation method



Simulation Case for CT =0.272 [s] for fault at point G

Critical waveform by methods A & B compared with conventional simulation method



Simulation case for CT=0.273 [s] for fault at point G

Formulation of Critical Trajectory Method

Variables: CCT, $\varepsilon,\ x^0,\ldots,x^{m+1}$

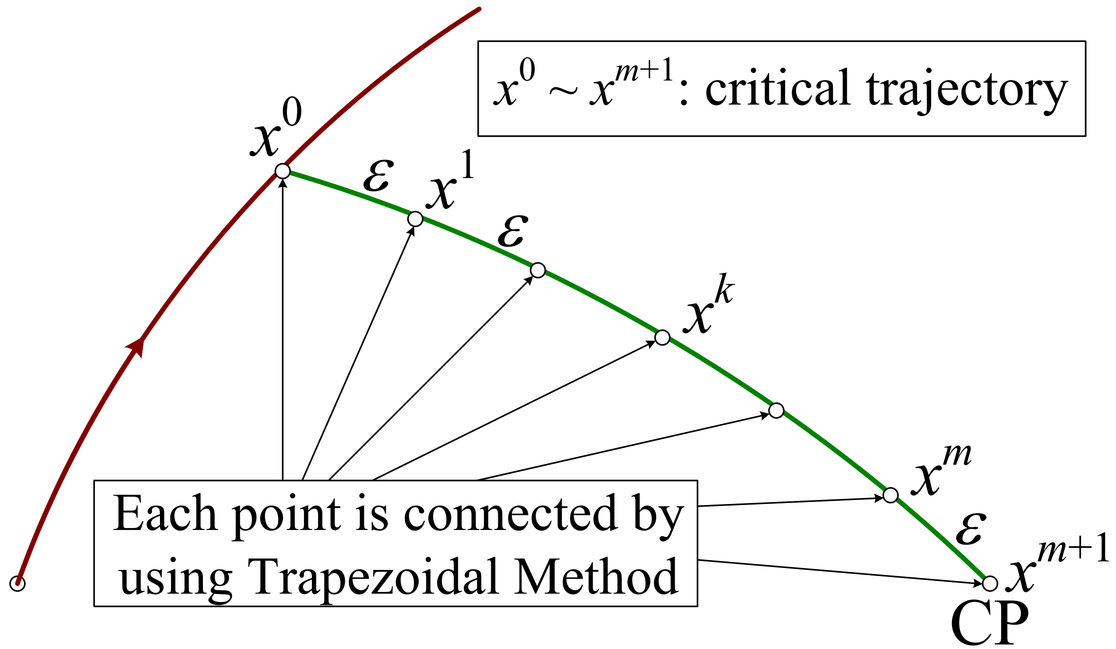
Boundary conditions

>Initial point Condition for x^0

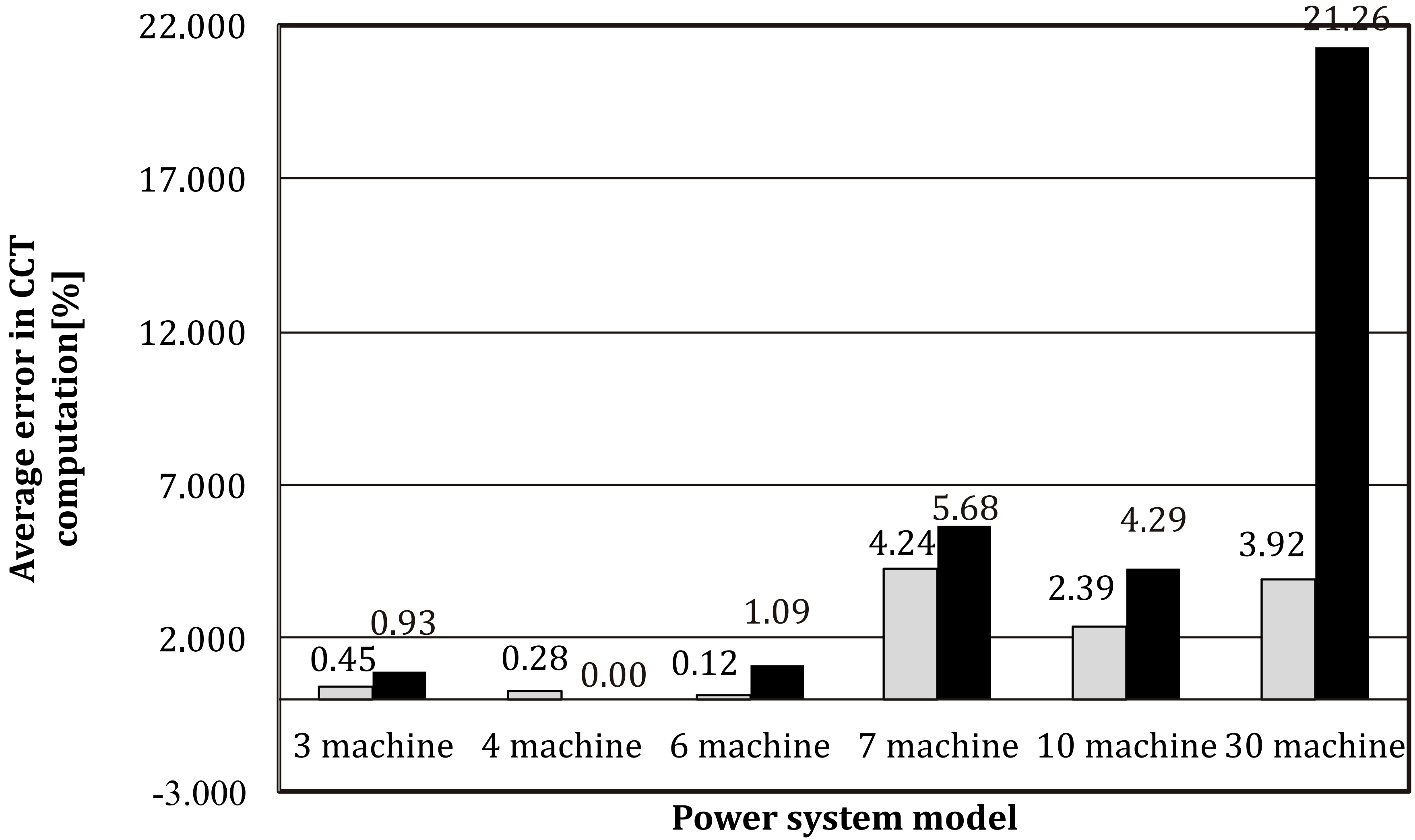
>End point Conditions for x^{m+1}

Trapezoidal Conditions for numerical integration

Number of points (m): specified. (Typically m=10)

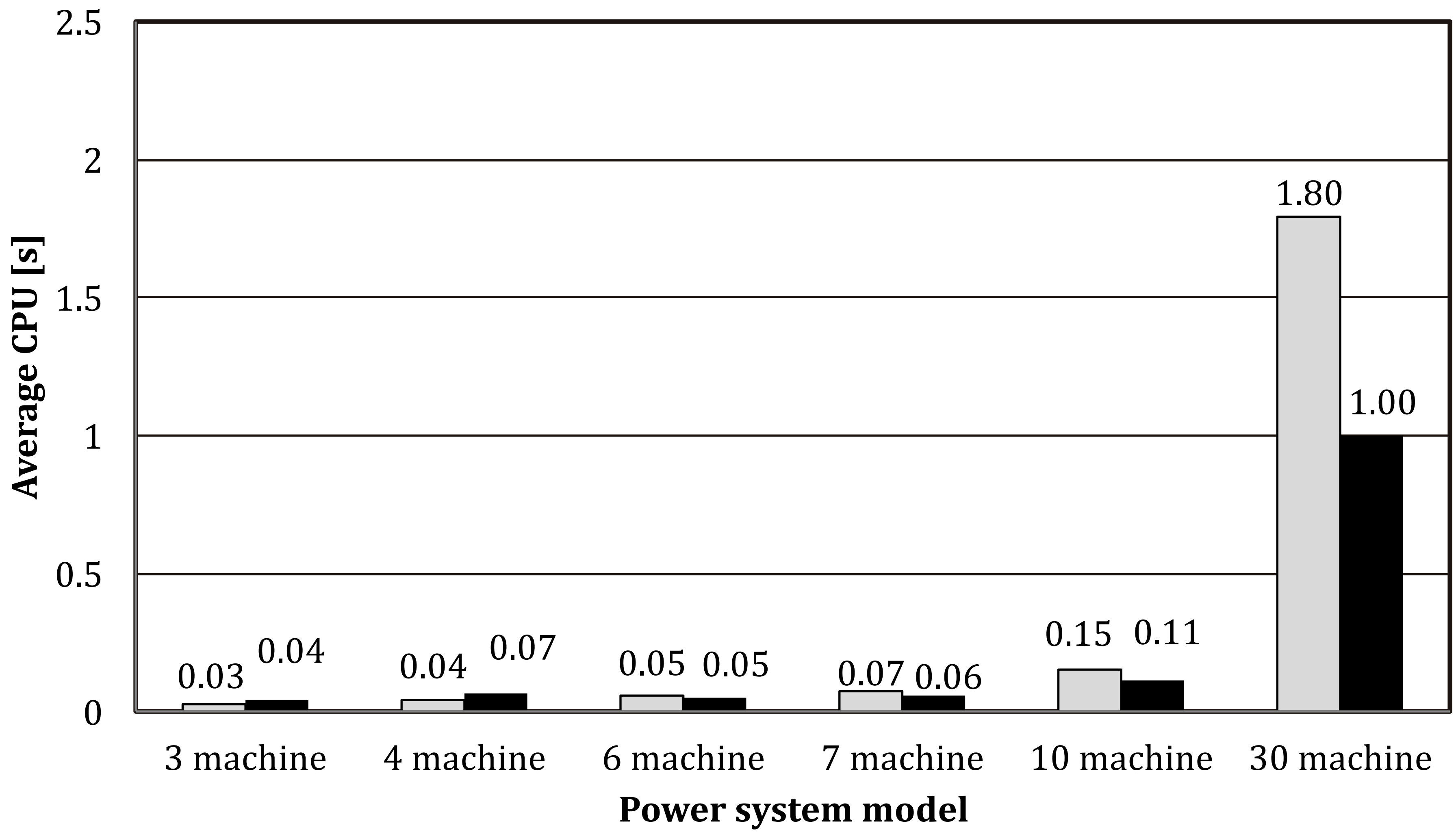


%Errors in CCT



□ New End Condition, ■ Previous End Condition

CPU Time



☐ New End Condition, ■ Previous End Condition

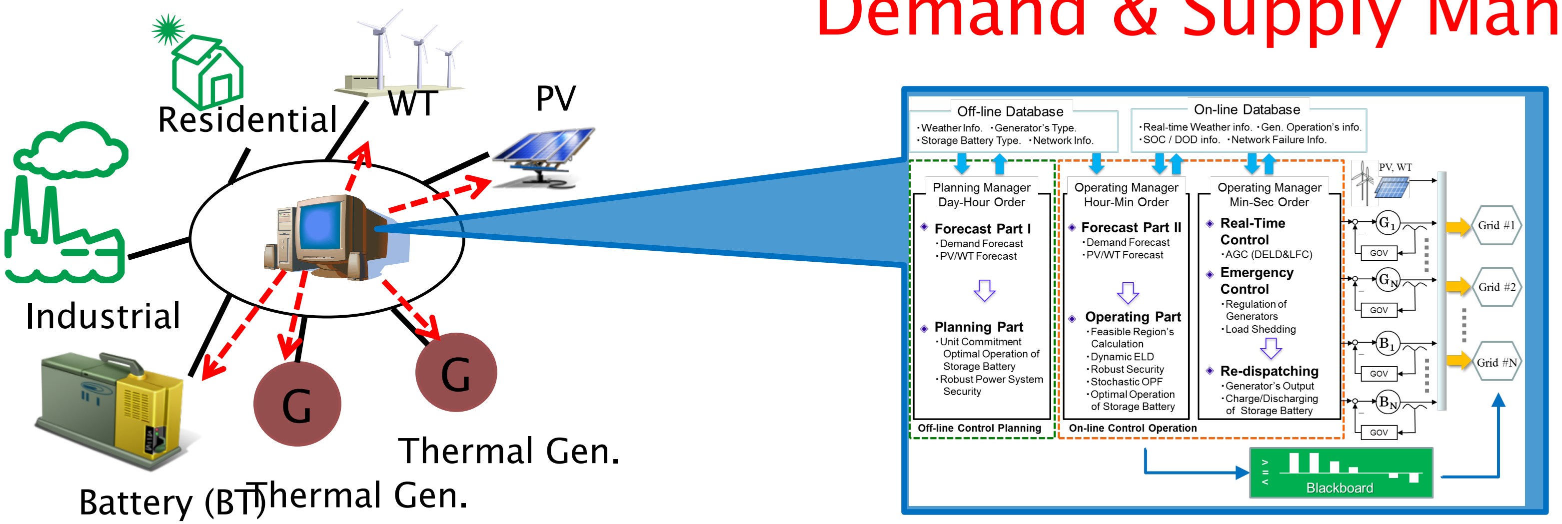
Subject (3)

Demand & Supply Management (Micro-EMS Controller)

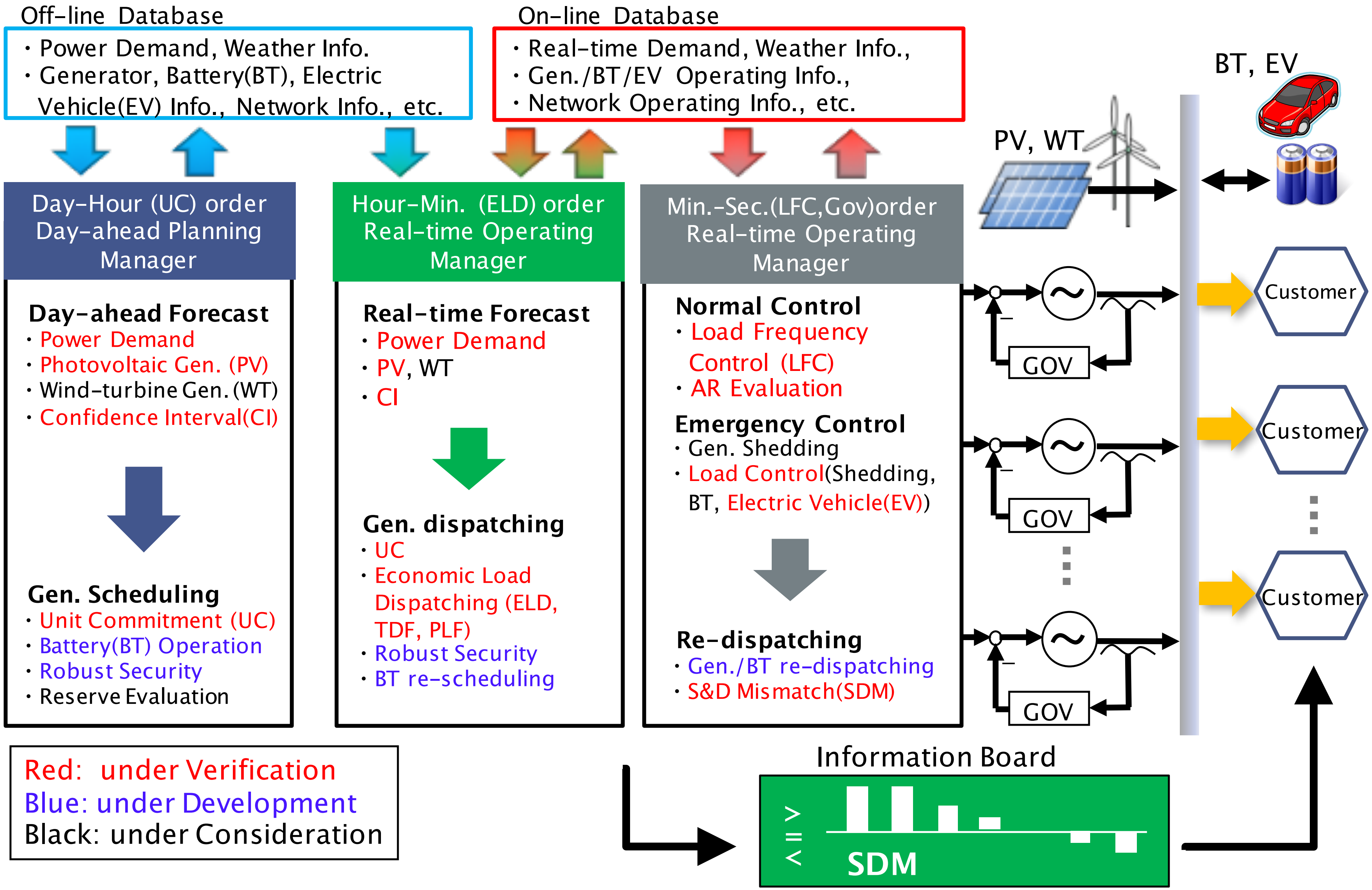
- PV Generation & Load Forecasts
- Operation Planning (Unit Commitment) using BT
- Computation of Dynamic Feasible Region
- Real Time Fast Economic Load Dispatch
- Stochastic Power Flow
- Frequency Control using BT, etc.

System Operation under Uncertainty

Demand & Supply Manager



Micro-EMS Controller



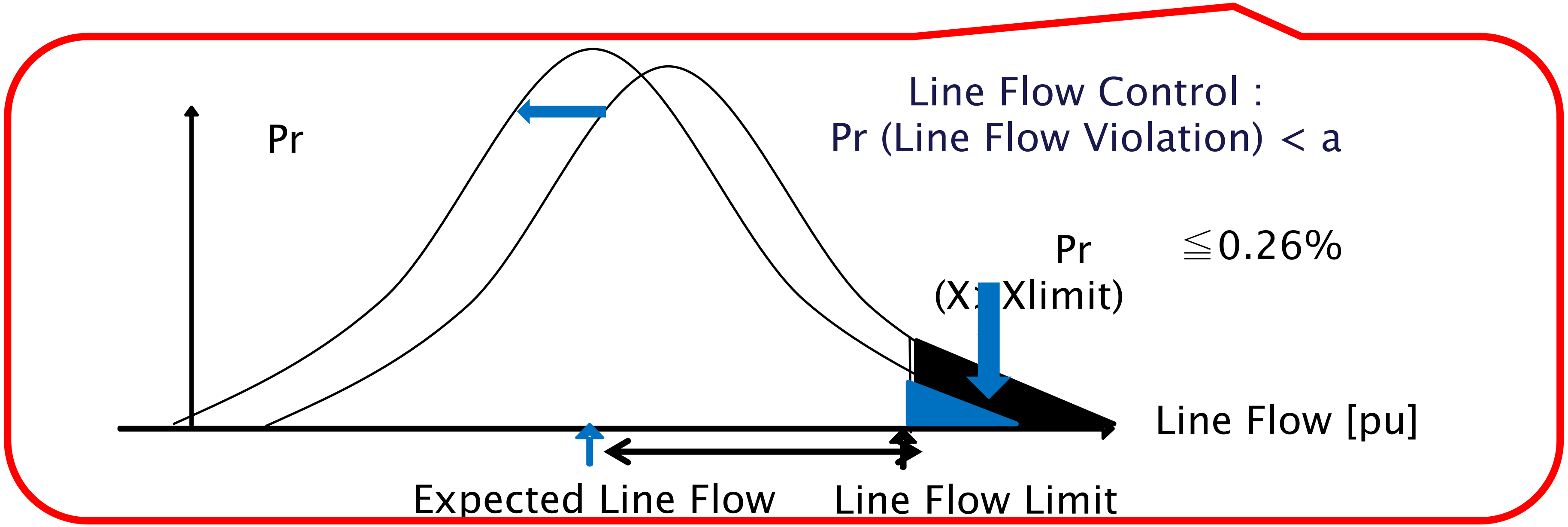
Stochastic Line Flow Model

Linear Line Flow Model

$$\boldsymbol{F} = \boldsymbol{S} \cdot \boldsymbol{P} \quad \Rightarrow \quad Cov[\boldsymbol{F}] = \boldsymbol{S} \cdot Cov[\boldsymbol{P}] \cdot \boldsymbol{S}^T = [\sigma_{ij}]$$

Node: *Cov*(P) → Line Flow: *Cov*(F) → Line Flow Limits

Assumption: Normal distribution of RE Prediction Error



Formulation for Robust Dynamic ELD

QP Problem to be solved every 5 minutes to update 1 hour Generation Schedule (GS).

minimize:

$$f = \sum_{t=t_1}^{T+t_1} f(t), \qquad t = t_1, \cdots, t_1 + T \tag{1}$$

$$f(t) = \sum_{k=1}^{N_n} \left(\frac{a_k}{2} P_k^{\,2}(t) + b_k P_k(t) + c_k \right)$$

subject to:

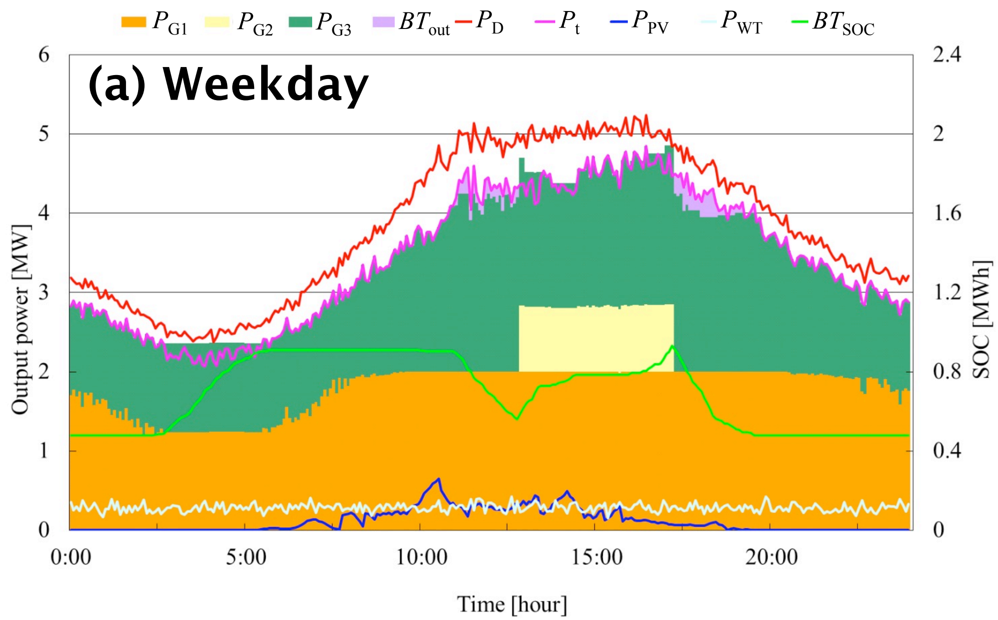
$$\sum_{k=1}^{N_n} P_{Gk}(t) = \sum_{k=1}^{N_n} E(P_{Dk}(t)), \qquad \text{D-S Balance} \tag{2}$$

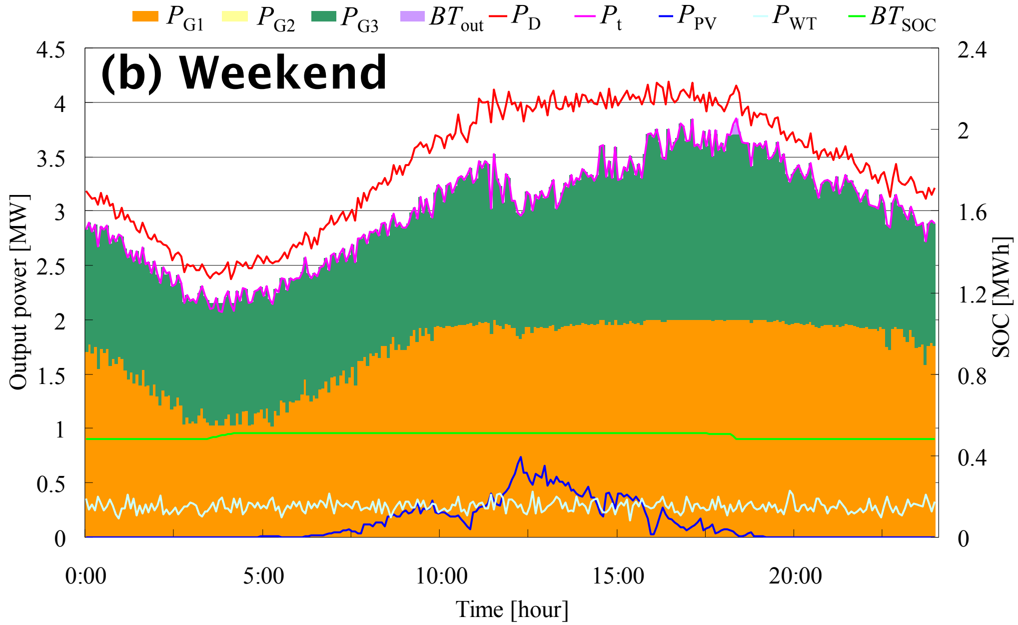
$$\underline{\alpha}_{kt} \le P_{Gk}(t) \le \bar{\alpha}_{kt} \qquad \text{FOR} \tag{3}$$

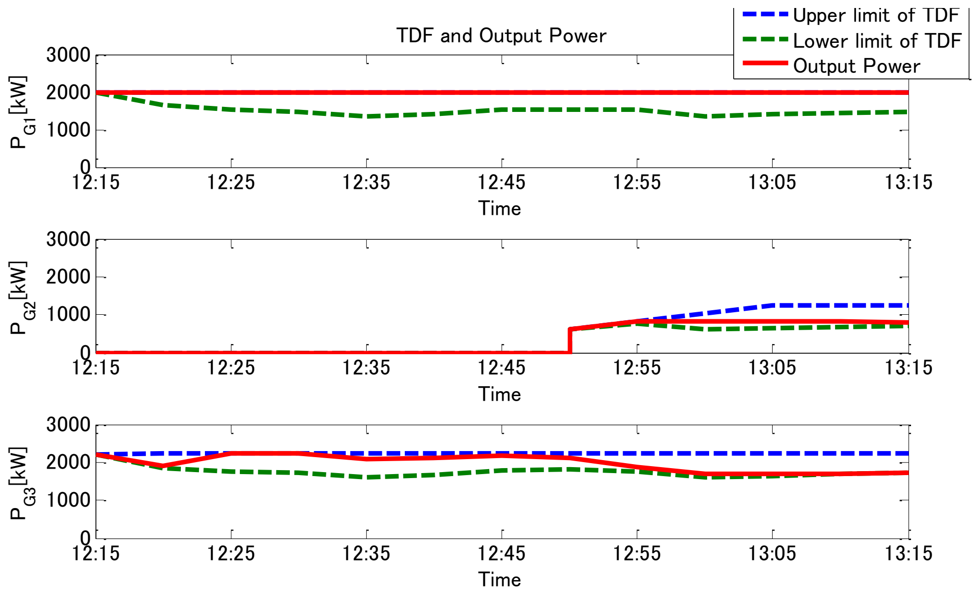
$$-\delta_k \le P_{Gk}(t-1) - P_{Gk}(t) \le \delta_k \qquad \text{Ramp rate} \tag{4}$$

$$-\bar{F}_l + \beta\sigma_{ll} + D_l(t) \le \sum_{j=1}^{N_n} S_{lj} P_{Gj}(t) \le \bar{F}_l - \beta\sigma_{ll} + D_l(t) \qquad \text{Network} \tag{5}$$

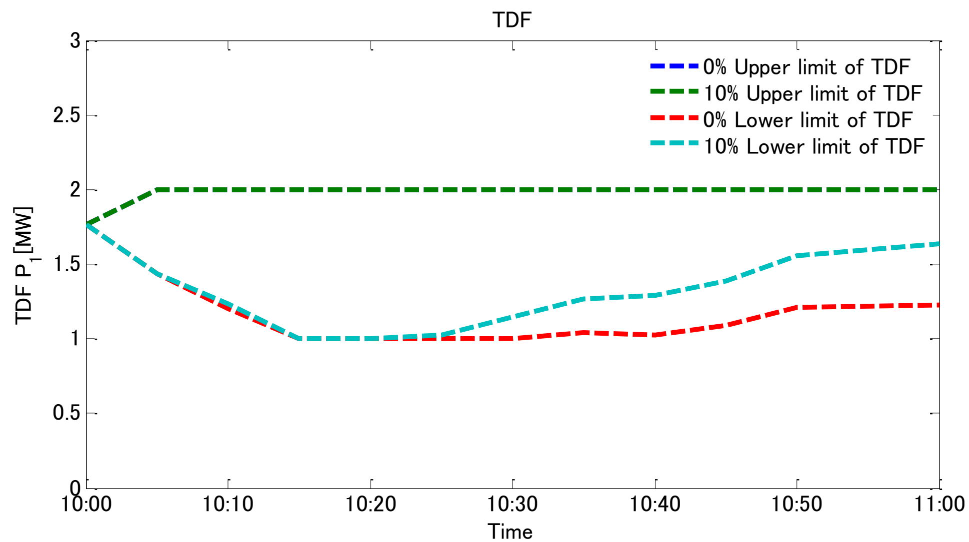
24-hours scheduling results





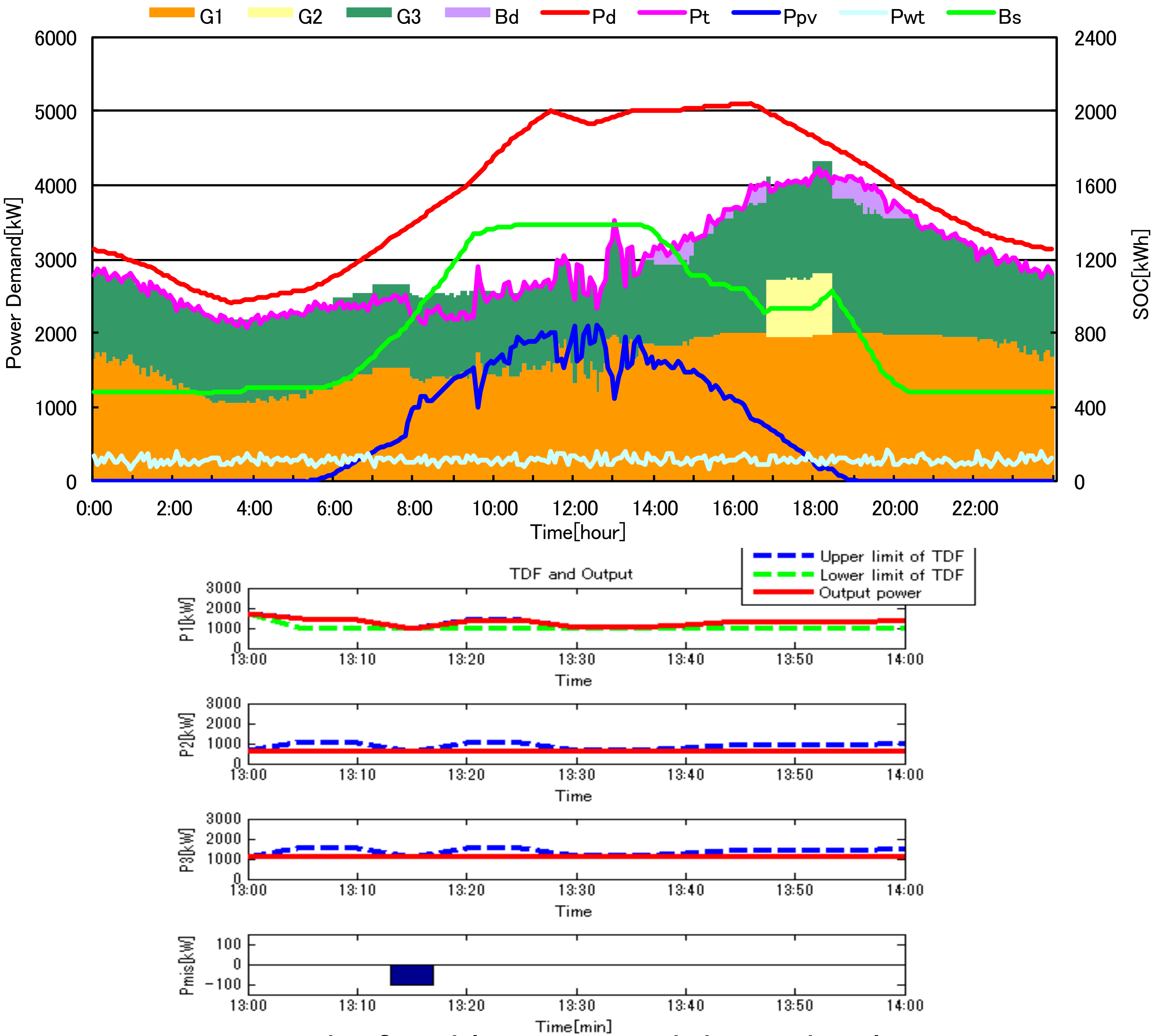


The feasible region and dispatch value on weekday



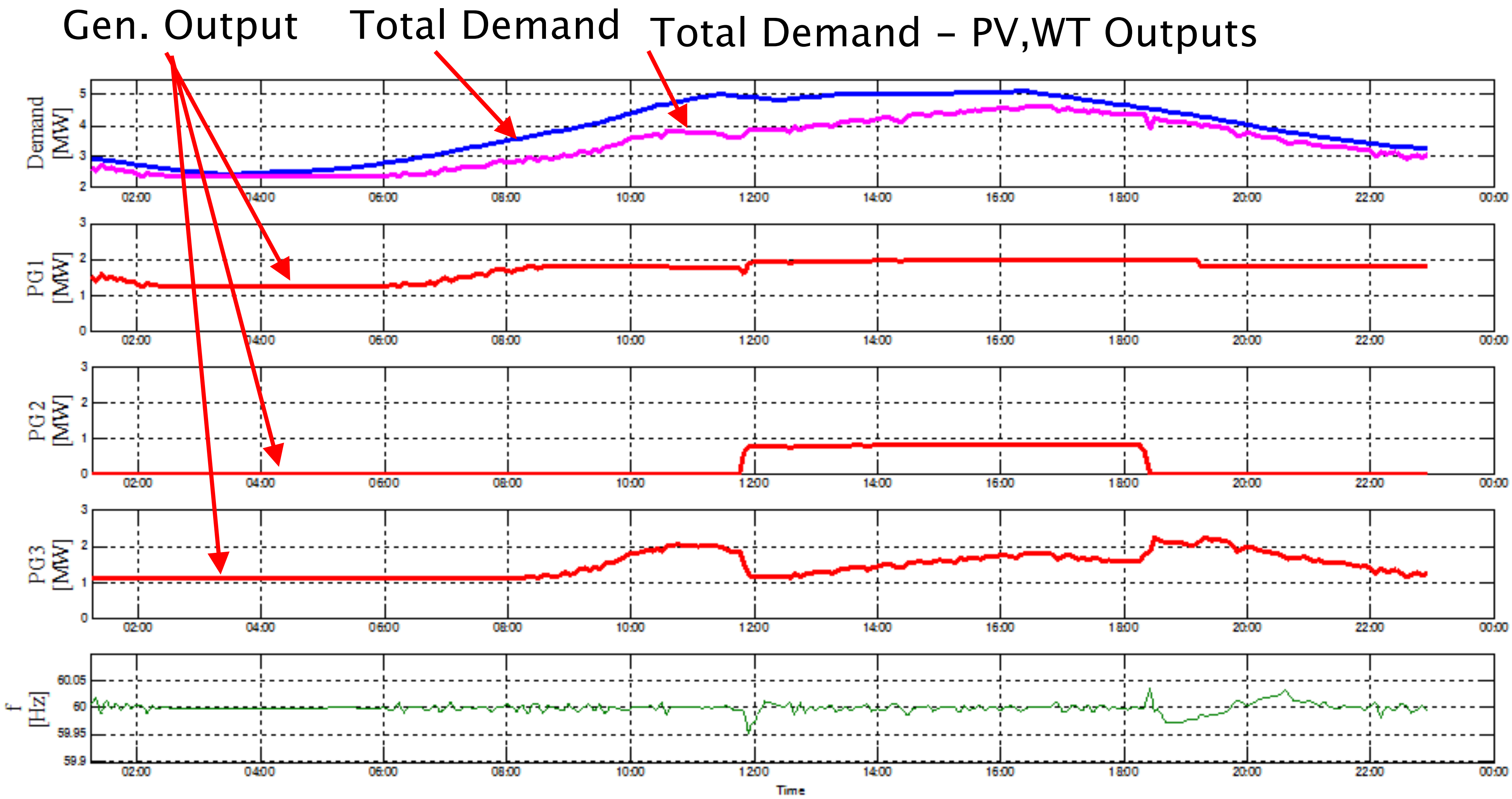
TDF at 10:00 on weekday.

High PV penetration case



The feasible region and dispatch value

Daily Operation Simulation



An outage work planning under the weather uncertainties

IEEJ Transactions on Power and Energy, (to be published)

Outage Work?

- Stable power supply
  - Important mission of power systems
  - Inspection, repair, reinforcement, …
  - → Outage works are necessary
- Outage work planning is to determine…
  - System configuration, work combination, work schedule, etc.
- In this study,
  - Regarded as the problem of system configuration

PV impacts?

Outage work planning must be done one-year ahead based on annual plan.

At planning stage, a maximum load is assumed for work days.

Load forecast + PV output → Outage work plan

However, if the weather is different from the assumed condition…

Load forecast + ~~PV output~~ → ~~Outage work plan~~

Power flow changes depending on PV outputs

IEEJ Technical Report (Analysis Tech.)

- IEEJ Technical Report
  - Hiroshima Univ.
  - Chugoku Electric Power Co.
  - Universities
  - Manufacturers
  - Institutes
  - Gas companies
  - Generation Co.
  - 10 Utilities

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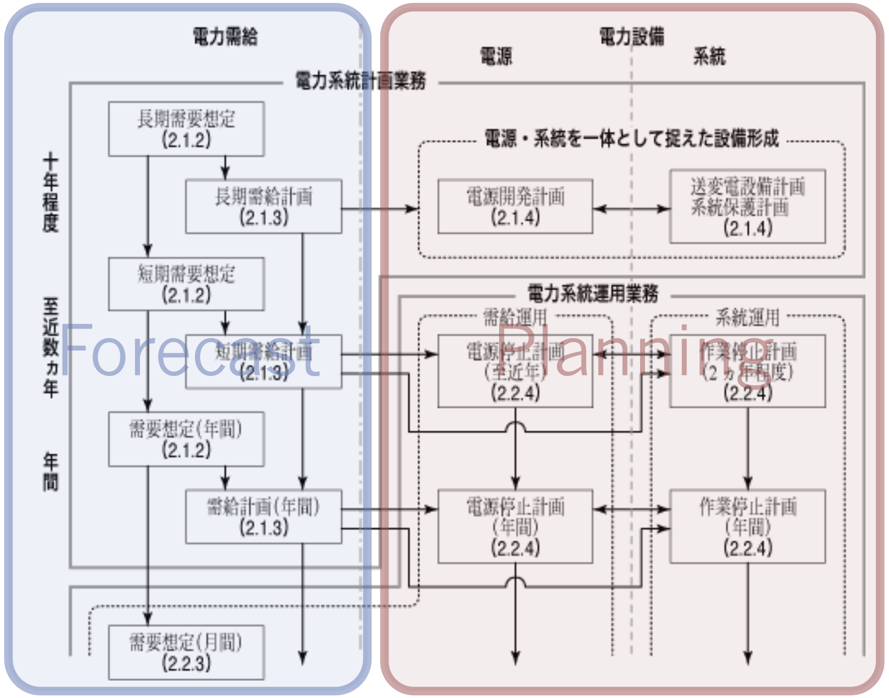
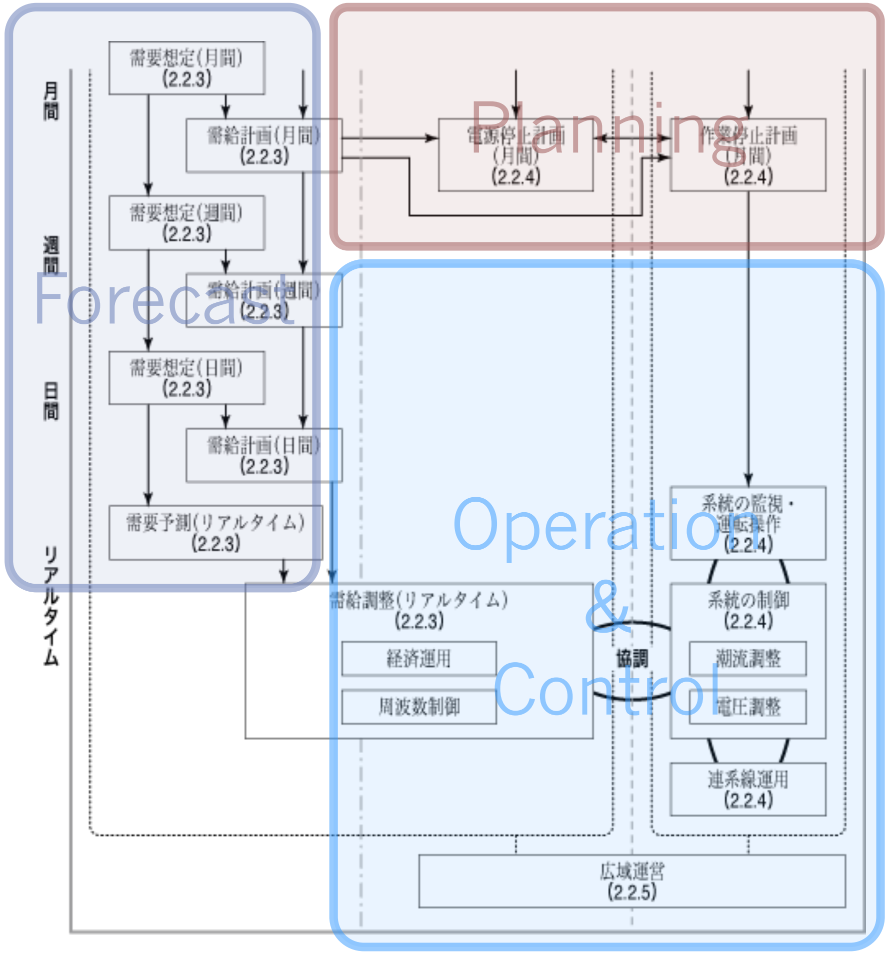
Typical actual workflow of utilities

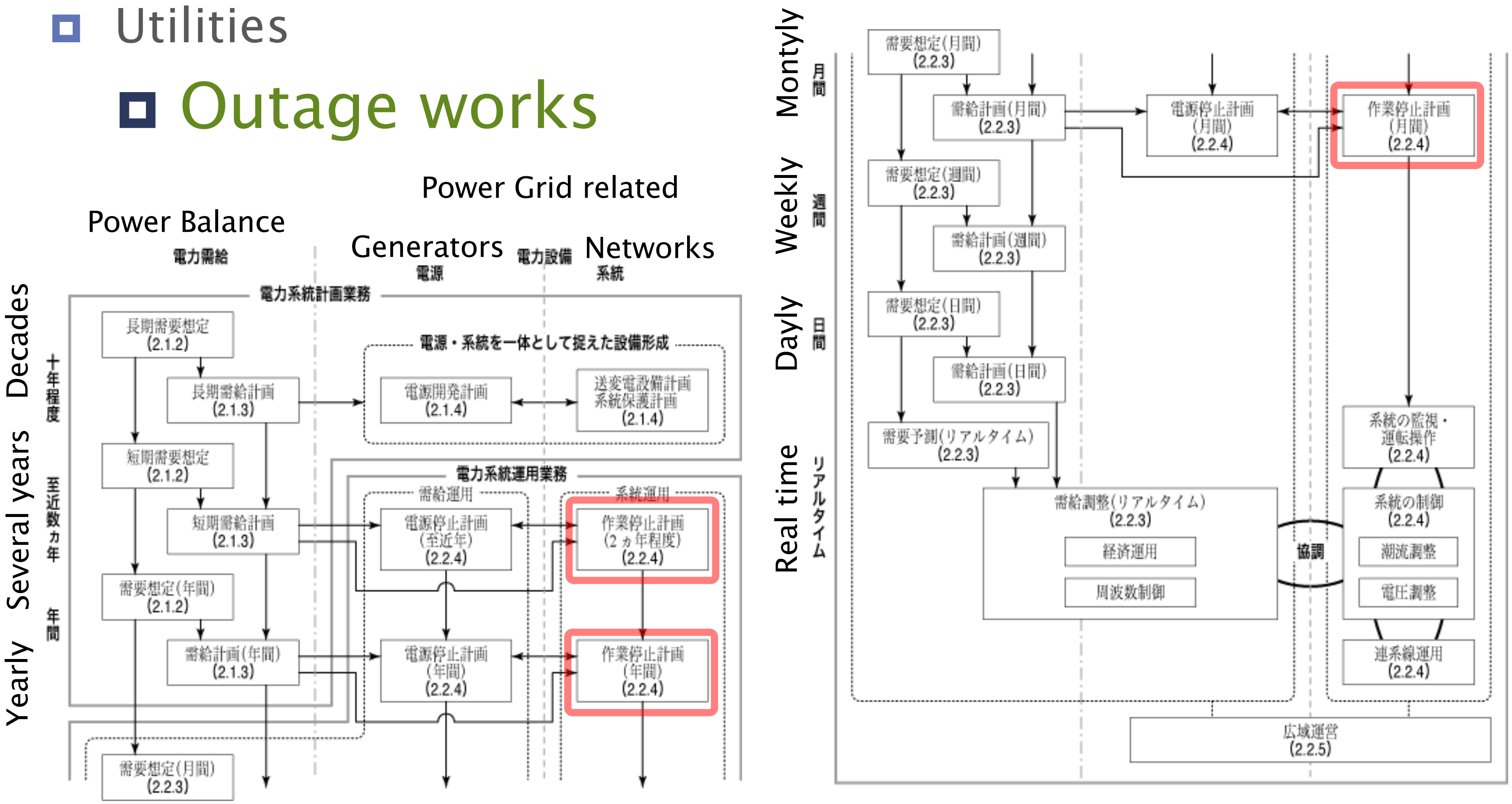
- Utilities
  - Outage works



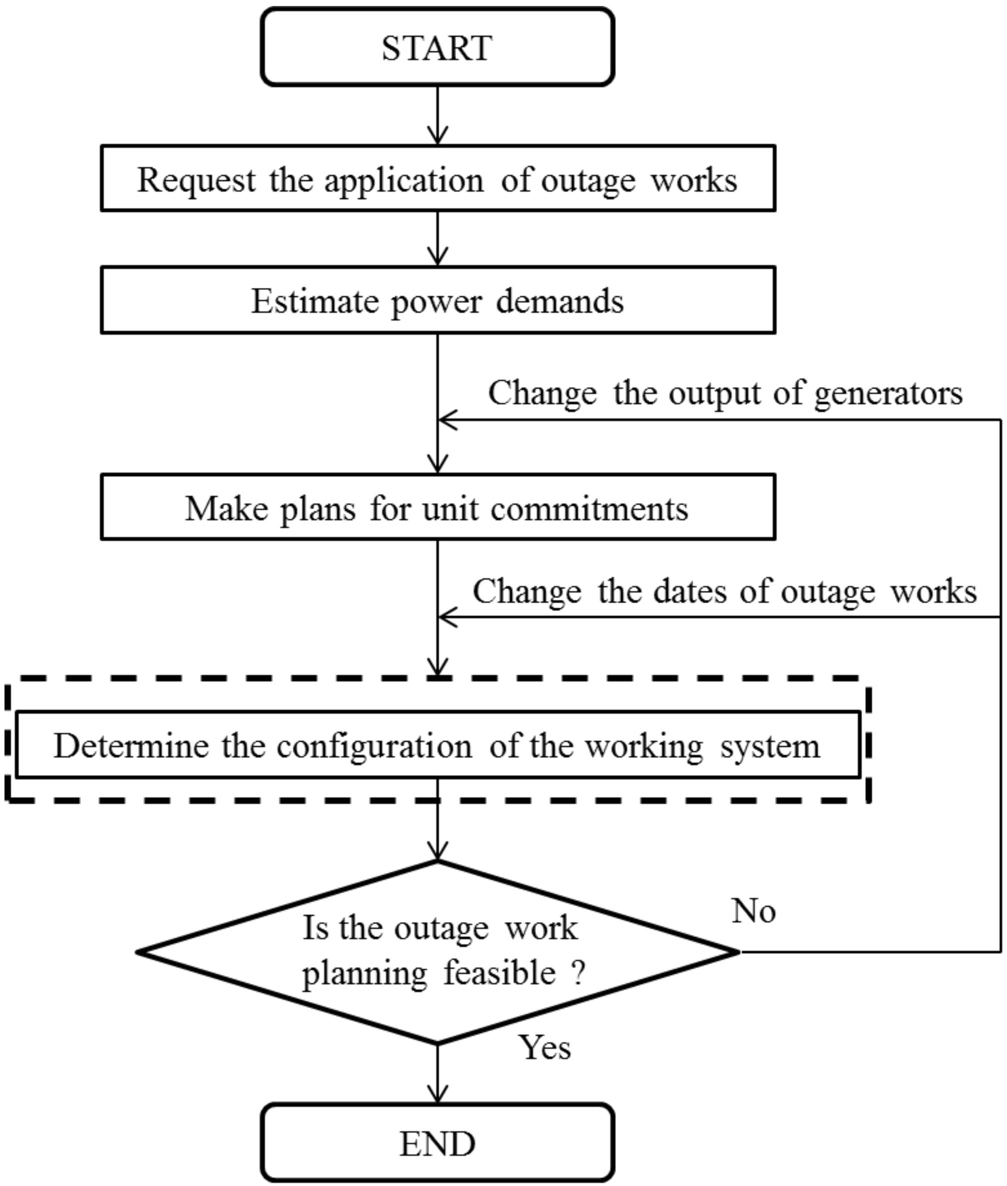


Typical actual workflow of utilities

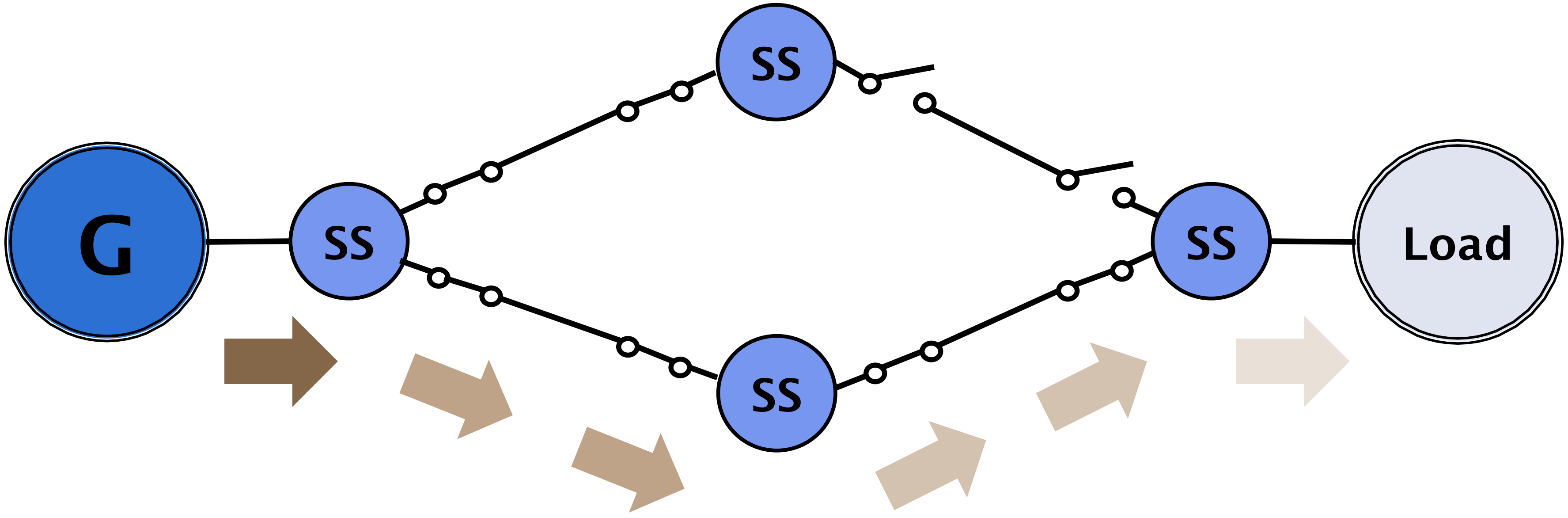
- Utilities
  - Outage works



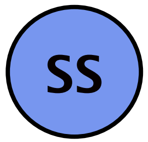
Flowchart (general)



Normal system

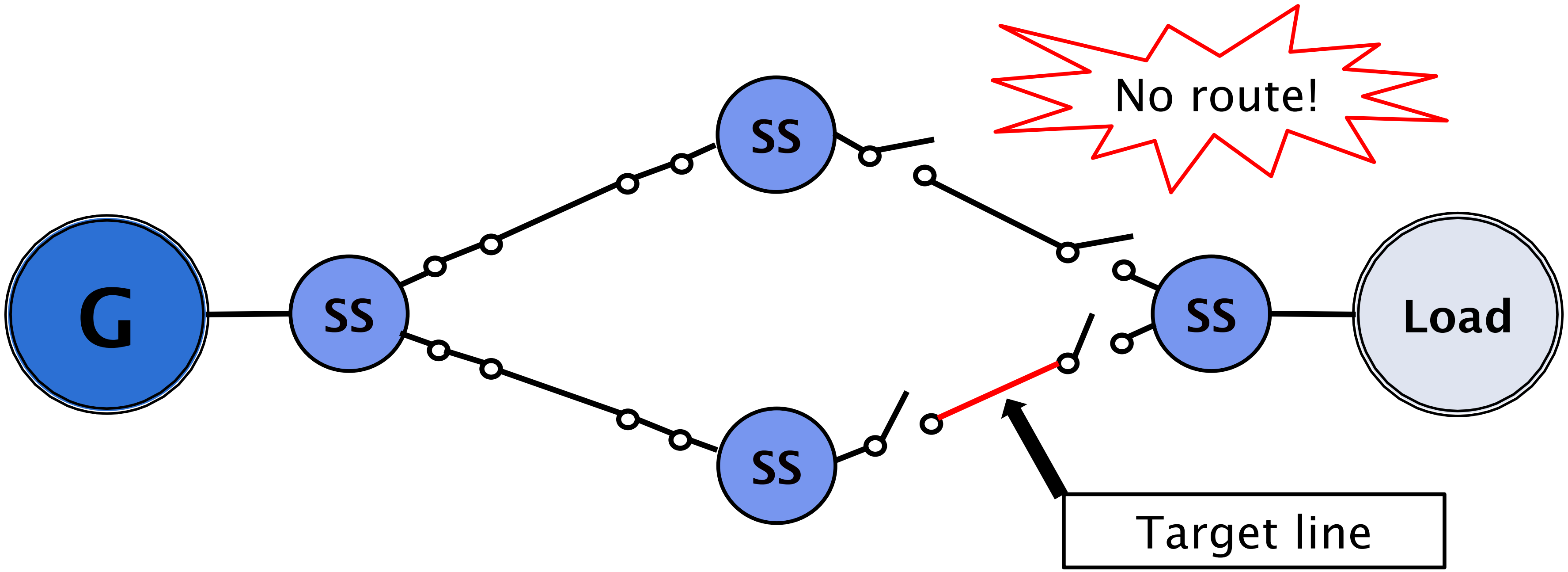


Power supply = Stable



: Substation

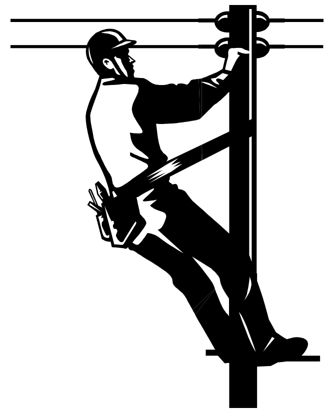
Normal system



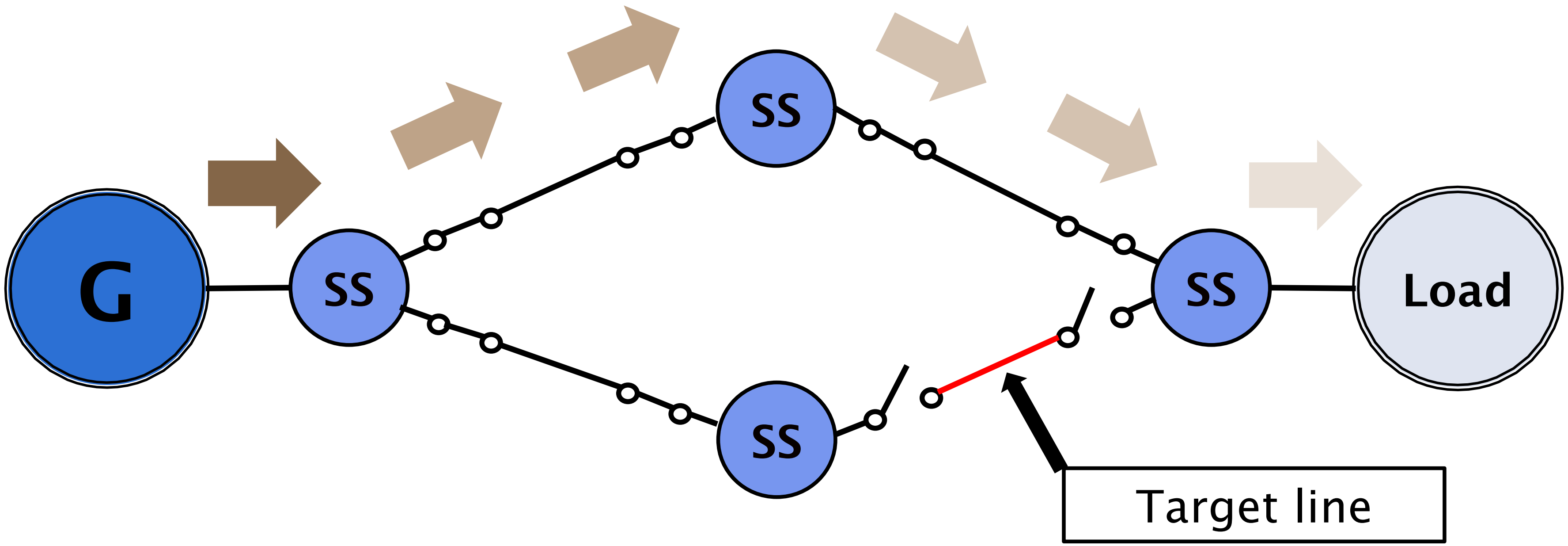
Supply failure to Loads

▼

Outage work = infeasible!

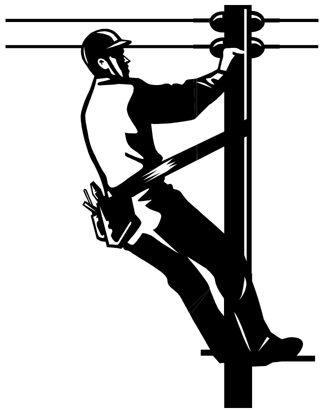


Outage work system



Power supply = stable

Outage work = feasible



Flow of the planning

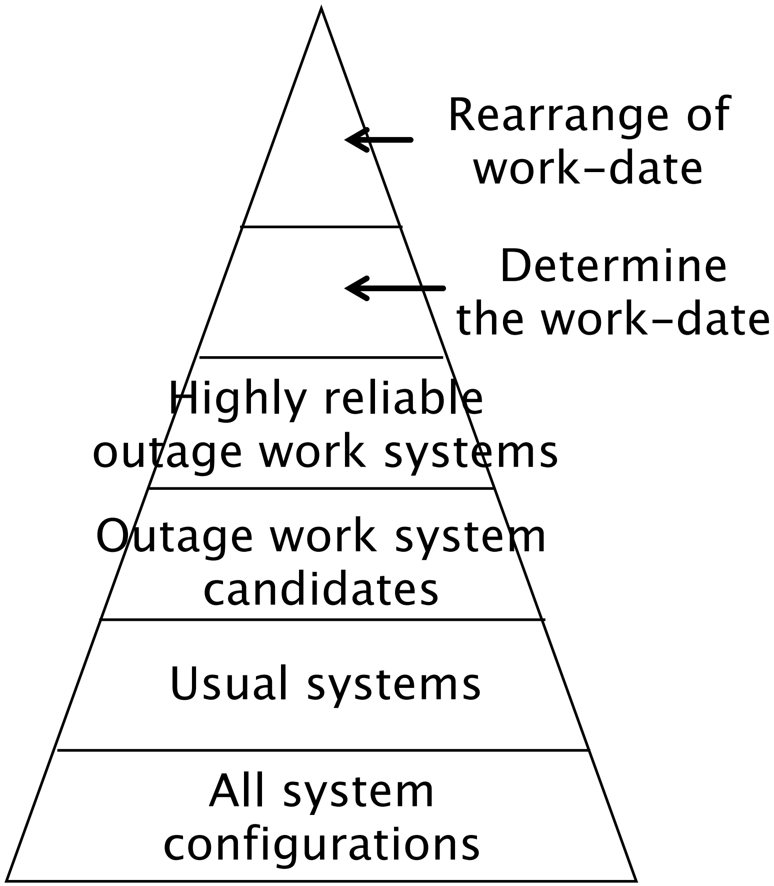
Define of the search space	Search space based on Hamming Distance*
⇓	⇓
Enumerate candidates	$\{sys_1, sys_2, \ldots, sys_N\}$ | N: total candidates
⇓	⇓
Check the constraints	Power balance, voltage, line power flow, …
⇓	⇓
Build a feasible candidate set	$\{sys_2, sys_7, sys_{10}\}$
⇓	⇓
Calculate the index	Index** = N-2 supply failure power
⇓	⇓
Make ranking of the set	$1^{st} = sys_7$, $2^{nd} = sys_2$, $3^{rd} = sys_{10}$
⇓	⇓
Select the outage work system	Outage work system = sys_7

*) Hamming Distance constraint: the number of switching from the normal system.

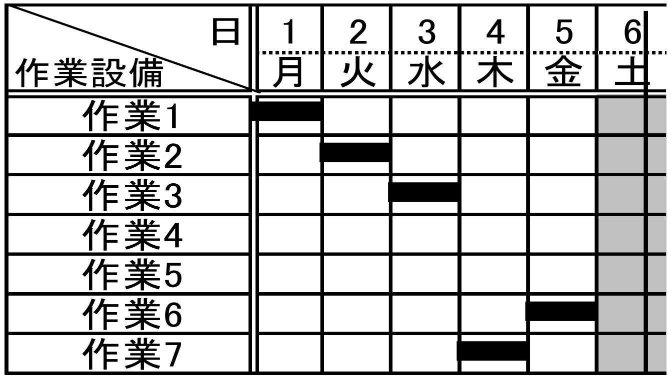
**) N-2 supply failure power: the failed amount of power supply when simultaneous 2-lines outage occur.

Background

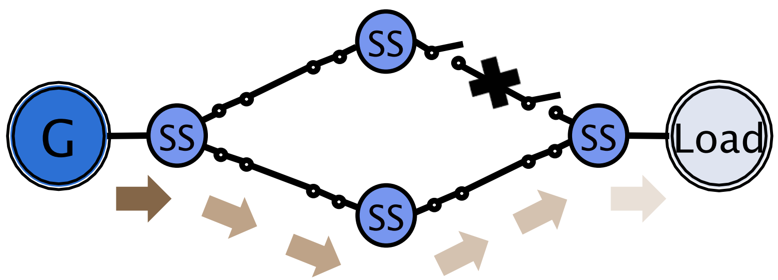
Outage work planning* = determine work schedules, orders, combinations, system configurations



Built up a chart



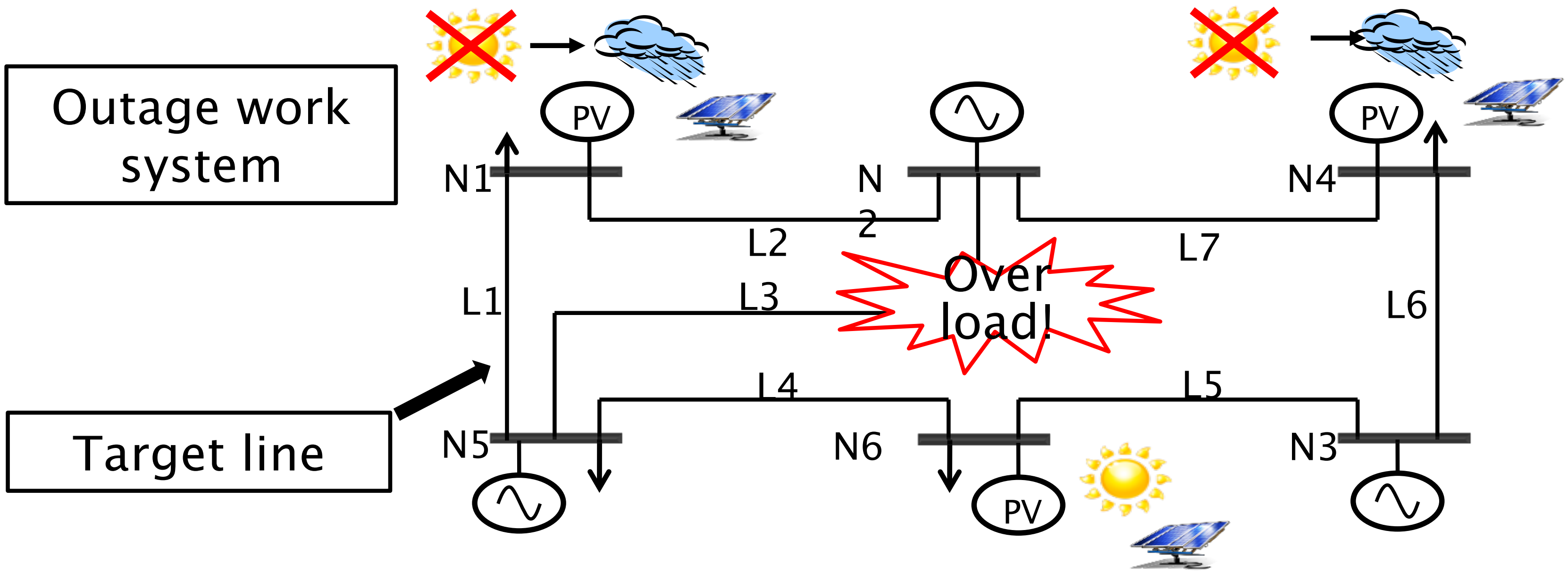
Outage work system candidates



Research Target

*) Outage work: temporal, partial stop for inspection, repair, etc. (not blackout)

An impact to outage work by PVs



In case of huge, rapid change of PV outputs

⇓

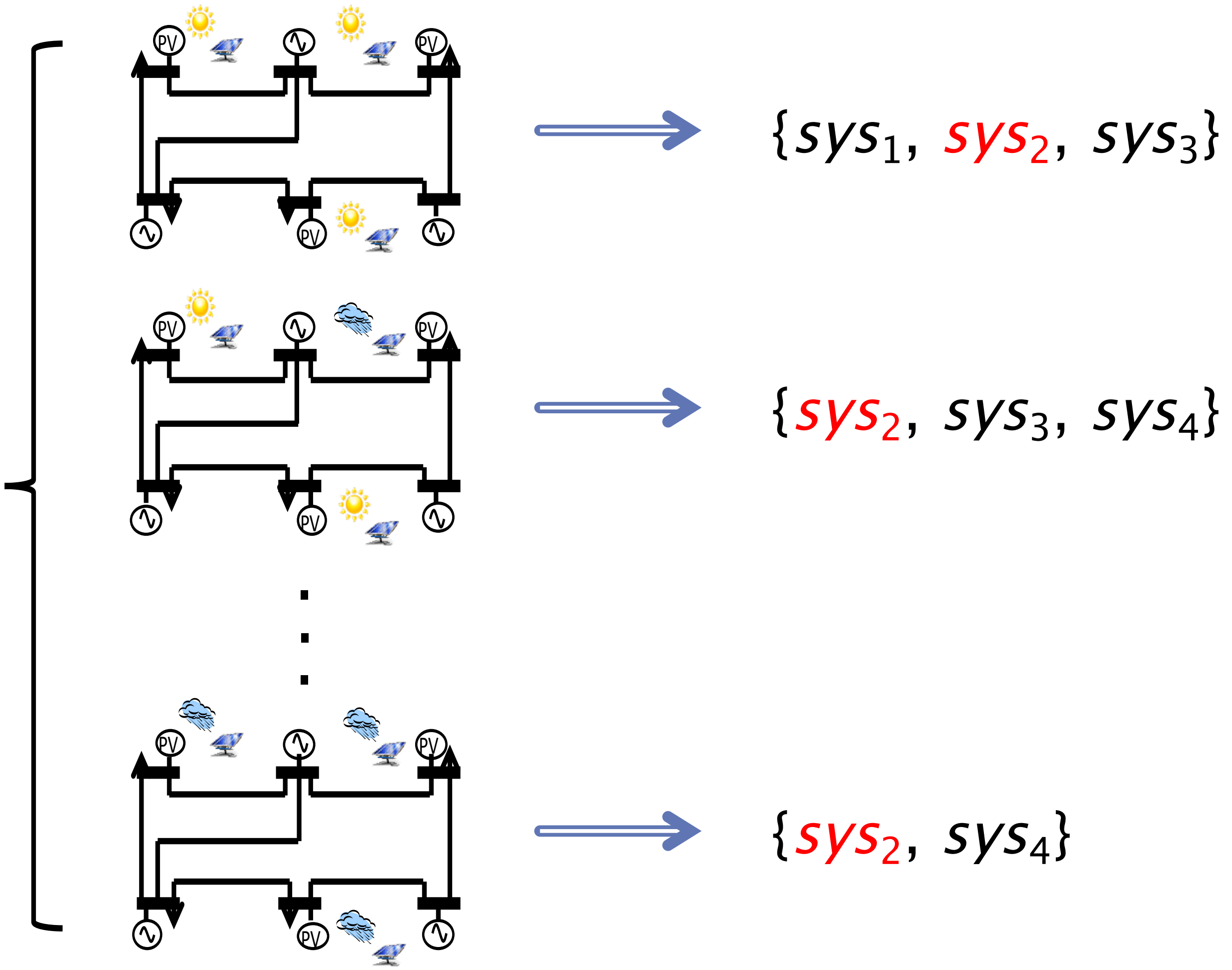
Due to the over loads, feasible outage work systems are different depending on PV output.

⇓

New outage work planning taking into account PV output uncertainties is necessary.

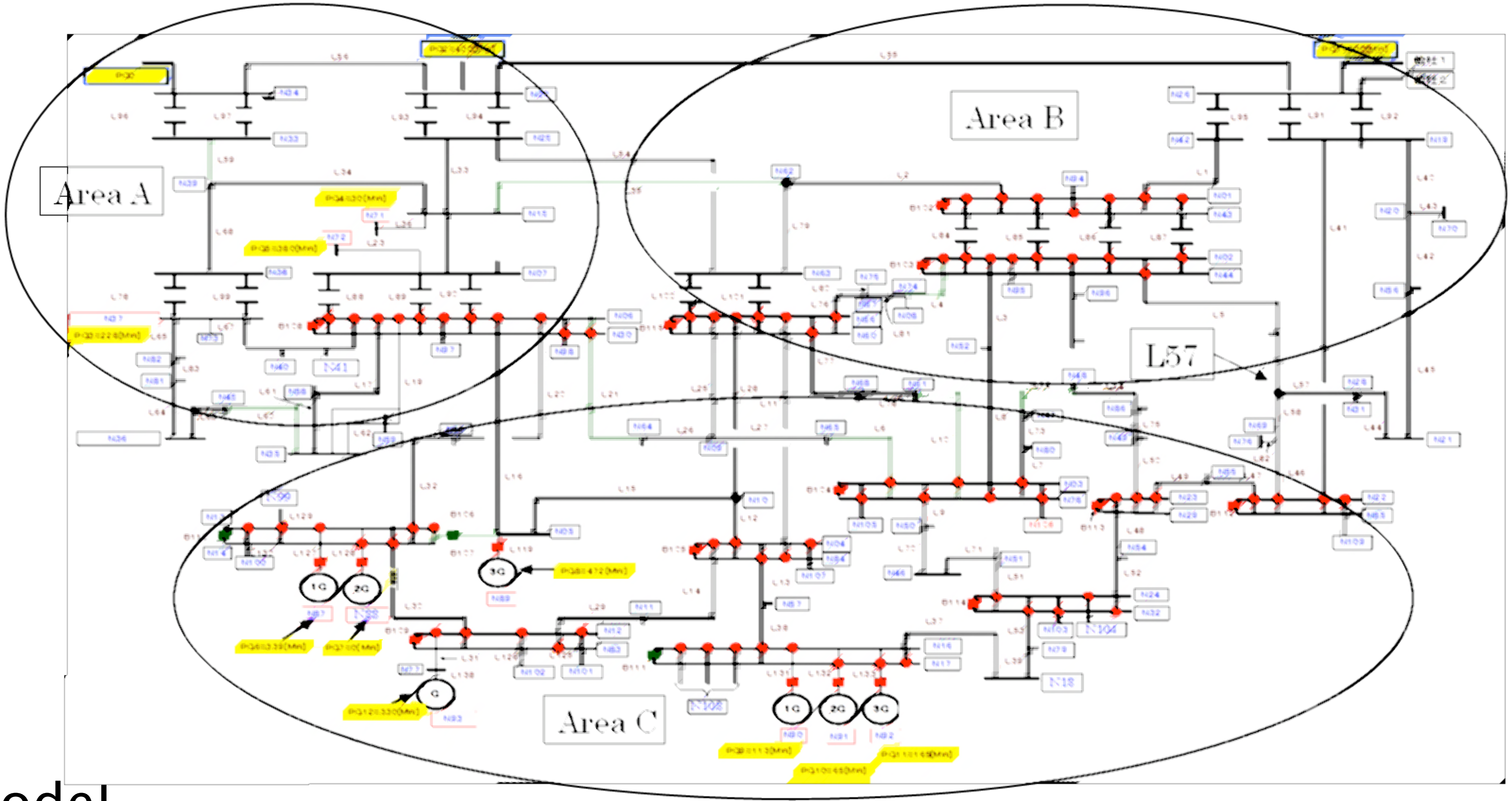
Intersection of the candidates

PV installed n nodes
→ 2^n patterns



If prepared as sys_2, the plan will be feasible even if any patterns of PV output occur.

A typical example



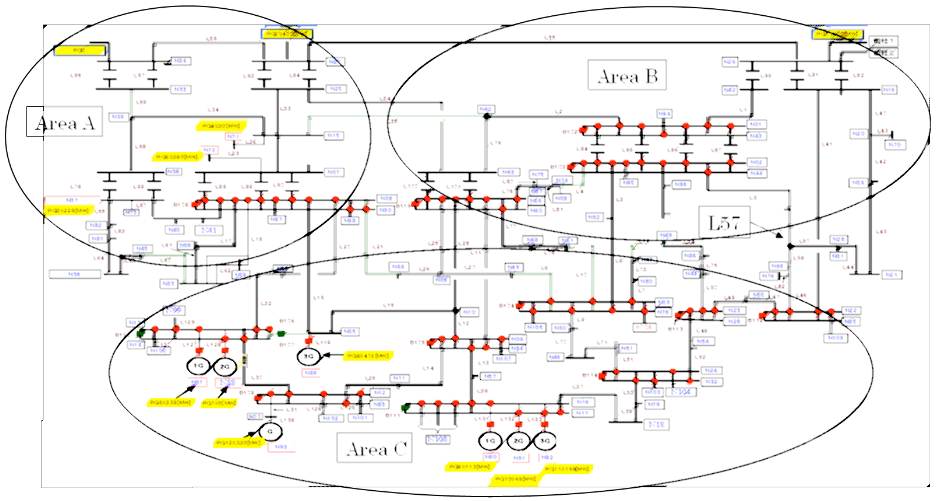
System model

- Data
  - Total load: 3,000MW
  - 7 generators
- 109 nodes, 138 branches
  - Upper system: loop-based
  - Lower system: radial-based

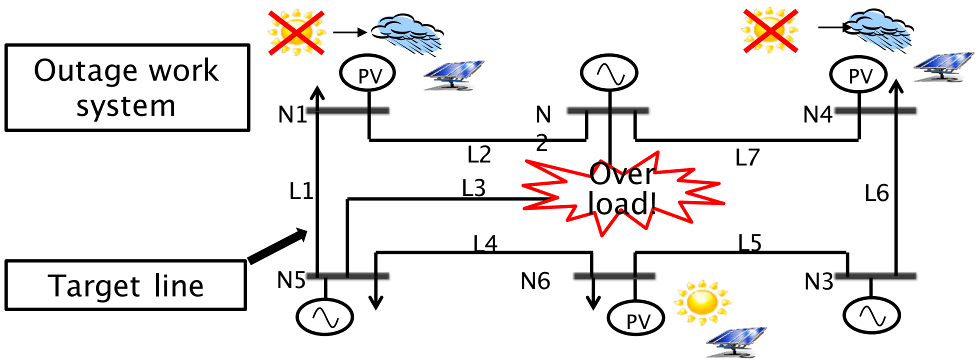
Assumptions (example)

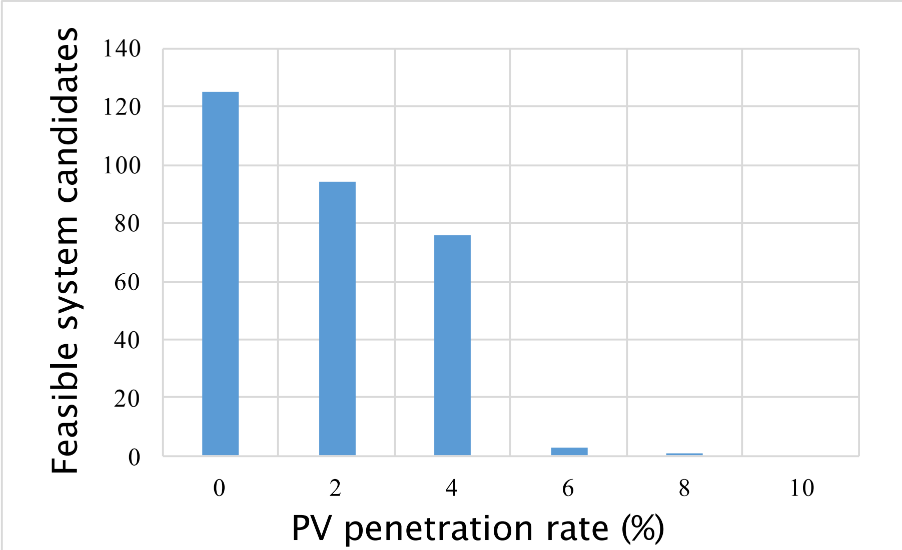
- PV assumption
  - Divided into 3 areas (A, B, C)
    - Same PV output states within the same area
  - PV Install conditions
    - PV installation types
      - Mega-solar : Roof-top PV = 1 : 1
      - Extrapolate for larger cases
    - Amount of installation
      - Mega-solar = actual data
      - Roof-top = based on household statistics

- Outage works
  - Target = L57 (1 cct)



Lost of feasible plan due to PVs





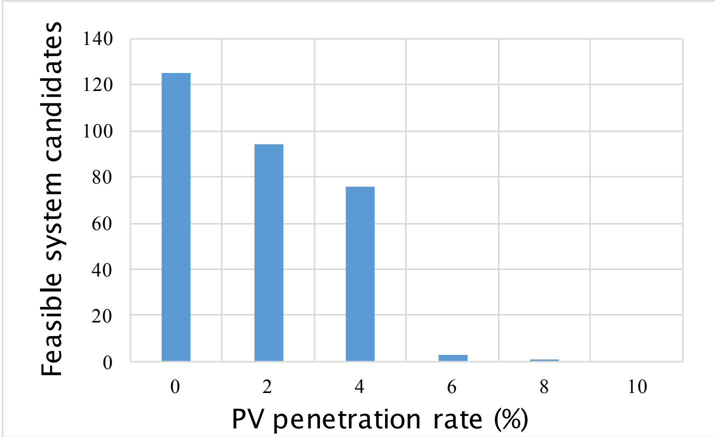
The more PV penetration, the fewer feasible outage work system candidates due to overload line.

Finally, no outage work plan obtained because of no feasible solution.

Lost of feasible plan due to PVs

Feasible system candidates depending on PV output patterns and penetration rates

	PV output conditions*			PV penetration rate assumptions					
Case	Area A	Area B	Area C	0%	2%	4%	6%	8%	10%
1	1	1	1	125	125	125	125	125	125
2	1	1	0		94	92	76	3	1
3	1	0	1		110	96	96	93	93
4	0	1	1		125	111	111	111	97
5	1	0	0		94	86	3	1	0
6	0	1	0		96	92	76	3	1
7	0	0	1		96	76	95	93	92
8	0	0	0		94	86	3	1	0
Common feasible systems				125	94	76	3	1	0



*) PV output conditions
- 1 = 100%
- 0 = 0%

Rapid reduction in the cases 2, 5, 6, and 8.

⇓

In area C, large number of roof-top PVs in residential area and many mega-solar systems in industry area.

⇓

Large power flow change occurs depending on PV output patterns.

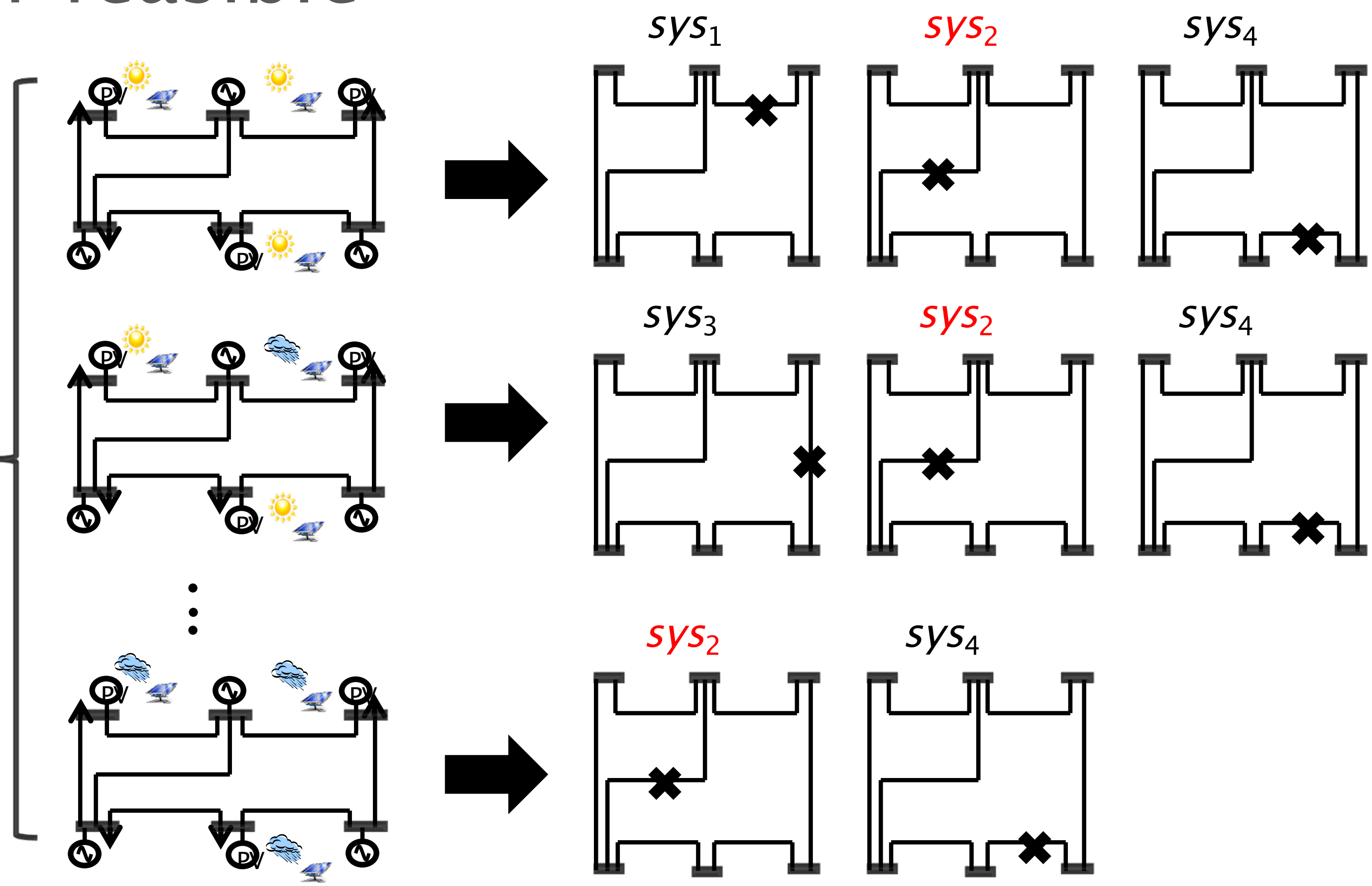
Problem to be solved

- Problem
  - No feasible outage work system obtained by PVs
    - Mainly due to overload problem
  - → An additional function to avoid overload conditions.

All weather feasible

PV installed n nodes
→ 2^n patterns*

*) PV output is assumed 0% or 100% because the most severe cases must be considered.



If prepared as sys_2, the plan will be feasible even if any patterns of PV output occur.

Formulation (minimization of N-2)

Minimize the index: N-2 supply failure power
(decision variables: x = facilities connection)
Subject to: feasible for any PV output patterns

N-2 supply failure power

$$A(x, y, p_k) = \sum_{\substack{i=1 \\ i \neq j}}^{MC} \sum_{j=1}^{MC} \sum_{b=1}^{MB} \omega_{bij}(x, y) \bullet L_b(p_k) \quad ^{*1}$$

Objective function

$$\min A(x, y, p_1)$$

*1 p_k : Load parameters for PV output pattern *k*

Subject to

$$\forall x, x \in \bigcap_{k=1}^{2^n} X_F(k) \quad ^{*2}$$

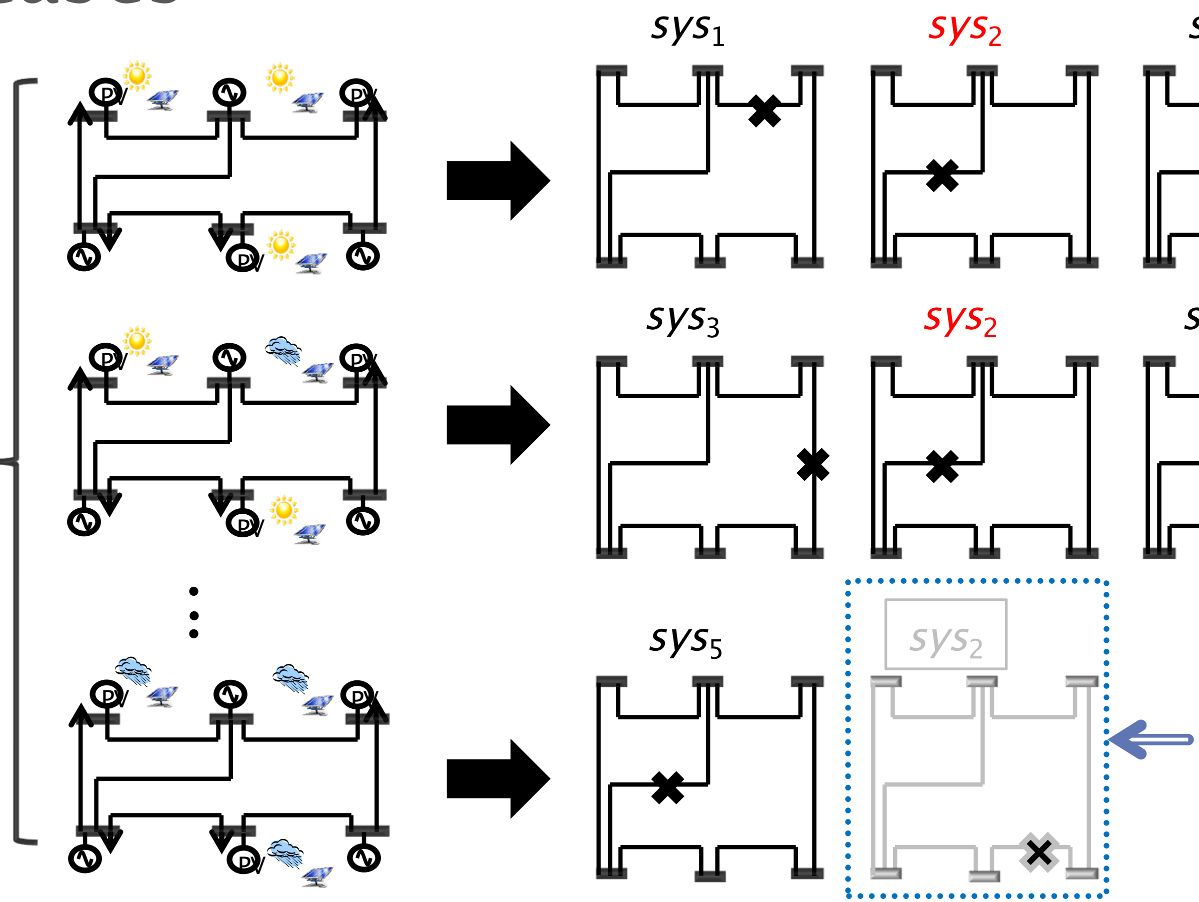
*2 $X_F(k)$: Feasible solution set for PV output pattern *k*

Find the system with minimum N-2 supply failure power when the weather is fine and feasible for any PV output patterns.

Overload cases

PV installed n nodes
→ 2^n patterns*

*) PV output is assumed 0% or 100% because the most severe cases must be considered.



If not obtained feasible solution, generator output adjustment (control) takes place and adopt it as additional candidates.

Formulation (G adjustment)

Minimize: amount of G adjustment
(decision variables: G = output adjustment)
Subject to: operation restrictions

Objective function

$$\min \sum_{m=1}^{MP} \left(\left| G_m^+ \right| + \left| G_m^- \right| \right)$$

: Amount of G adjustment

Constraints

$$-F_j^{\max} \le F_j \le F_j^{\max}$$

: Limits of line flows

$$\sum_{m=1}^{MP} (G_m^+ + G_m^-) = 0$$

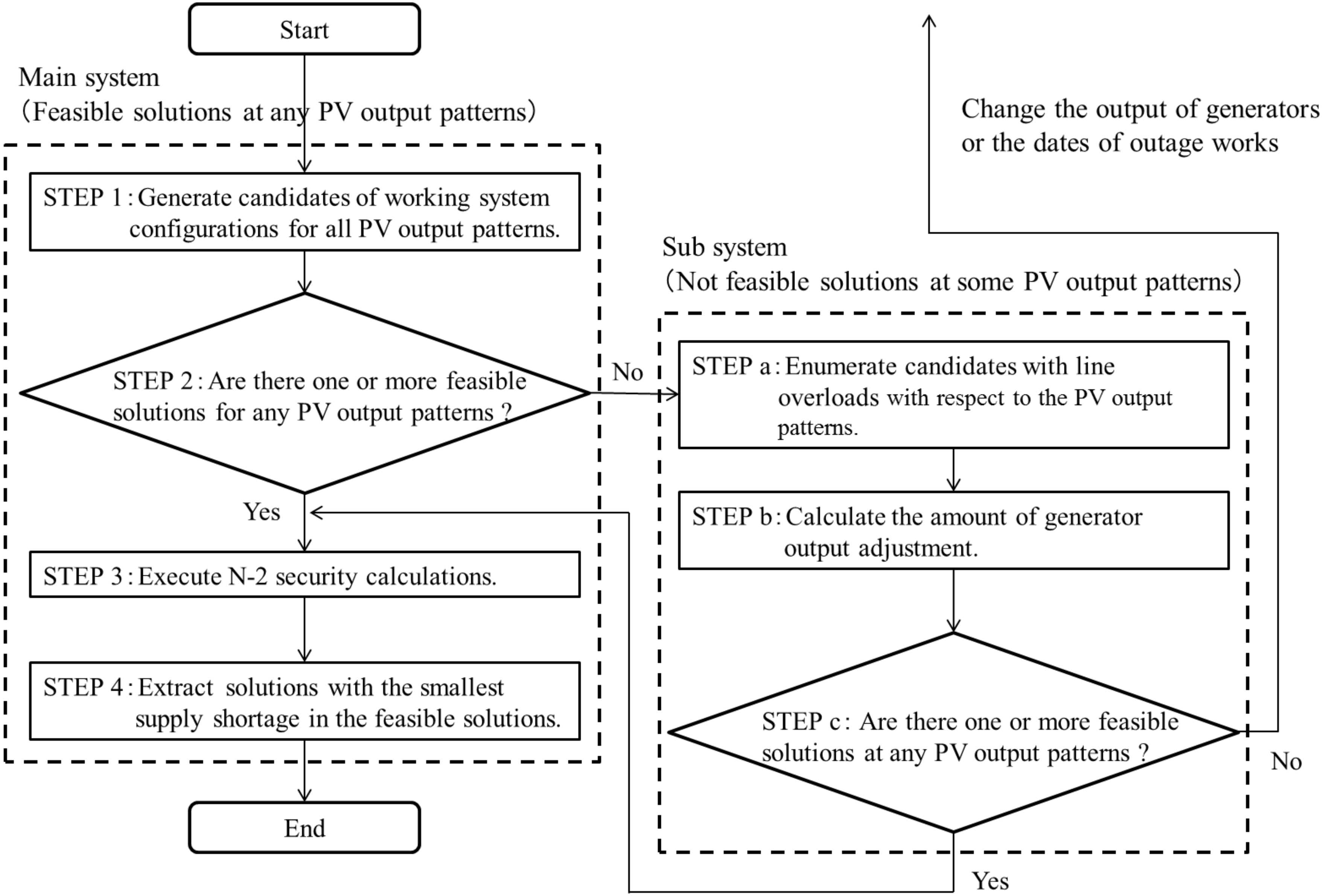
: Power balance

$$P_m^{\min} \le P_m \le P_m^{\max}$$

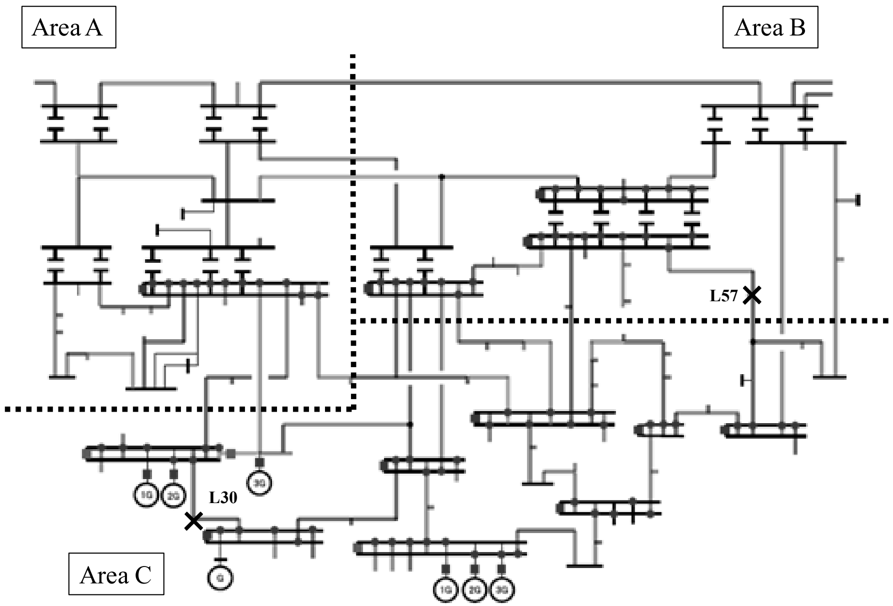
: Limits of G outputs

Determine the amount of G adjustment and its location for N-1 overload banishing.

Flowchart of the algorithm



Numerical simulations



Case	Area A	Area B	Area C
1	1	1	1
2	1	1	0
3	1	0	1
4	0	1	1
5	1	0	0
6	0	1	0
7	0	0	1
8	0	0	0

- Data
  - Total load: 3,000MW
  - 109 nodes, 138 branches
    - (Same as before)

- PV assumption
  - Divided into 3 areas (A, B, C)
  - PV Install conditions
    - (Same as before)

- Outage works
  - Target = L57 (1 cct)
  - Target = L30 (1 cct) ← overload case

Simulation results

- All weather feasible
  - Obtained a solution feasible for all weather conditions
    - Shaded part of the table below
    - Covering all cases

	Ranking											
	1st			2nd			3rd			4th		
Case	off→on	on→off	Connection change	off→on	on→off	Connection change	off→on	on→off	Connection change	off→on	on→off	Connection change
1	L107	L29	L129(N13→N14)	L107	L29		L107	L29	L127(N13→N14)	L107	L29	L128(N14→N13)
2	L107	L29		L107	L29	L127(N13→N14)	L107	L29	L128(N14→N13)	L107	L29	L131(N16→N17)
3	L107	L29		L107	L29	L127(N13→N14)	L107	L29	L128(N14→N13)	L107	L29	L131(N16→N17)
4	L107	L29		L107	L29	L127(N13→N14)	L107	L29	L128(N14→N13)	L107	L29	L131(N16→N17)
5	L107	L29		L107	L29	L127(N13→N14)	L107	L29	L128(N14→N13)	L107	L29	L131(N16→N17)
6	L107	L29		L107	L29	L127(N13→N14)	L107	L29	L128(N14→N13)	L107	L29	L131(N16→N17)
7	L107	L29	L127(N13→N14)	L107	L29	L30(N14→N13)	L110	L29		L107	L29	L30(N14→N13)
8	L107	L29	L127(N13→N14)	L107	L29	L30(N14→N13)	L110	L29		L110	L29	L131(N16→N17)

Simulation results

- Overload case
  - In Case 7 & 8, no feasible system obtained.
  - → Additional G adjustment works well.
    - Shaded part of the table below

	Ranking											
	1st			2nd			3rd			4th		
Case	off→on	on→off	Connection change	off→on	on→off	Connection change	off→on	on→off	Connection change	off→on	on→off	Connection change
1	L107	L30	L129(N13→N14)	L107	L30		L107	L30	L128(N14→N13)	L107	L29	L131(N16→N17)
2	L107	L30		L107	L30	L128(N14→N13)	L107	L30	L131(N16→N17)	L107	L30	L132(N17→N16)
3	L107	L30		L107	L30	L128(N14→N13)	L107	L30	L131(N16→N17)	L107	L30	L132(N17→N16)
4	L107	L30		L107	L30	L128(N14→N13)	L107	L30	L131(N16→N17)	L107	L30	L132(N17→N16)
5	L107	L30		L107	L30	L128(N14→N13)	L107	L30	L131(N16→N17)	L107	L30	L132(N17→N16)
6	L107	L30		L107	L30	L128(N14→N13)	L107	L30	L131(N16→N17)	L107	L30	L132(N17→N16)
7	L107	L30										
8	L107	L30										

Conclusions

- Summary
  - PV penetration affects outage work planning
    - It has been found out that the number of feasible outage work systems decreases depending on PV penetration.
  - A new method has been proposed
    - To avoid overload cases.
- Future works
    - PV penetration assumption should be brushed up.
    - PV installation patterns should be analyzed more in detail.
    - PV output classification (area) should be studied based on actual data.