YOKOHAMA National University

7th Solar Integration Workshop, 5C-2

Optimal Voltage Control in Distribution Systems with PV and EV for Cooperation with Transmission Grid

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Takao Tsuji, Hiroki Nishigami, Hieu Xuan Nguyen,
Tomoyoshi Takano
Yokohama National University

Background

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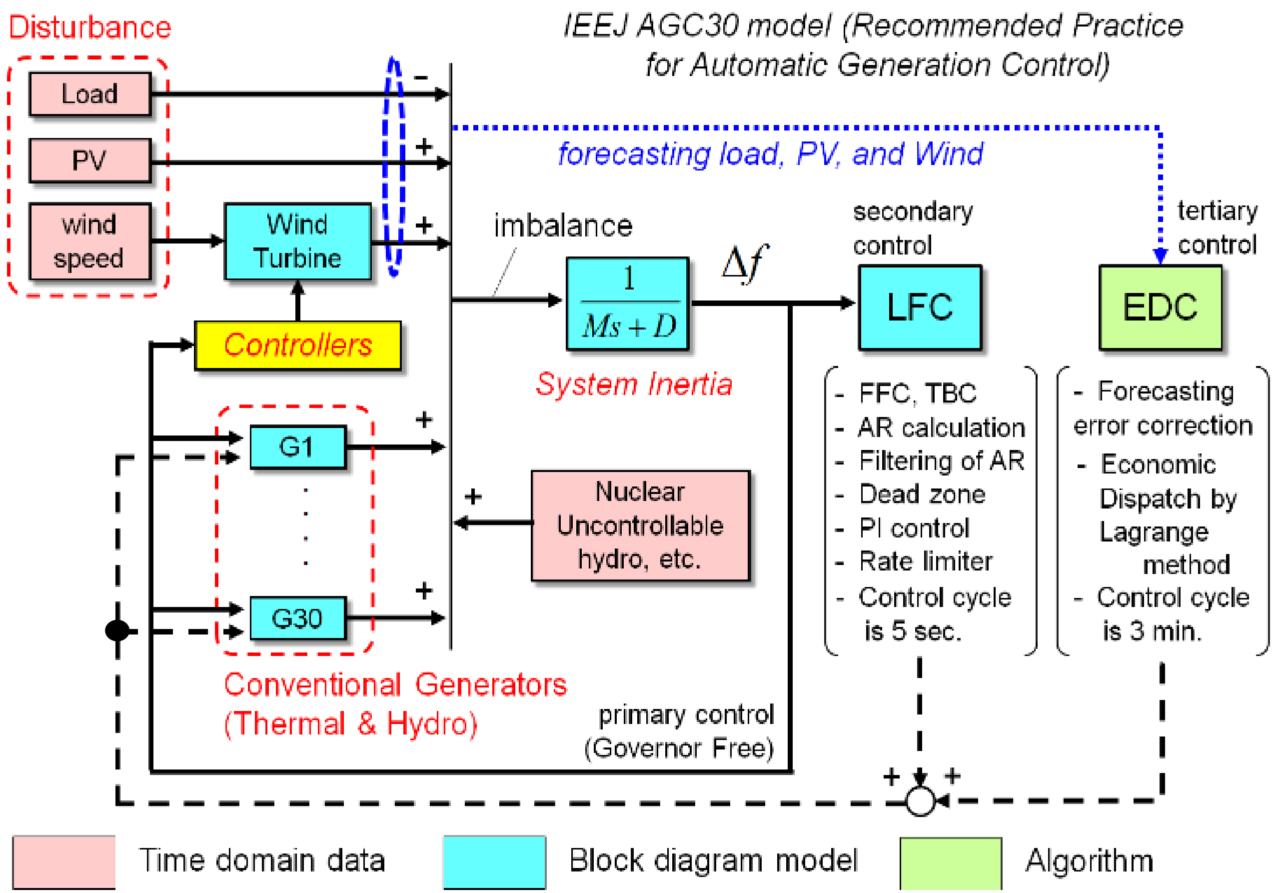
Targeted value of renewable energy integration by Japanese Government

PV : 64 [GW]
WT : 10 [GW]

as of 2030

A large amount of RES installation causes frequency issues and various countermeasures will be needed.

Frequency Issue in Japan



Power system in Japan is isolated from other countries and frequency control is of prime importance.

RES Integration and Frequency Control

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- The massive installation of RES into the power system causes large frequency fluctuation.

- Implementation of Real time balancing market is also planned from 2020, and it is expected that distributed balancing power will participate in the market in the future.

    - Charging (and Discharging) control of EVs
    - Demand Response
    - Active and reactive power control of RES
    - Electrolyzer control for producing hydrogen.

Coordinated Control Strategy

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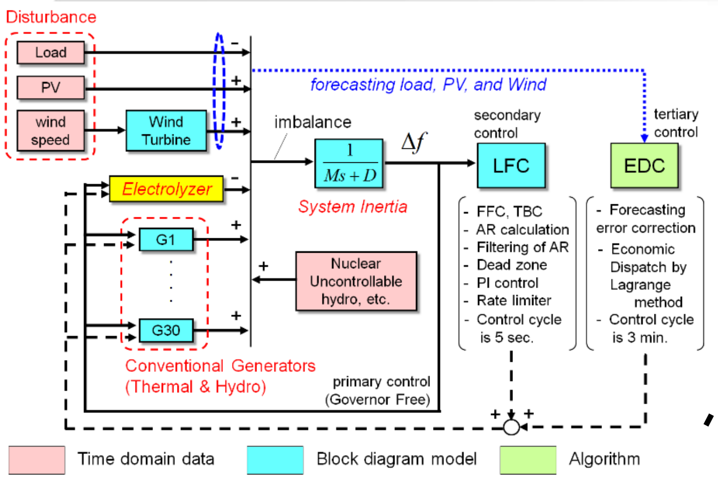
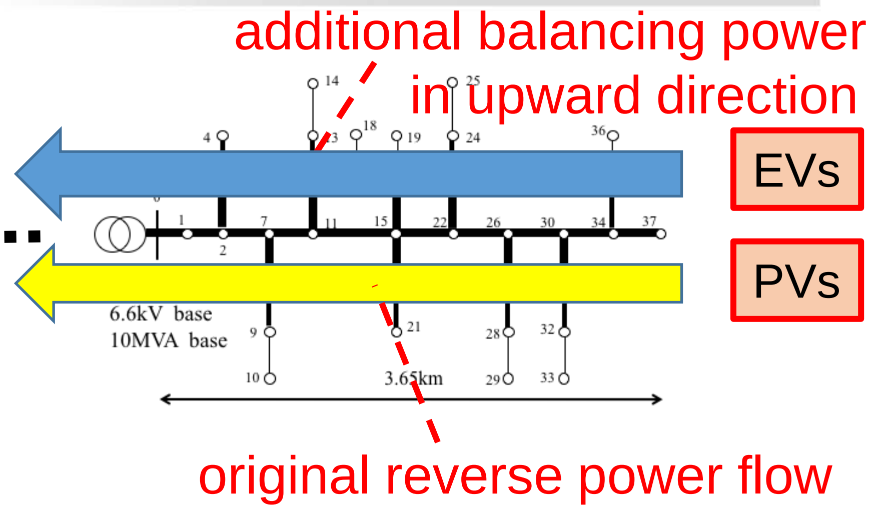
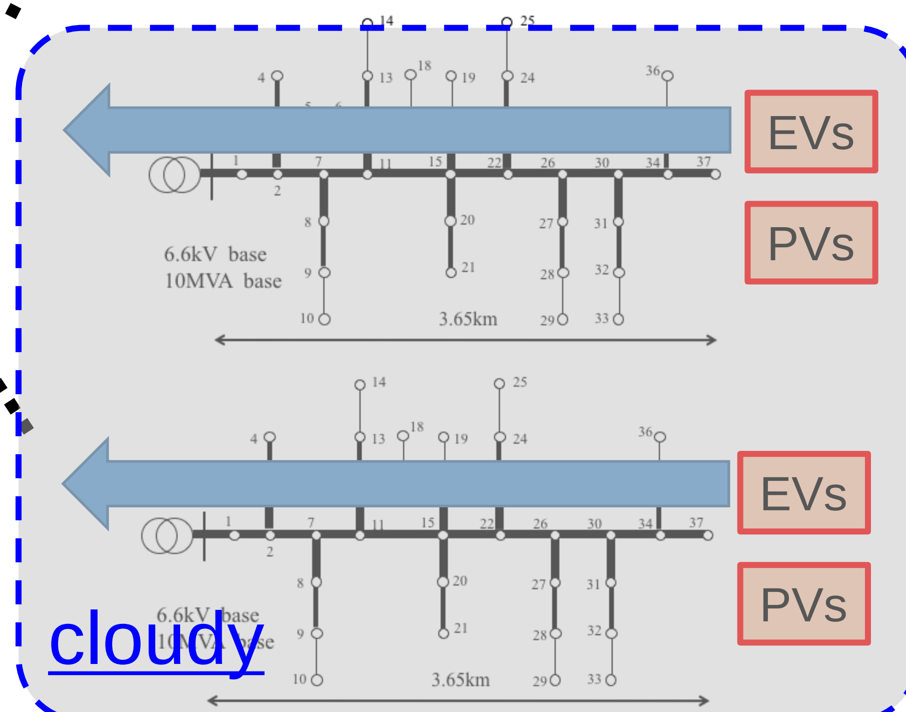


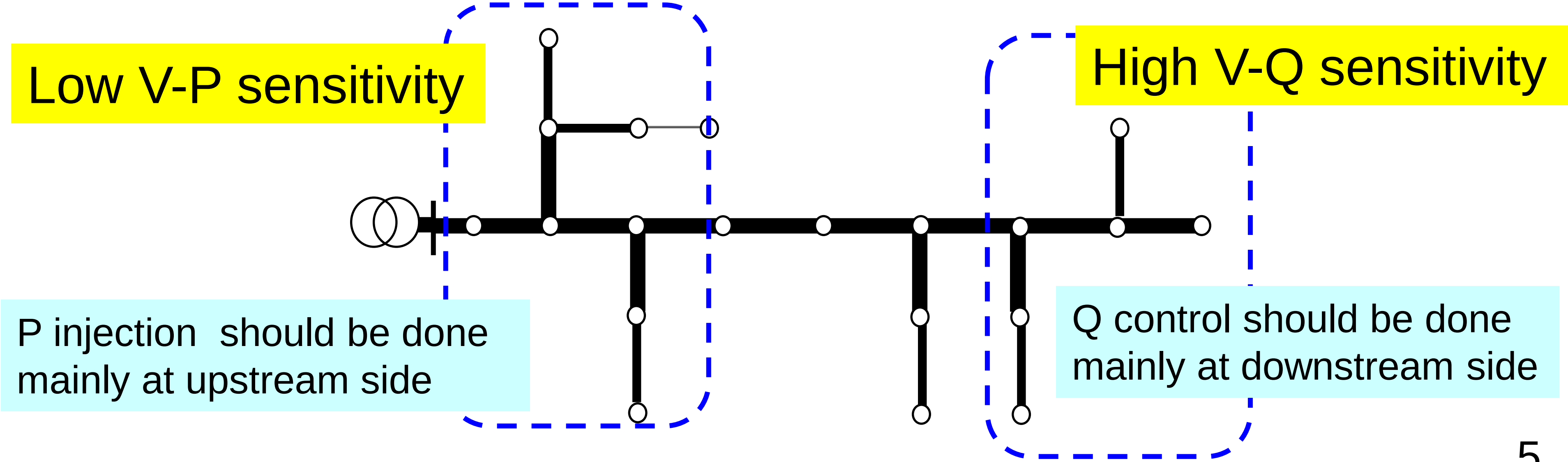


When balancing power is provided by distribution level, bottleneck in distribution level has to be considered.



Main Purpose

- To develop the maximization method of balancing power to be provided with main grid from distribution system with improving voltage and overloading bottlenecks.
- The problem is formulized as "optimization problem" supposing centralized control signals are sent to all the PVs and EVs.



Assumptions

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- Both discharging and charging are available from EVs.

- Flexible P and Q controls are available from PCS of PVs and EVs within the current limitation.

- Final goad of this control strategy is to develop decentralized (or autonomous decentralized) control method which can follow the control signal for balancing power without using centralized calculation with high control speed.

Distribution System Model for Residential Area

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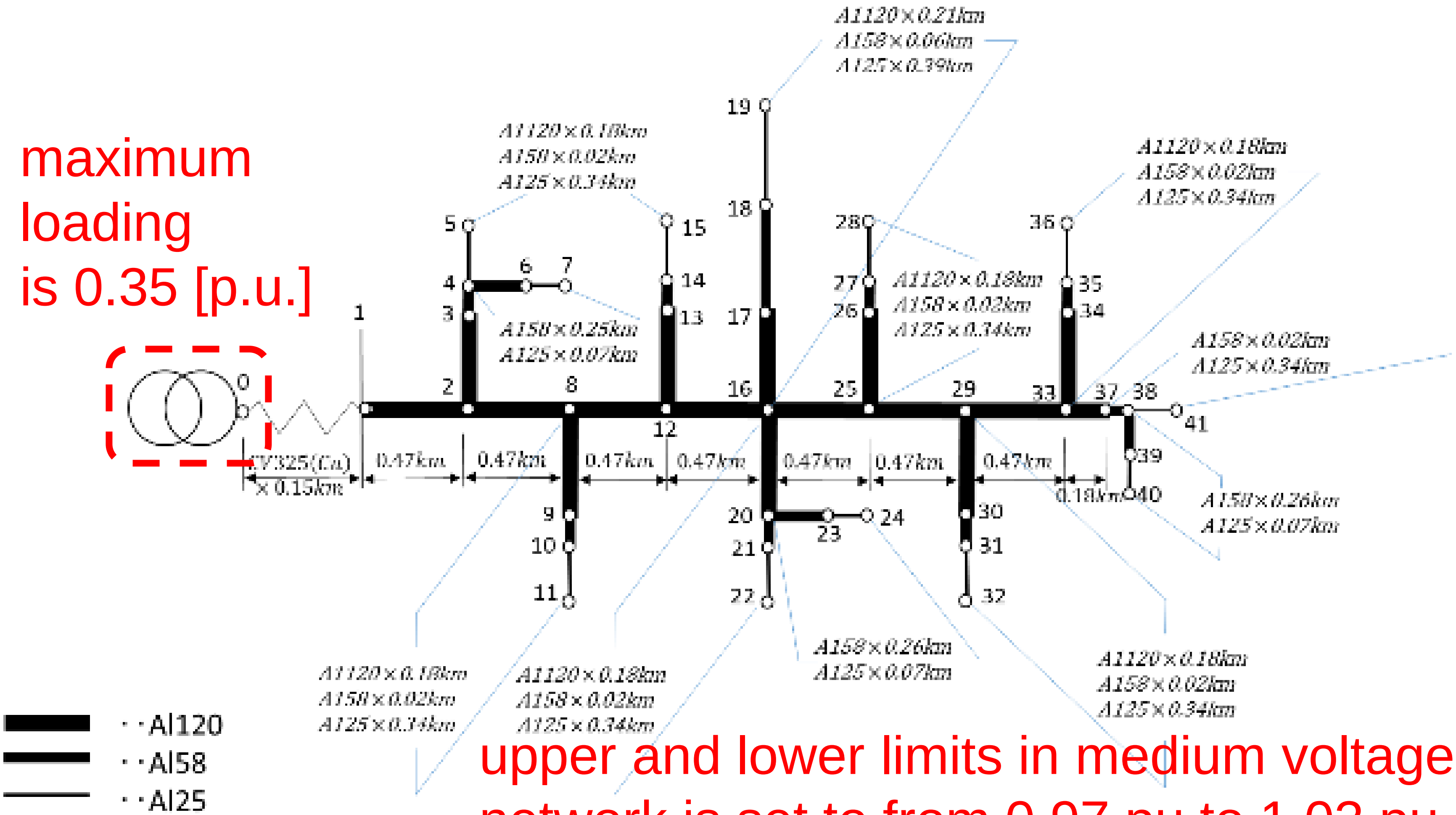
maximum loading is 0.35 [p.u.]



upper and lower limits in medium voltage network is set to from 0.97 pu to 1.03 pu.

Total load : 500kW, total capacity of PV and EV: 2.5MW, EV2.5MW (distributed to all nodes uniformely)

Optimization

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Objective function

$$\left|P_{flow,SS,ref} - P_{flow,SS}\right| + \alpha \sum_i (P^*_{PVi} - P_{PVi}) \to \min.$$

constraint conditions

$$P_{Gi} + P_{DGi} - P_{Li} = \sum_{j=1}^{N} V_i V_j (G_{ij} \cos\phi_{ij} + B_{ij} \sin\phi_{ij})$$

$$Q_{Gi} + Q_{DGi} - Q_{Li} = \sum_{j=1}^{N} V_i V_j (G_{ij} \sin\phi_{ij} - B_{ij} \cos\phi_{ij})$$

(power flow equation)

$$V_{i,\min} \le V_i \le V_{i,\max}$$ (upper and lower limits of voltage profile)

$$I_{DT} \le I_{DT,\max}$$ (thermal limit at distribution substation)

decision variables

$$\sqrt{P^2_{EVi} + Q^2_{EVi}} \le S_{EVi}$$

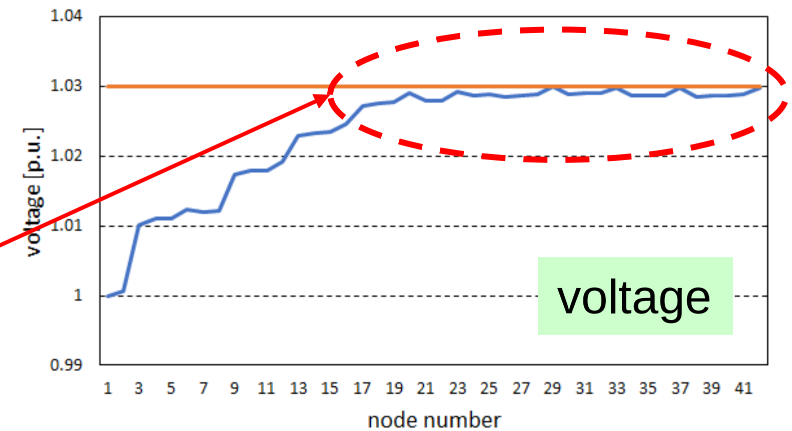
(PCS capacity constraint for EV, and PV)

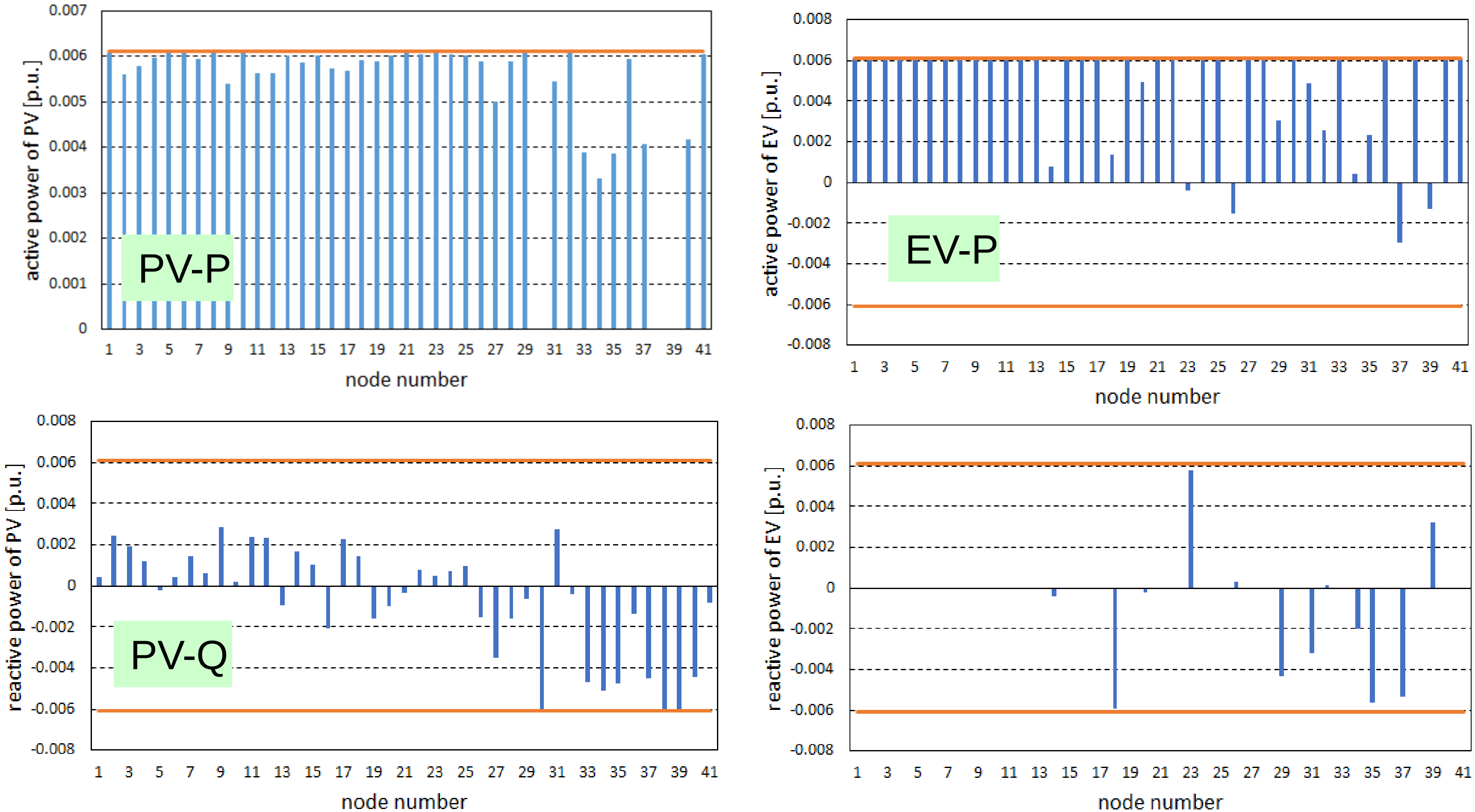
$$P_{PVi} = \begin{cases} \sqrt{S^2_{PVi} - Q^2_{PVi}} & if\ P_{PVi} \le P^*_{PVi} \\ P^*_{PVi} & else \end{cases}$$

$$-S_{PVi} \le Q_{PVi} \le S_{PVi}$$

$P_{DT,set}$ = -0.35 p.u.

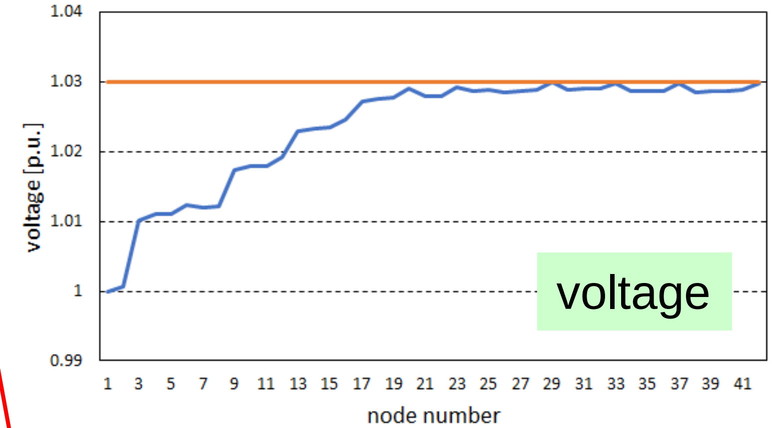
voltage profile reaches upper limit in the end of feeder line

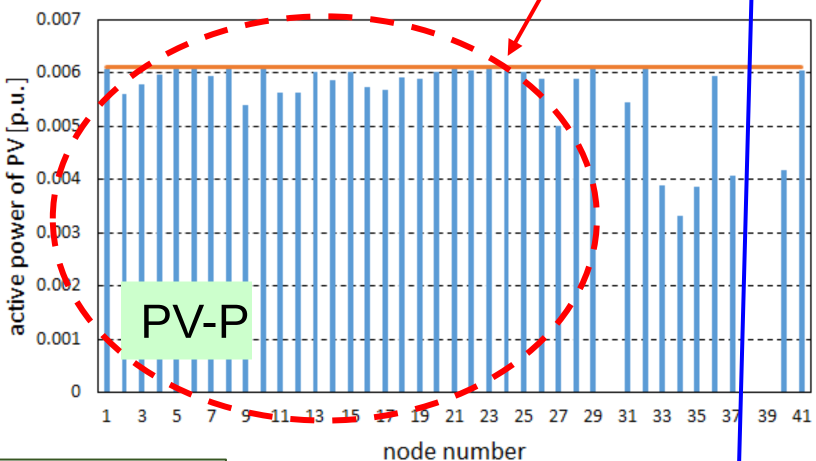


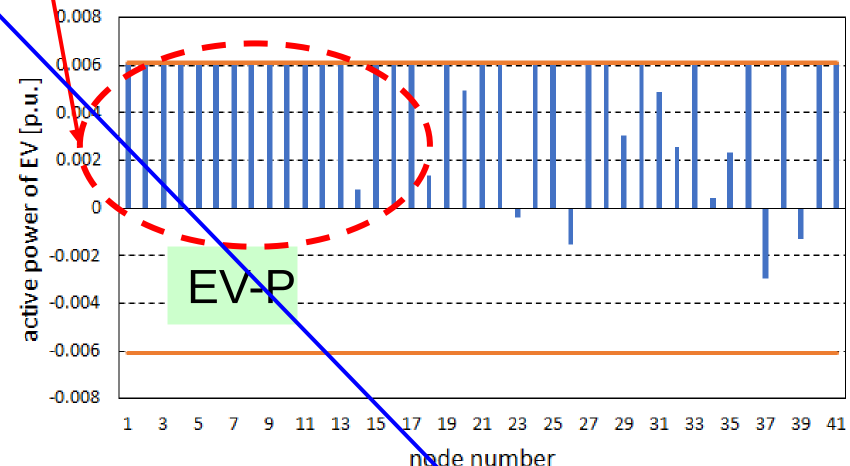


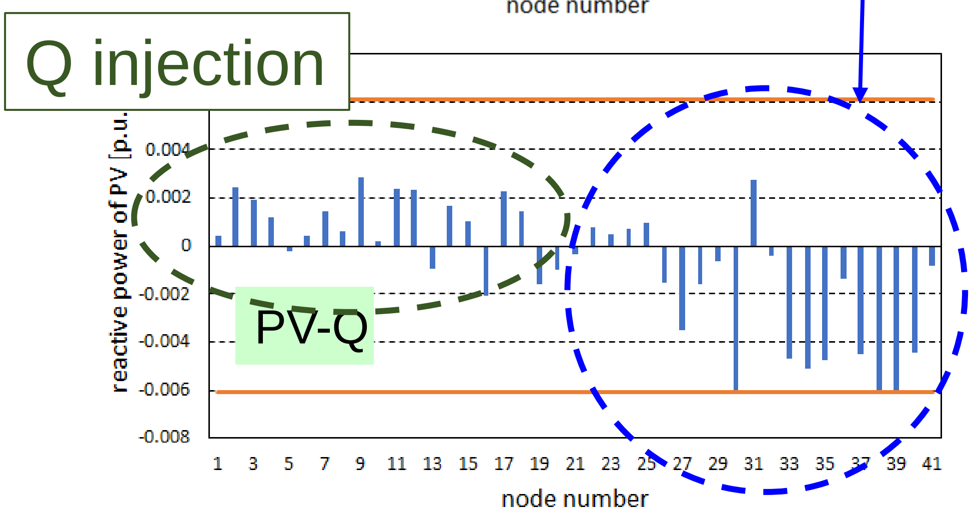
$P_{DT,set}$ = -0.35 p.u.

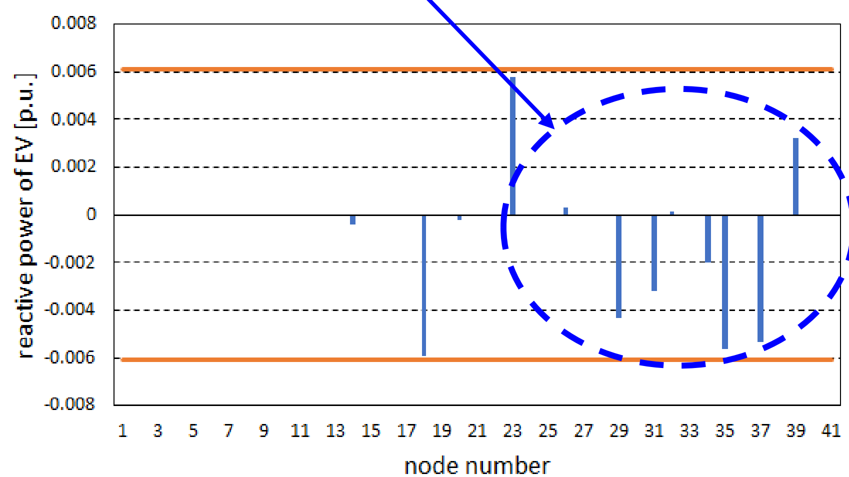
active power injection mainly at upstream side and Q control at downstream side











Reactive Power profile

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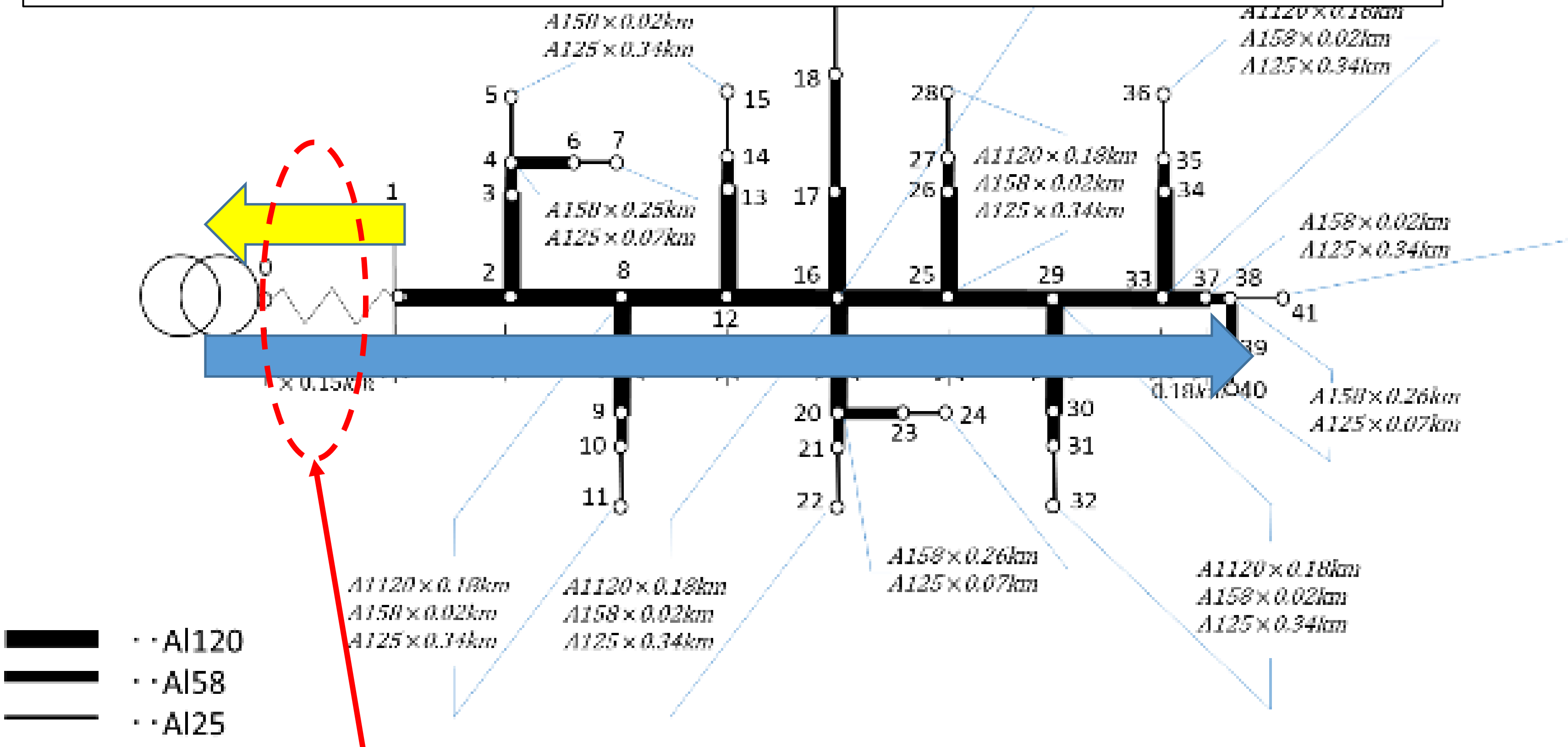
active power flow at distribution substation becomes almost 0.35 p.u. (reference value)



overloading will be caused by reactive power absorption at the end of feeder line.

Reactive Power profile

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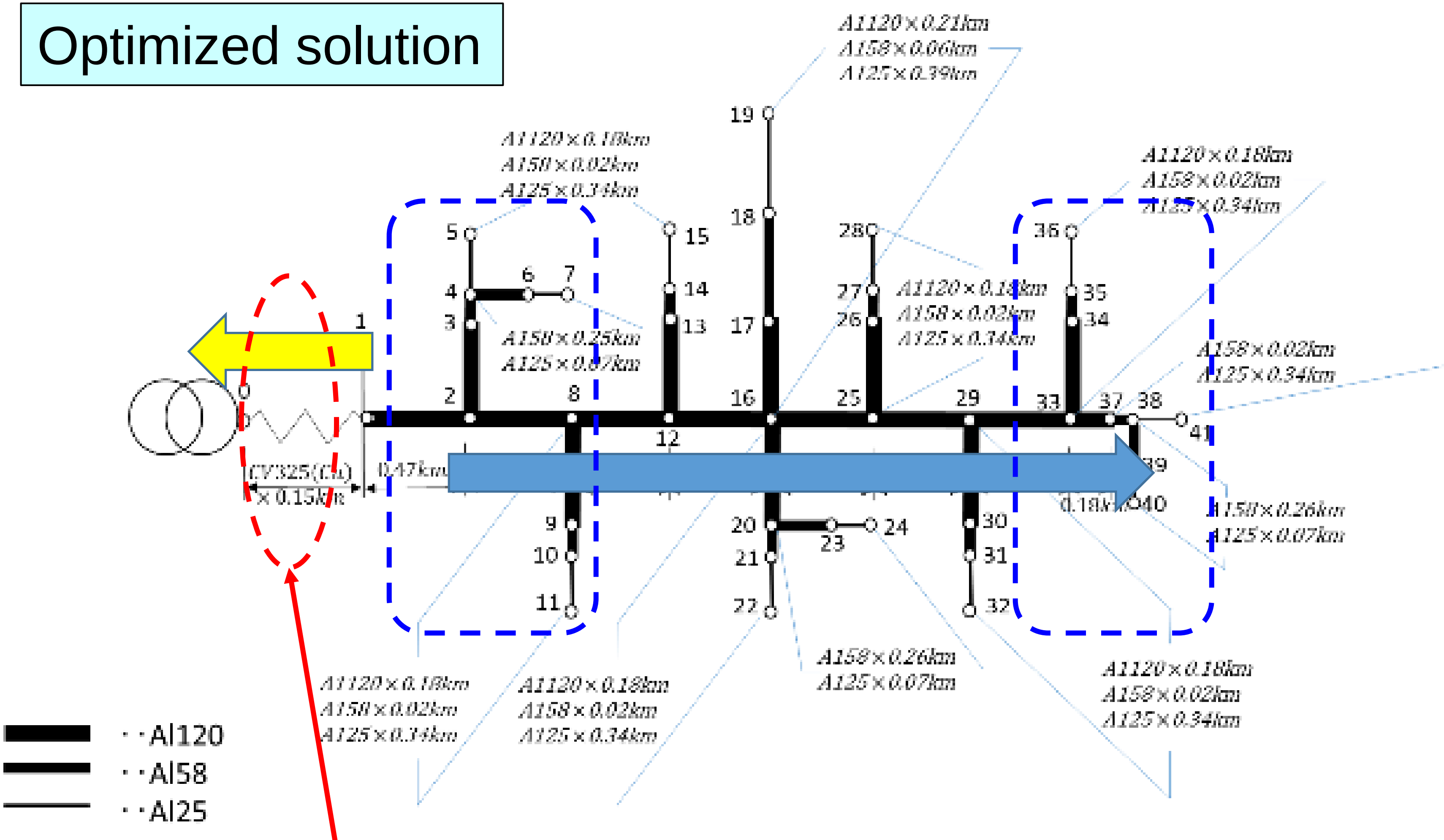
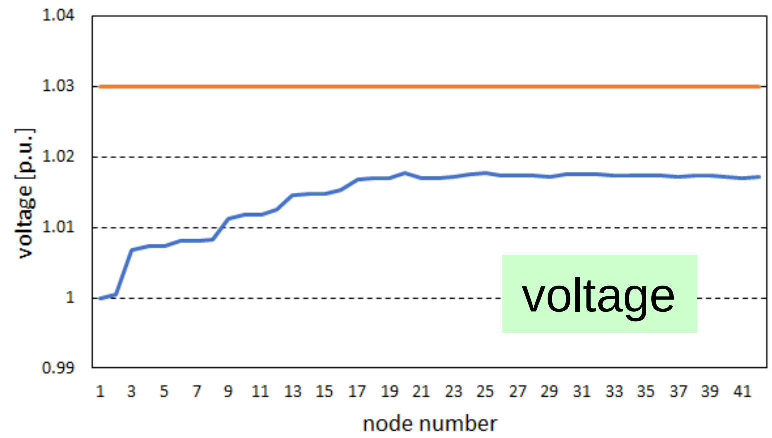
Optimized solution

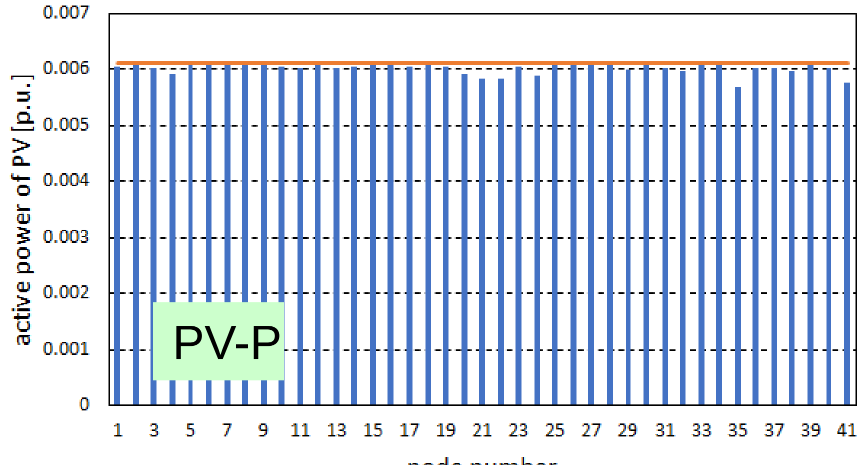


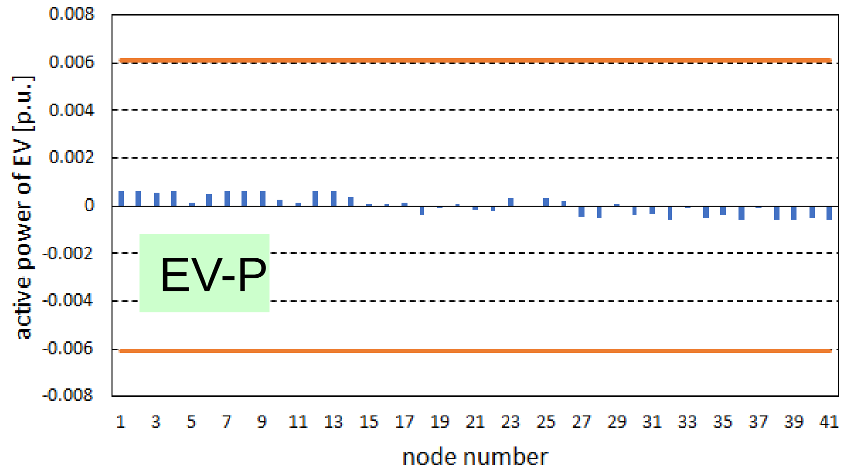
overloading can be avoided by injecting Q at upstream side

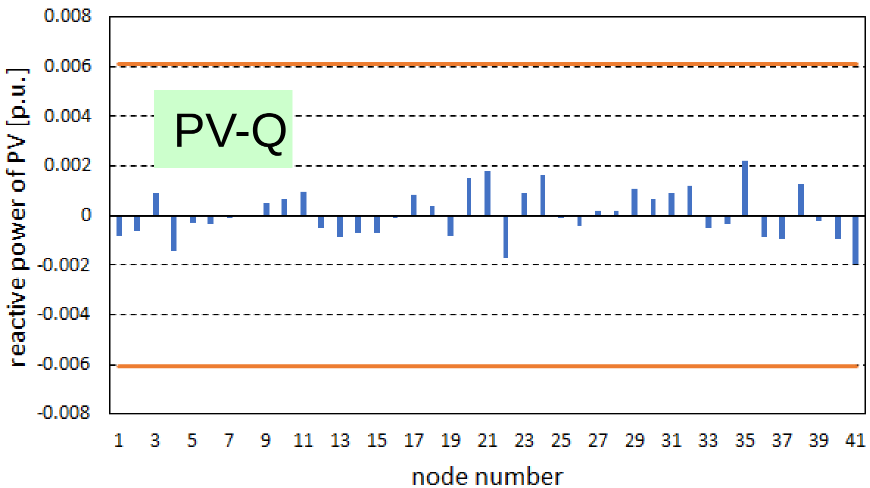
$P_{DT,set}$ = -0.20 p.u.

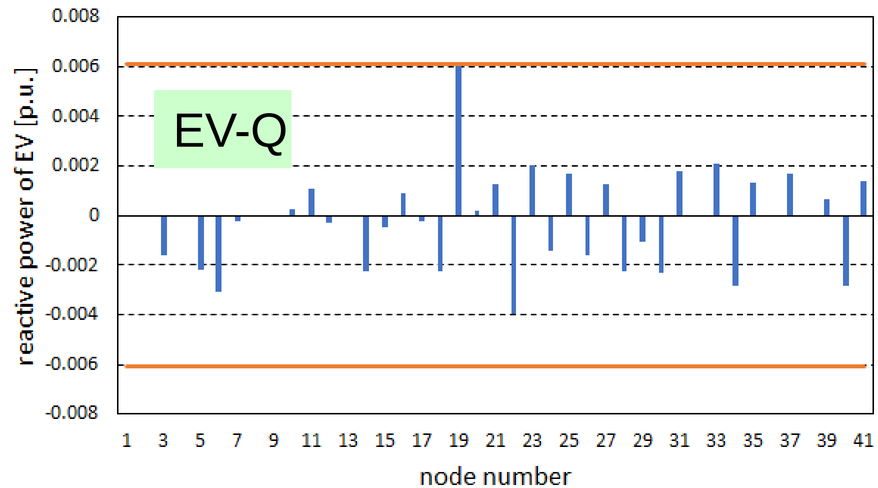
without any curtailment or charging control, reverse power flow follows the reference value





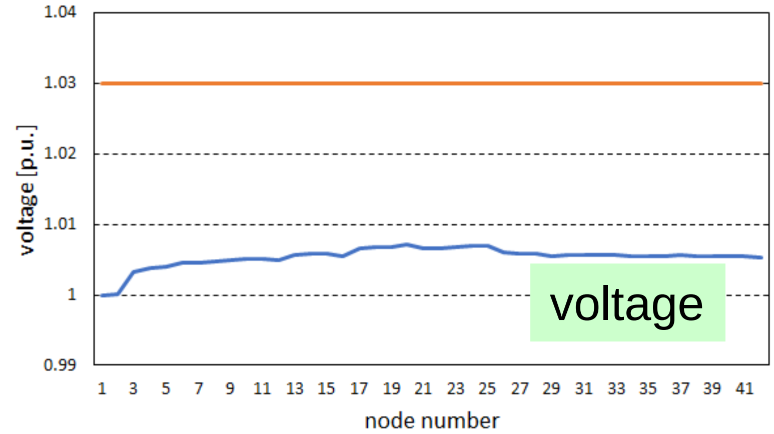


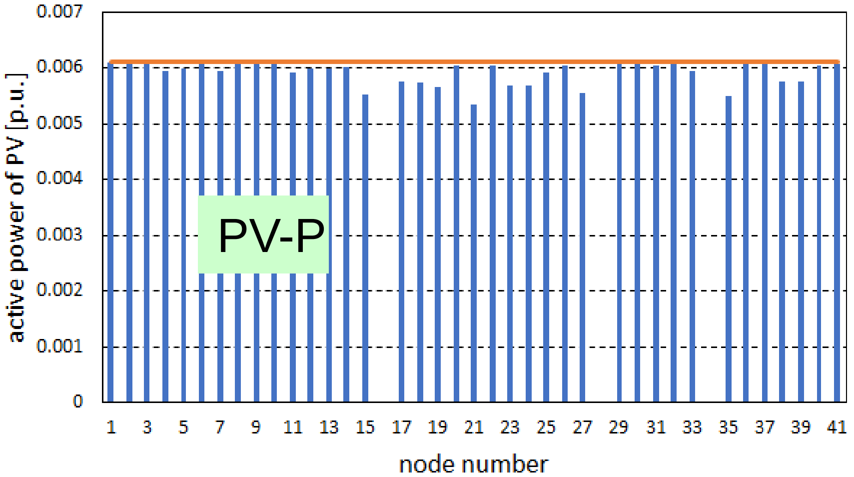


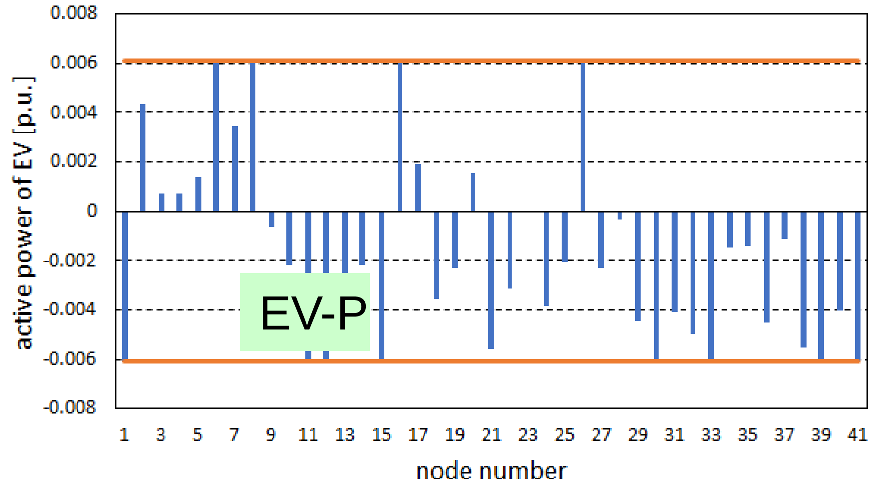


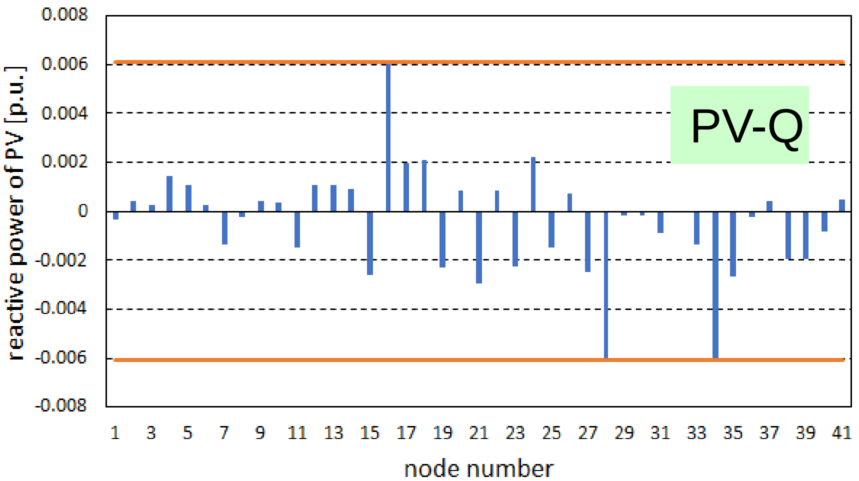
$P_{DT,set}$ = -0.10 p.u.

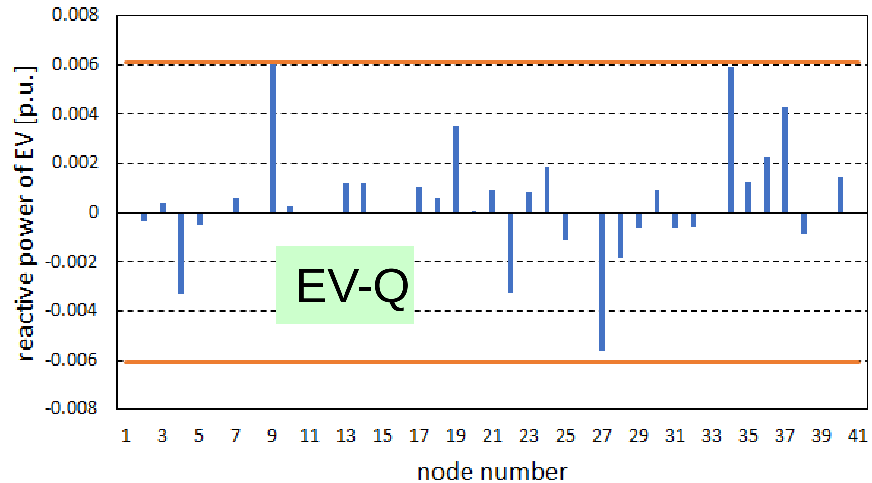
active power curtailment charging control are used to reduce the reverse power flow











Conclusions

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- Active power control at upstream side and reactive power control at downstream side is reasonable to mitigate the impact on voltage profile when reverse power flow has to be increased.
- In order to avoid overload at distribution transformer, the reactive power injection at upstream side is effective.

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Based on these knowledge, the control strategy should be changed to decentralized or autonomous decentralized control approach in order to realize high speed control which can follow the control signal for secondary control.