Increasing Market and Planning Efficiency and Enhancing Resilience through Improved Software

Advanced On-line volt/var(Q) Control System: Design, Implementation and High Hosting Capability for Renewable Energy

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Vision & Presentation Overview

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The following vision is shared among the authors.

"Innovation in power grid operation by online-optimization technology"

The OPENVQ solution has been developed

Optimized Performance Enabling Network for Volt/var(Q)

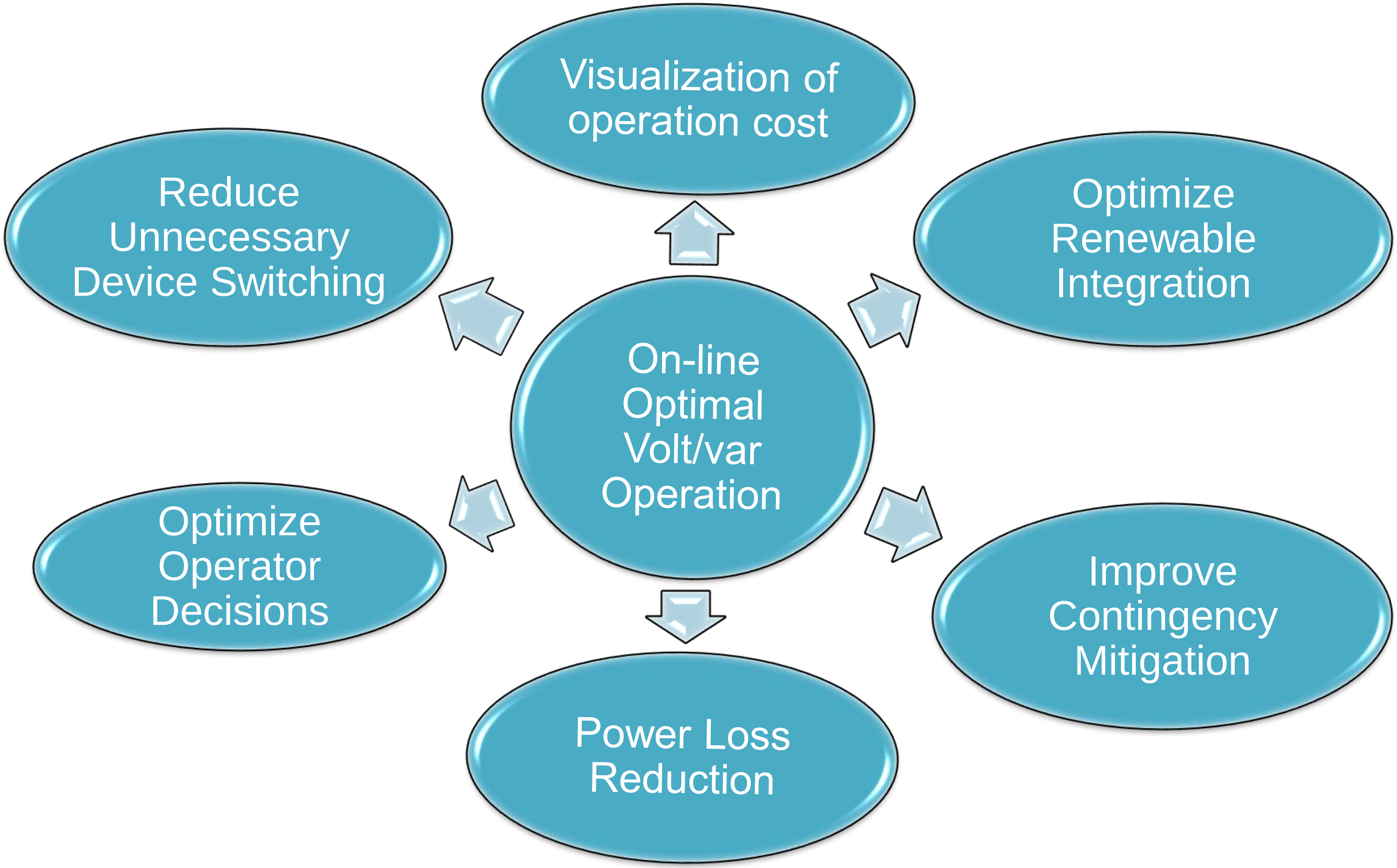
Goals of OPENVQ

- Development of key technology for optimal volt/var operation
- Cost reduction oriented planning & operations
- Increase and optimize the penetration of renewable energy on the grid

Presentation Overview

- Benefits of OPENVQ
- TEPCO Project & Results
- OPENVQ Details
- Typical TEPCO simulation results
- Implementation Lessons Learned & Suggestions

OPENVQ Benefits



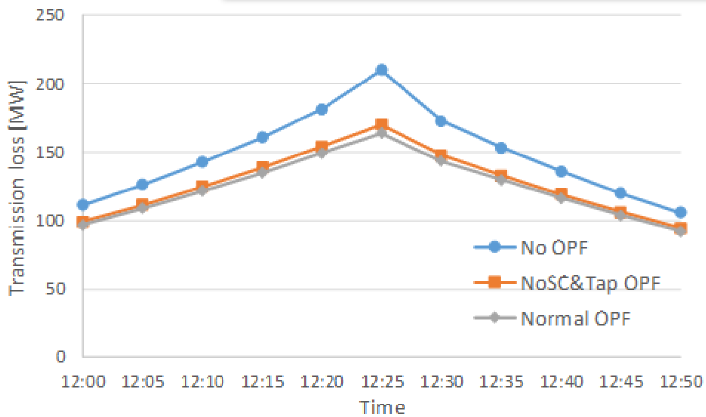
Challenges for OPENVQ

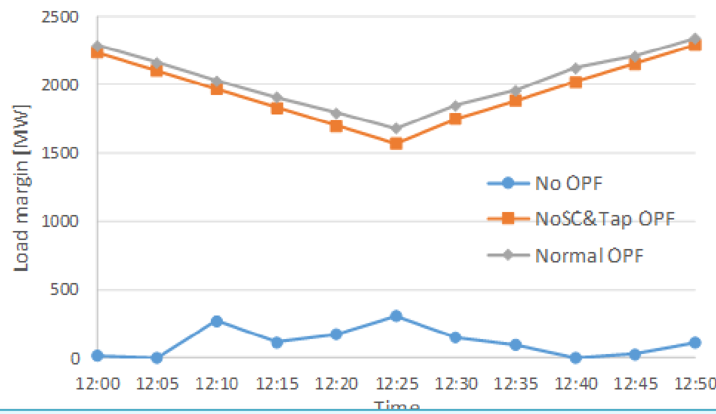
Issues		Solutions
Operation decisions at substation might be increased by utilizing snapshot OPF	→	Establish smart logic to determine the best operational scenario from online conditions
Current calculation methods of ACOPF is not effective enough – too small to apply on-line control	→	Utilize 'Look-ahead' function to determine optimized predictive solution
Cost evaluation of each scenario is one dimensional and may not be the optimized solution	→	Multi-dimensional cost evaluation using simulation results to optimize decisions

Fundamental Knowledge of optimal voltage profile operation

- Theoretically, there is the unique optimal voltage profile on every snapshots
- OPENVQ provides practical system control decisions, not only to optimize device effectiveness, but also minimize loss reduction

OPENVQ solves this issue by using flexible and powerful simulations based on the look-ahead function.





Note from IEEE 118 model simulation results:

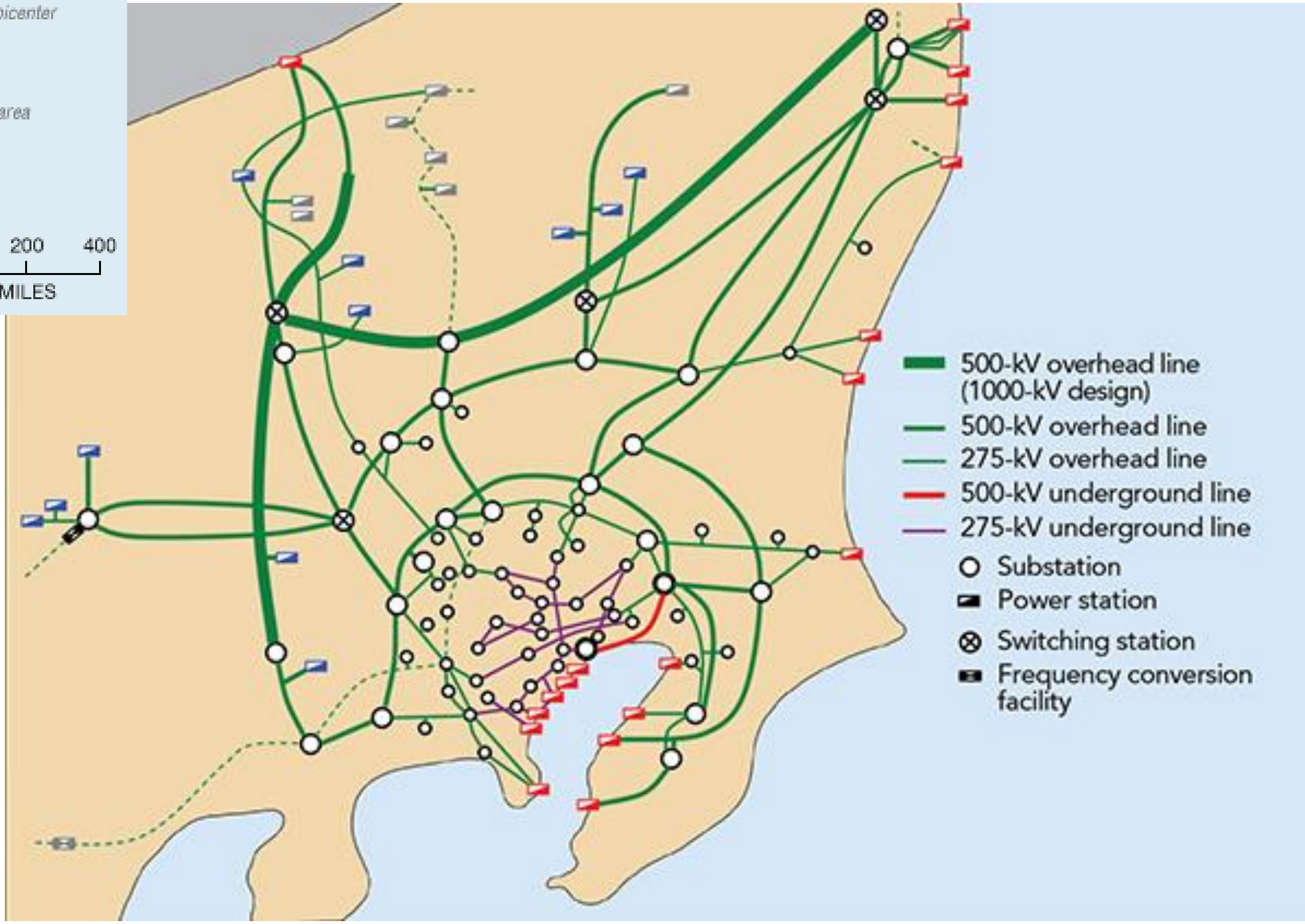
A) In this time period, decay of KPIs are small enough even though sub station devices unlisted from control devices.

B) Of course, this decision should be done with considering potential contingencies and not only health condition.

Definition of Scenario in this presentation
Specification of which devices are listed into control variables for solving optimal condition

Tokyo Electric Power Company (TEPCO)

- Maximum demand: 61.47 GW
- Annual Energy: 297.4 billion kWh,
- Revenue: ~45 billion US$
- Number of buses: 2344
- Number of generators:290
- Number of shunt devices: 507, Number of OLTCs: 794



Tokyo Electric Power Company (TEPCO) OPENVQ Project

- OPENVQ simulation has proven results from the TEPCO project
  - Power Loss Reduction
  - Reduce Unnecessary Device Switching
  - Visualization of operation cost
- Evaluation Method
  - OPENVQ simulator has been developed for TEPCO system
  - Five day simulations were performed
- Specifications of simulations
  - The maximum demand snapshot of TEPCO is utilized to determine the grid configuration
  - Some demand-supply balancing conditions were modeled
  - Uncertainties from renewable energy is also modeled (5% variation)
- Assumptions
  - Grid operator can order the reference voltage of exciters
  - Grid operator can order the operation of devices in sub-stations

Results from TEPCO OPENVQ Project

Phase of OPENVQ project

Phase 1: F/S by OPENVQ simulator - **COMPLETED**

Phase 2: Development the key functions with commercial grade of OPENVQ

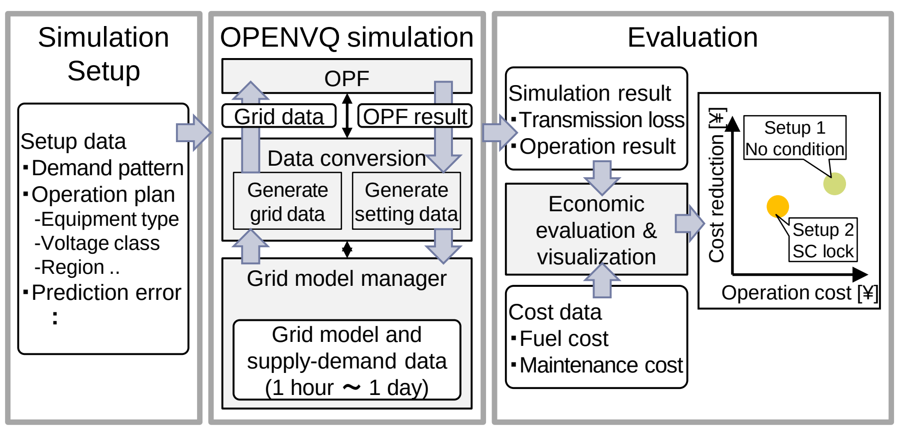
Estimated Benefits from Phase 1

- **Reduction of power losses: $10-20M/year**
- **Reduction of asset maintenance expenses: $2-3M/year**
  - reduction of substation equipment switching by 50%
- **Increased in area transfer capacity (ATC)**
  - 5 to 15 %

Details of OPENVQ
Function modules of OPENVQ & simulator

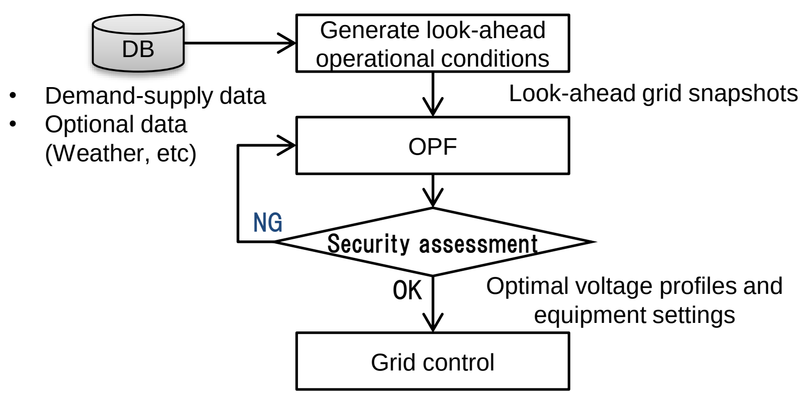
- **Advanced OPF**
  - Robust solving optimal status
- **Online application P/F**
  - Ever-green applications
- **Technologies of look-ahead**
  - Resilient backup
  - Uncertainty
- **Coordinate operation both Gen & S/S**
  - Reducing operation efforts
  - Rational Assets
- **Advanced Security Assessment**
  - Maintaining grid security
- **Flexible online simulator**
  - Performance Confirmation of OPENVQ
- **Cost evaluation**
  - Choosing the best scenario

To verify the missions of each component, following OPENVQ simulator has been developed

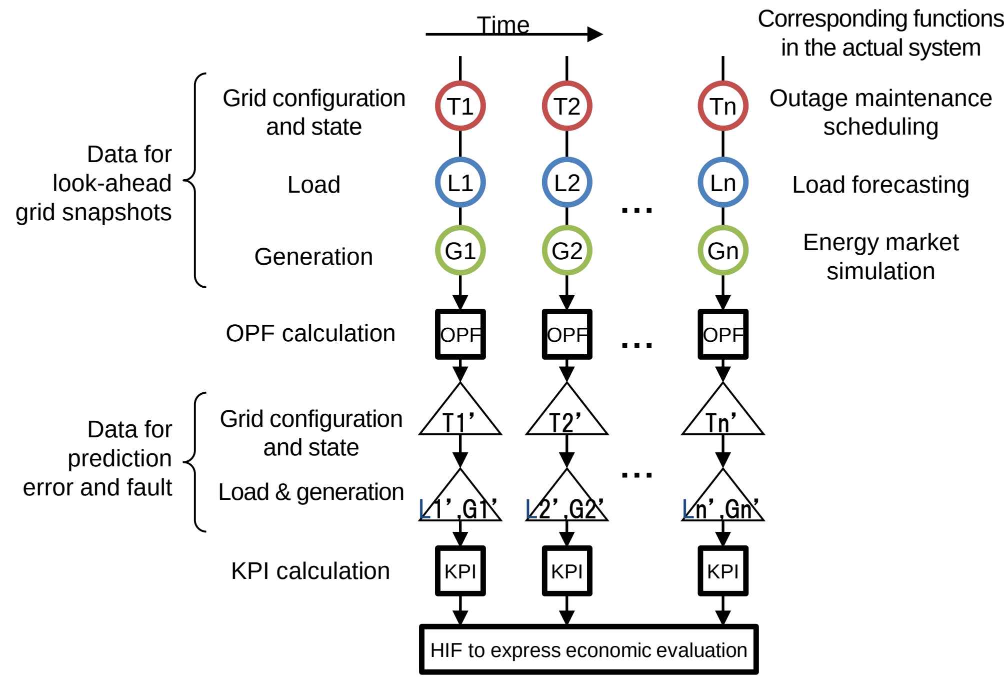


Details of OPENVQ
Description of OPENVQ simulator

- Main objective of OPENVQ simulator can balance between maintaining grid security and minimizing operation/capital cost
- OPENVQ simulator can specify a scenario easily, so that it is useful to find the best way to maintain an optimal voltage profile during the target time period



Flowchart



Architecture

Details of OPENVQ
Evaluation of look-ahead error and contingency

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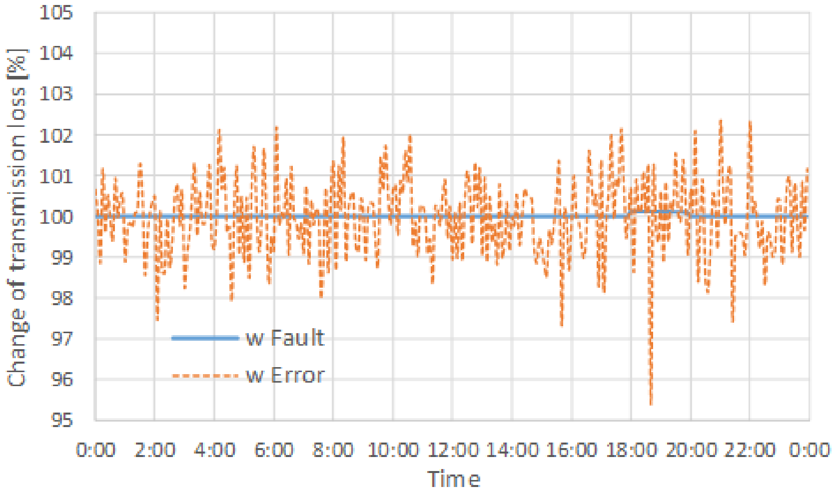
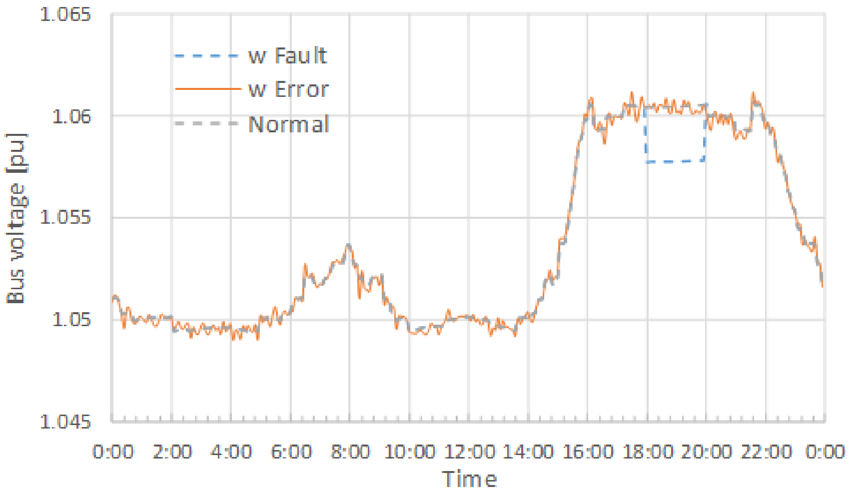
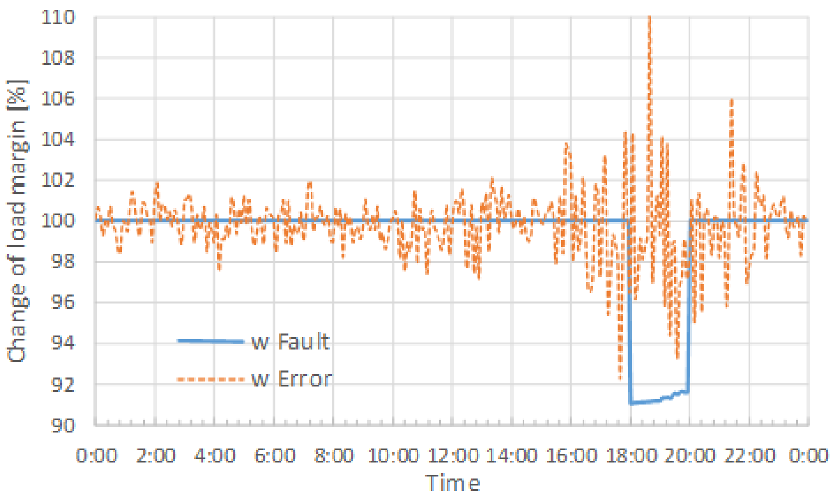
- OPENVQ simulator can evaluate control strategies through look-ahead error and contingency.
- Voltage operation determined using day-ahead market information could be validated with grid securities, then it can recommend appropriate counter measures prior to operation.



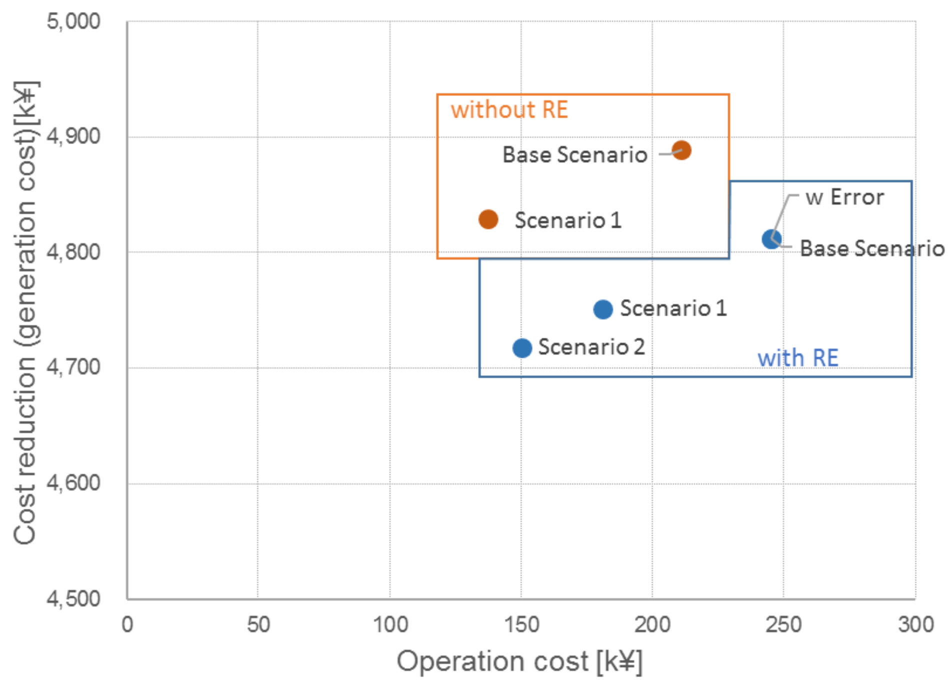




Note:
- Orange lines for evaluating influence of look-ahead error
- Dotted blue lines for impact of contingency

Details of OPENVQ
Cost Evaluation of Optimal Voltage Operation

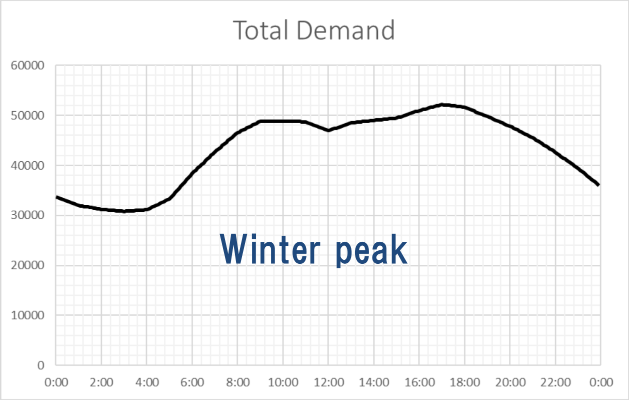
- IEEE 118 model is utilized to show the effectiveness of cost evaluation
  - Vertical axis: Loss reduction effects
  - Horizontal axis: Operation cost calculated from maintenance fee of sub-station apparatuses
- There is a trade-off between the cost reduction effect and the operation efforts generally.
  - Larger operation efforts can make a larger cost reduction as following figure.
  - Sensitivity analysis about cost can be done by visualization scheme of OPENVQ simulator, cost oriented evaluation is important for decision making.

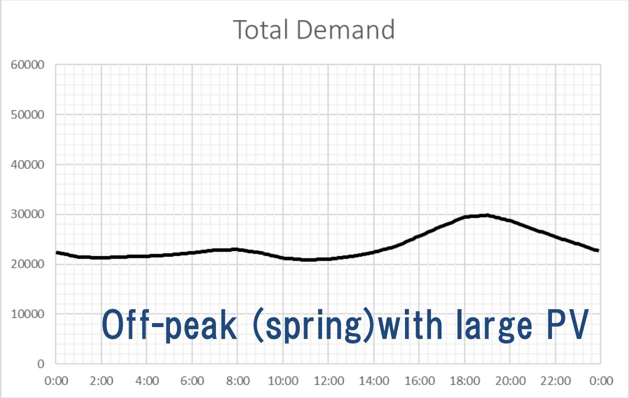


Base Scenario: All devices are available
Scenario 1 &2: Reducing operation of sub station

Simulation results of TEPCO Case

- Some daily simulations make clear that OPENVQ can reduce the power loss and maintenance cost of sub-station equipment by TEPCO grid model.
  - In this simulation, SOPF, which is AC-type OPF and developed by BSI, solves grid snapshot at 5-min time interval, it means 288 times per day.
  - There is no case that numerical divergence was carried out during five days.





Scenario 1: All voltage control apparatuses are used
Scenario 2: Sub-station operation are suppressed

	No. Tap op.	No. Shunt op.	Sum. of changing ref. of Exciter Voltage	Daily power loss[MWh]
Scenario1	2706	1163	13.3	14,386
Scenario2	2328	781	119.0	14,692

	No. Tap op.	No. Shunt op.	Sum. of changing ref. of Ex.	Daily power loss[MWh]
Scenario1	1266	786	7.5	256.3
Scenario2	745	287	40.9	258.2

Note
- Power loss of both scenarios are almost same
- var-management at generators' side can reduce sub-station operations

Lessons Learned & Suggestions

- **High Quality Models are Desired for Grid Operation**
  - Data security issues need to be resolved; both look-ahead & historical data can be used
  - System for the calibration of model parameters of power grid model might be a big issue

- **Trends of Grid Operation and Control**
  - Automated operation of voltage control devices at sub-station
  - Need to incentivize the on-line exciter reference voltage control
  - Online update for special integrated protection scheme

- **Incentivize optimal operation for power grid operators**
  - While optimal operation can make the reduction of OPEX/CAPEX, there is a discussion to make an appropriate balance between the efforts of rationing assets and rate regulation.

- **Expansion of usage of ACOPF**
  - Coherent operation both the voltage/var control and power market running, ACOPF solver of market operation is more preferable than DCOPF.
  - It is an important discussion point how to guarantee the ACOPF performance.

Thank You!

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Appendix

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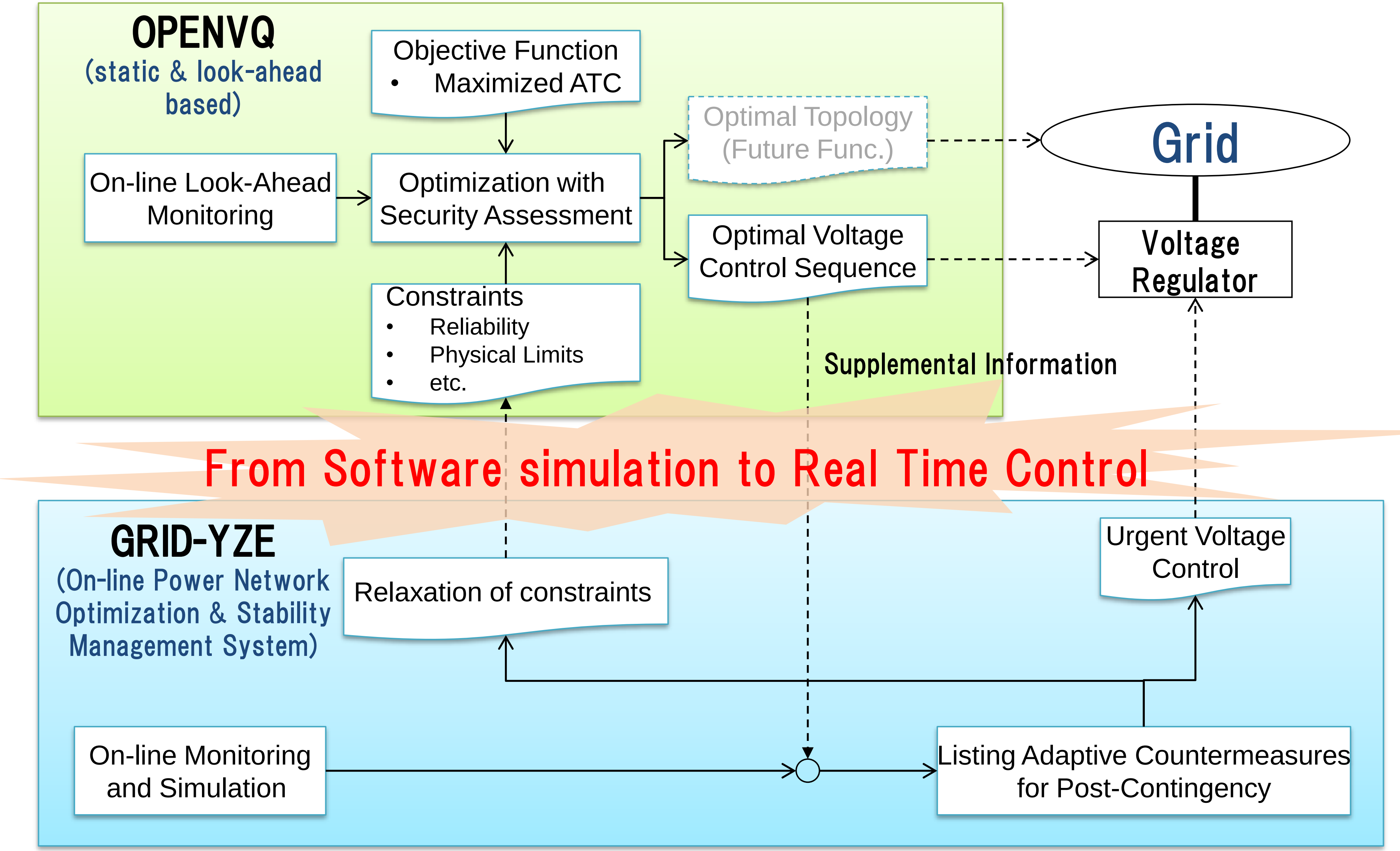
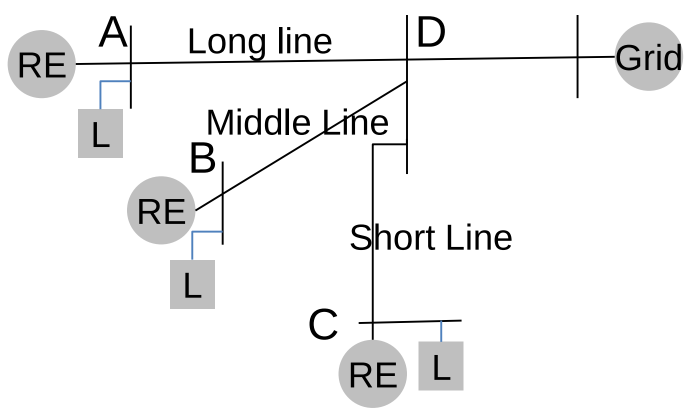
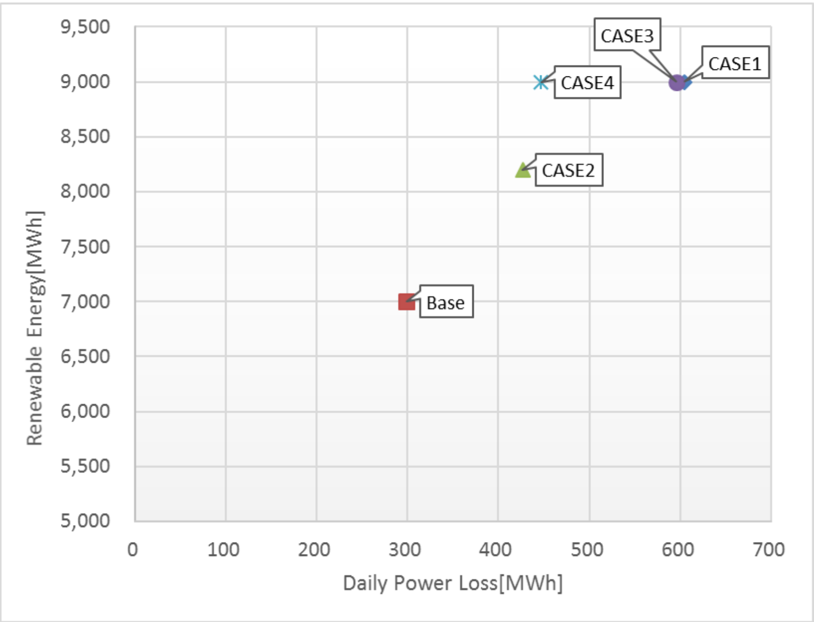
An Example of Integrated control system



OPENVQ Benefits - Enhancing penetration of Renewables

- OPENVQ can optimize voltage profile in real time to react to the uncertainty of grid operation.
- To maximize ATC while under heavy renewable penetration dispatch of fast ramping generation becomes critical
- Daily simulation based on optimal operation can provide useful information which counter measure is effective and has large V/C such as following simple example





- Base case cannot use energy from RES because of grid constraints
- Adding capability of reactive power output is the best in this case.
- Finding out the best way, detail numerical simulation like OPENVQ is important

1. CASE1: Add the capability of output reactive power at Node A
2. CASE2: Add the shunt device into Node D
3. CASE3: CASE1 & CASE2
4. CASE4: Reinforcement of the line between NODE A and D as adding 1cct.