Risk-Aware Optimal Droop Gain Determination to Minimize Voltage Violation Risk in AC/DC Hybrid Microgrid

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Introduction

- **Why AC/DC Hybrid Microgrid(HMG)?**
  - Improving DER hosting capacity
  - Improving grid stability and efficiency

Fig. 1. The simplified target HMG

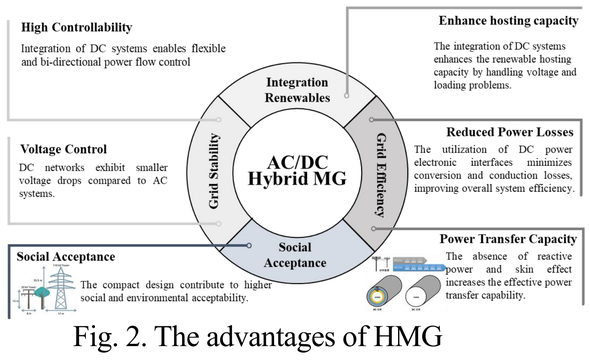


Fig. 2. The advantages of HMG

- **Increasing uncertainty with DER penetration**
  - Uncertainties in DER
    - forecast error, output fluctuation
  - Impact of uncertainties
    - **Voltage violation issue**, power imbalance

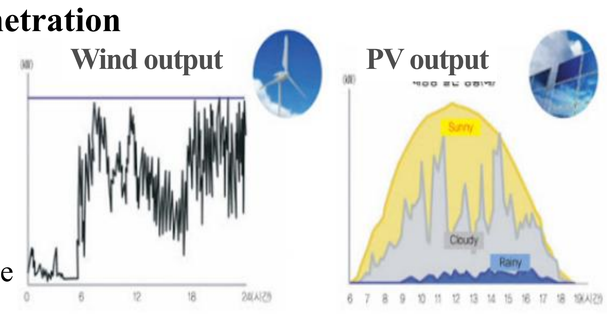


Fig. 3. Intermittent characteristic of DERs

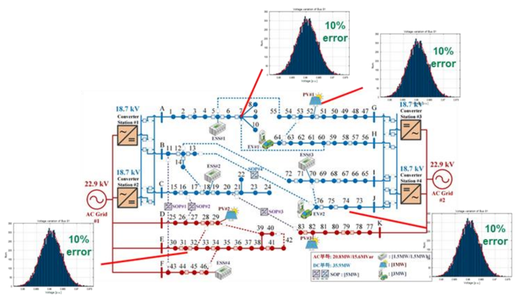
Probabilistic analysis is required to mitigate voltage violation issues

Probabilistic power flow

Methodology

- Using voltage sensitivity matrix, standard deviation of each bus voltage is calculated

$$\Delta \boldsymbol{V} = \boldsymbol{S}_P^V \Delta \boldsymbol{P} + \boldsymbol{S}_Q^V \Delta \boldsymbol{Q}. \rightarrow \boldsymbol{\sigma}_v^2 = \boldsymbol{S}_P^{V^2} \boldsymbol{\sigma}_P^2 + \boldsymbol{S}_Q^{V^2} \boldsymbol{\sigma}_Q^2,$$



Bus Num.	62	61	60	59	9
V(μ, σ)	[0.9604, 3.87e-3]	[0.9605, 3.80e-3]	[0.9607, 3.77e-3]	[0.9609, 3.70e-3]	[0.9610, 3.76e-3]
Prob. of within acceptable range	90%	92%	93%	94%	94%

Bus Num.	8	10	7	77	58
V(μ, σ)	[0.9611, 3.70e-3]	[0.9611, 3.70e-3]	[0.9613, 3.70e-3]	[0.9615, 3.70e-3]	[0.9618, 3.66e-3]
Prob. of within acceptable range	94%	94%	95%	96%	96%

Fig. 4. Bus voltage mean, standard deviation, voltage violation probability under uncertainty (PPF results)

Proposed droop gain determination method

Basic idea of proposed method

- Reduce voltage violation probability to below 1% by adjusting droop gains
- Droop gain adjustment → Changes in voltage standard deviation → Reduce in voltage violation risk

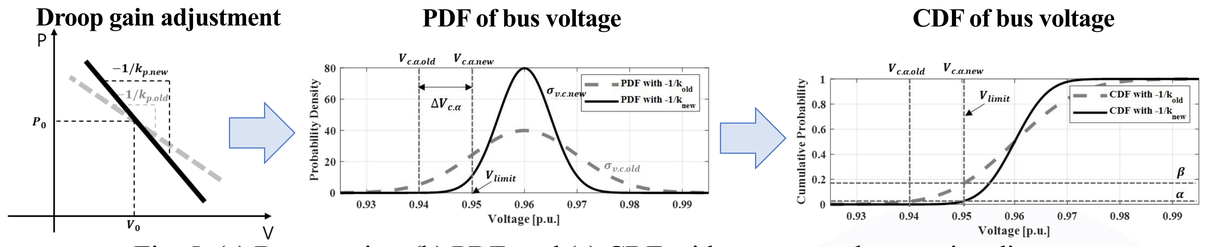


Fig. 5. (a) Droop gains, (b) PDF, and (c) CDF with respect to droop gain adjustments

- Derivation of the required standard deviation variation to maintain the voltage violation probability below 1%

$$\Delta \sigma_{v.c} = \frac{1}{Z_\alpha} (\boldsymbol{S}_P^{V_c} \boldsymbol{S}_{k_p}^P \Delta \boldsymbol{k}_p + \boldsymbol{S}_Q^{V_c} \boldsymbol{S}_{k_q}^Q \Delta \boldsymbol{k}_q).$$

Framework of proposed method

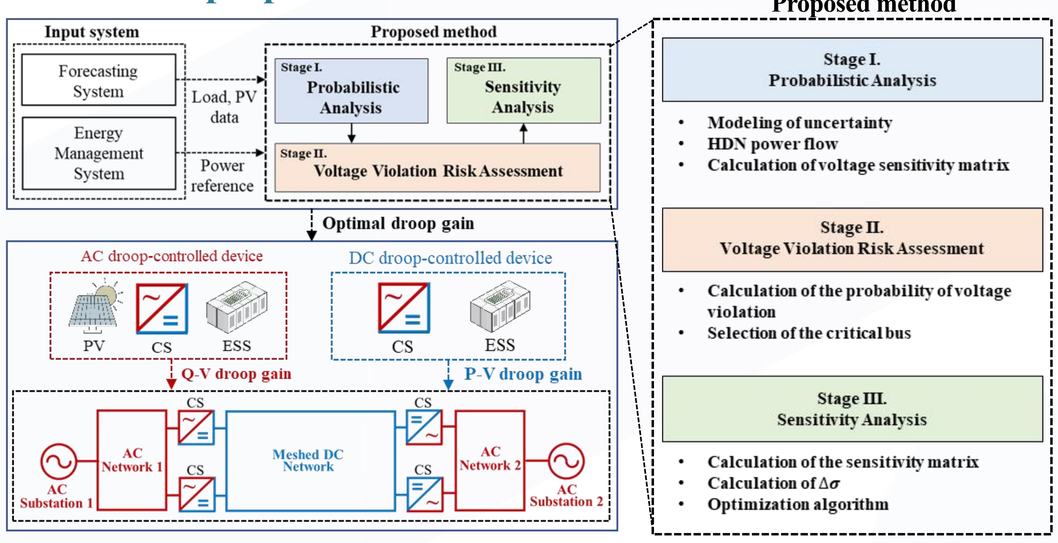


Fig. 6. Framework of proposed method

Optimization algorithm

Objective fcn.

$$\min . \sum_{i \in B_{ac}^{drp}} \left[\omega_{Q,i} (\Delta k_{q,i})^2\right] + \sum_{j \in B_{dc}^{drp}} \left[\omega_{P,j} (\Delta k_{p,j})^2\right]$$

AC DC

Decision variable
- Converter station, ESS,PV droop gain

$$\boldsymbol{x} = [\Delta \boldsymbol{k}_q^T \quad \Delta \boldsymbol{k}_p^T]^T$$

Weight factor

$$\omega_{P,i} = \frac{1}{K} \times m_{P,i} \times n_{P,i}, \quad i \in B_{dc}^{drp}$$

AC/DC interdependency Voltage limit Capacity limit

Constraints
- Voltage, Current limit
- Standard deviation
- Amount of Droop gain variation

$$V_{down.lim} \le V_i \le V_{up.lim},$$
$$|I_i| \le I_{lim},$$
$$\Delta \sigma_{v.c.\Delta k} \ge \Delta \sigma_{v.c},$$
$$|\Delta k_{q.i}| \le k_{q.i.old}/1.3,$$
$$|\Delta k_{p.j}| \le k_{p.j.old}/1.3.$$

Fig. 7. Optimization algorithm of proposed method

Case Study

System Configuration

- 2 substations, 11 Feeders
- 2 decoupled AC MG (22.9 kV)
  - 20.8MW load, 4 PVs, 1 ESS
  - AC system 1 : DER rich system
- Meshed DC MG (20 kV)
  - 34.7 MW load, 6 PVs, 3 ESS

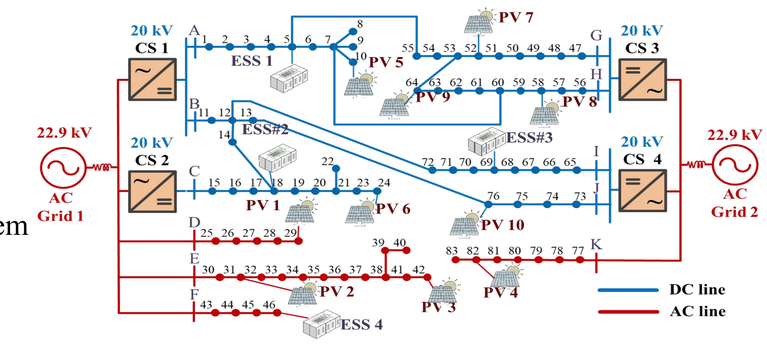


Fig. 8. System Configuration

Necessity of optimal droop gain determination

- Power variations in the DC network influence the AC side
  - AC/DC interdependency
- DC droop changes → AC voltage changes

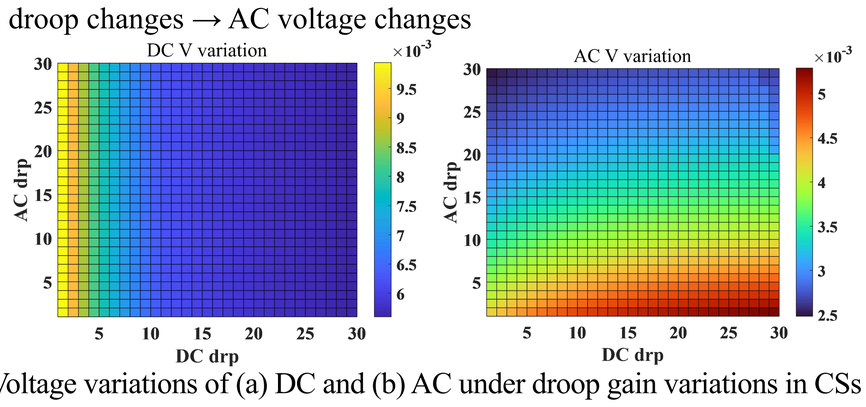


Fig. 9. Voltage variations of (a) DC and (b) AC under droop gain variations in CSs 3 and 4

Case 1 : Voltage violation risk in AC MGs

- Voltage violation risk in AC MG 1 and 2 (max prob. 3.1%)
  - Bus 34, 35, and 83
- By adjusting both AC and DC droop gains, Probability of voltage violation is mitigated

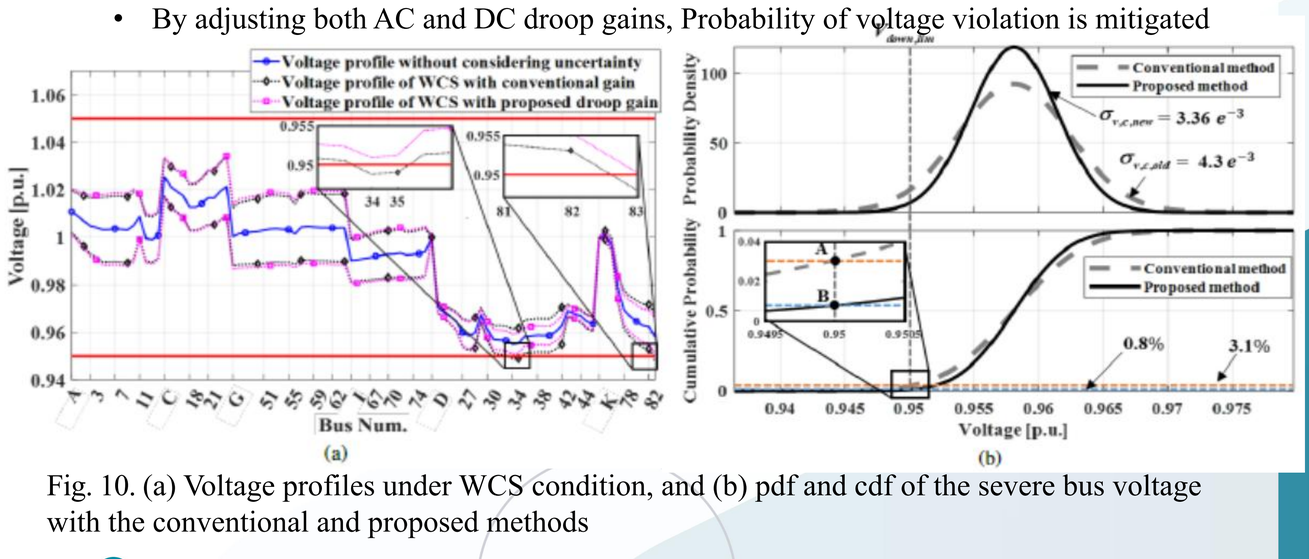


Fig. 10. (a) Voltage profiles under WCS condition, and (b) pdf and cdf of the severe bus voltage with the conventional and proposed methods

Case 2 : Voltage violation risk in AC MG and DC MG

- Voltage violation risk in AC MG 2 and DC MG (max prob. 11.1%)
  - A total of 23 buses, including Bus 10(DC), Bus 83(AC)
- By adjusting both AC and DC droop gains, Probability of voltage violation is mitigated

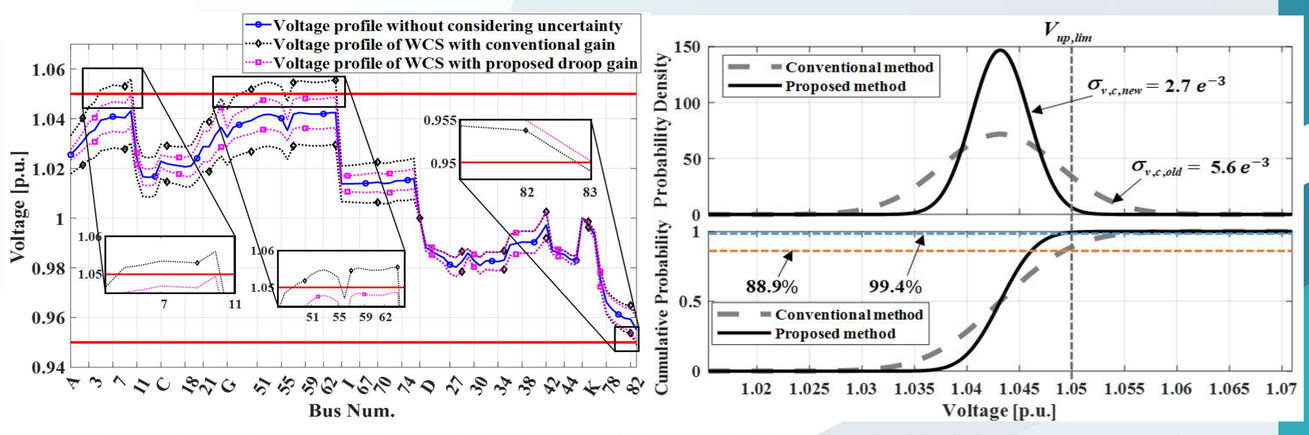


Fig. 11. (a) Voltage profiles under WCS condition, and (b) pdf and cdf of the severe bus voltage with the conventional and proposed methods

Discussion & Conclusion

Minimizing the probability of voltage violation to below 1% by optimal droop gain adjustment

Validation of the proposed method in HMG with a high penetration of uncertain resources