Distributed Control of AC/DC Microgrid Voltage Containing EVs

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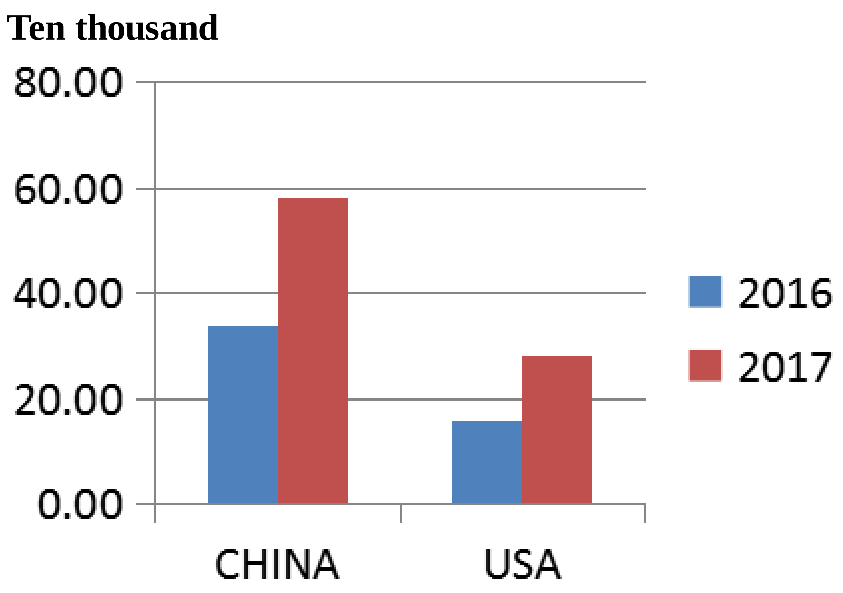
Outlines

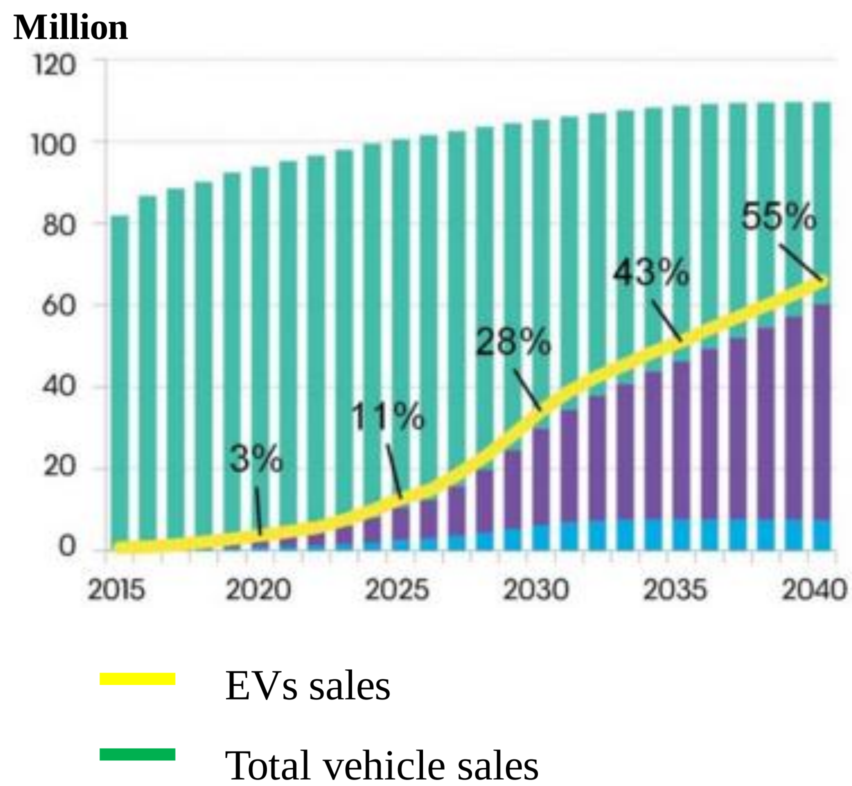
1. Introduction
2. Relationship between voltage and power incensement in AC&DC-HMG
3. Distributed voltage regulation algorithm
4. Simulation results and discussion

Current status of electric vehicles

Annual sales of EVs In China



(2015-2040)Annual sales volume and forecast of global vehicle



Introduction

Challenges of EVs integration into power system

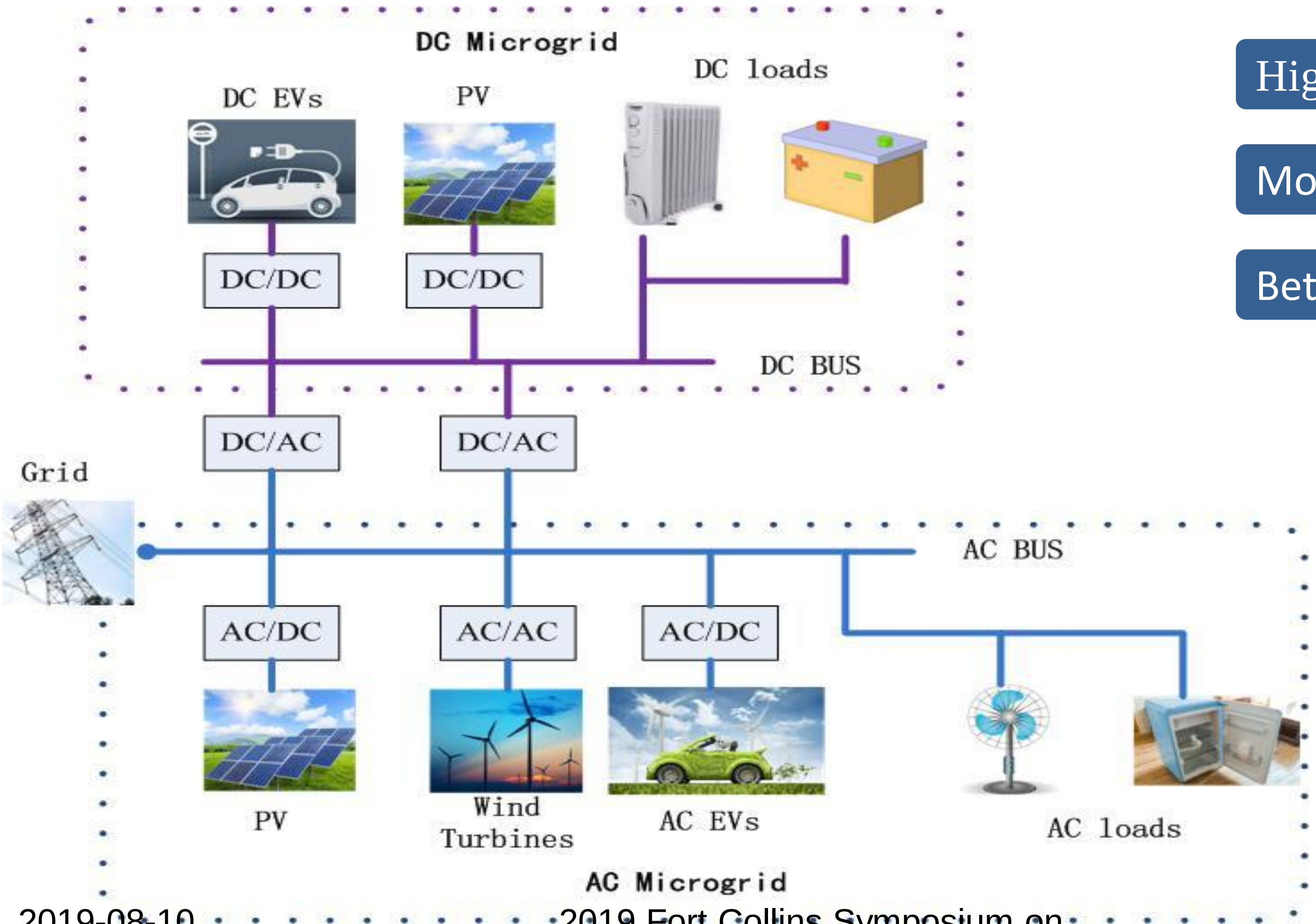
large-scale EVs integration

Disordered charging

- Voltage fluctuations
- Frequency fluctuations
- Gird harmonic distortion
- Other problems

Introduction

AC&DC hybrid microgrid



- Higher efficiency
- More reliable
- Better Expandability

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Relationship between Voltage Deviation and Power Increment in AC-MGs

In MGs:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial U} \\ \frac{\partial Q}{\partial \theta} & \frac{\partial Q}{\partial U} \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \Delta U / U \end{bmatrix} = \begin{bmatrix} M & N \\ K & L \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \Delta U / U \end{bmatrix}$$

$$M_{ij} = U_i U_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij})$$

$$M_{ij} = -U_i \sum_{\substack{j=1 \\ j \neq i}}^{N} U_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij})$$

$$L_{ij} = -U_i (G_{ij} \sin\theta_{ij} + B_{ij} \cos\theta_{ij})$$

$$L_{ij} = \sum_{\substack{j=1 \\ j \neq i}}^{N} U_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij})$$

Higher R/X in MGs

$$M \approx 0; L \approx 0$$

$$\Delta U / U = N^{-1} \Delta P$$

$$\Delta \theta = K^{-1} \Delta Q$$

Relationship between Voltage Deviation and Power Increment in DC-MGs

Different from AC-MGs, the line of DC-MGs is only of the resistance characteristics

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_2 \\ \cdots \\ \Delta P_4 \end{bmatrix} = \begin{bmatrix} N_{11} & N_{12} & \cdots & N_{1n} \\ N_{21} & N_{22} & \cdots & N_{11} \\ \cdots & \cdots & \cdots & \cdots \\ N_{n1} & N_{n2} & \cdots & N_{nn} \end{bmatrix} \begin{bmatrix} \dfrac{\Delta U_1}{U_1} \\ \dfrac{\Delta U_2}{U_2} \\ \cdots \\ \dfrac{\Delta U_n}{U_n} \end{bmatrix} \Rightarrow \Delta \boldsymbol{U} / \boldsymbol{U} = \boldsymbol{N}^{-1} \Delta \boldsymbol{P}$$

This paper:

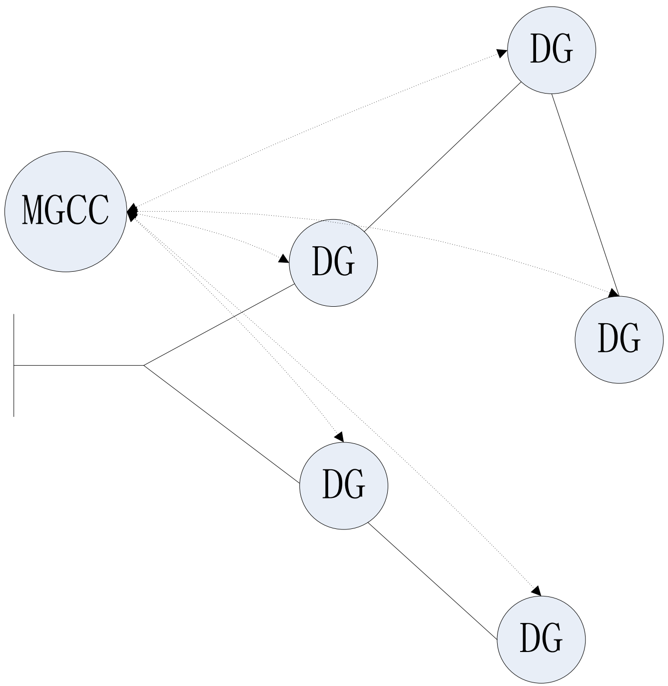
Thus, ΔU are mainly related to ΔP in the AC-MGs and DC-MGs

The EVs are used as active power units to regulate the bus voltages

Outlines

Distributed voltage regulation algorithm

Centralized algorithm



1.Central controller.

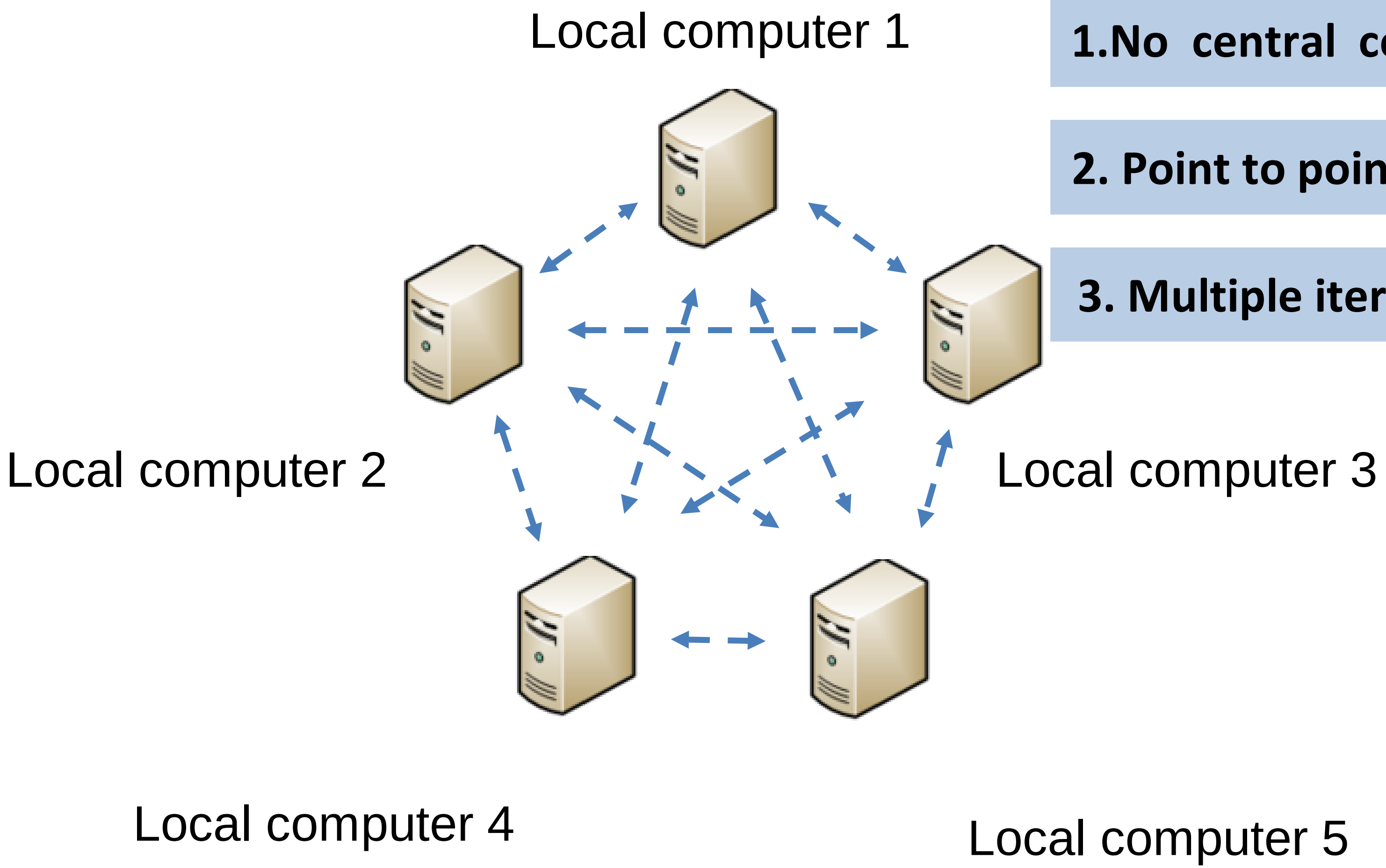
2.High communication burden.

3. Communication period is longer.

4. Lower expandability.

Distributed voltage regulation algorithm

Decentralized algorithm - Gossip Algorithm



1.No central controller

2. Point to point

3. Multiple iterations

Distributed voltage regulation algorithm

Objective Function

$$minF = \sum_{i=1}^{N} (\Delta U_i)^2 = \sum_{i=1}^{N} (U_i(\boldsymbol{\Delta P}) - \mathrm{U}_{\mathrm{REF}})^2$$

voltage deviations

voltage magnitudes

power increments

$$s.t. \qquad U_{imin} \le U_i \le U_{i\max}$$

$$\Delta P_{imin} \le \Delta P_i \le \Delta P_{i\max}$$

Distributed voltage regulation algorithm

Solution of the Proposed Model

$$\begin{aligned} &\min && F(x) \\ &s.t. && g_j(x) \geq 0,\ j = 1, \ldots m \end{aligned}$$

By the penalty function method

$$F' = F + \mu \sum_{i=1}^{M} (\min\{0, g_i(\boldsymbol{x})\})^2$$

quadratic function

$$F' = \frac{1}{2} \boldsymbol{x}^T \boldsymbol{H} \boldsymbol{x} + \boldsymbol{c}^T \boldsymbol{x}$$

optimal solution

$$\boldsymbol{x}^* = -\boldsymbol{H}^{-1} \boldsymbol{c}$$

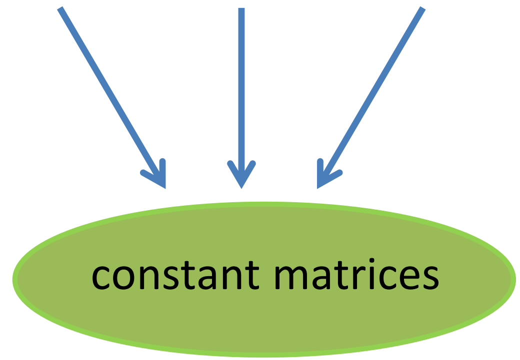
Distributed voltage regulation algorithm

Solution of the Proposed Model

$$\boldsymbol{H}=\begin{bmatrix} \frac{\partial^2 F'}{\partial x_1^2} & \frac{\partial^2 F'}{\partial x_1 \partial x_2} & \cdots & \frac{\partial^2 F'}{\partial x_1 \partial x_n} \\ \frac{\partial^2 F'}{\partial x_2 \partial x_1} & \frac{\partial^2 F'}{\partial x_2^2} & \cdots & \frac{\partial^2 F'}{\partial x_2 \partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2 F'}{\partial x_n \partial x_1} & \frac{\partial^2 F'}{\partial x_n \partial x_2} & \cdots & \frac{\partial^2 F'}{\partial x_n^2} \end{bmatrix}$$

&

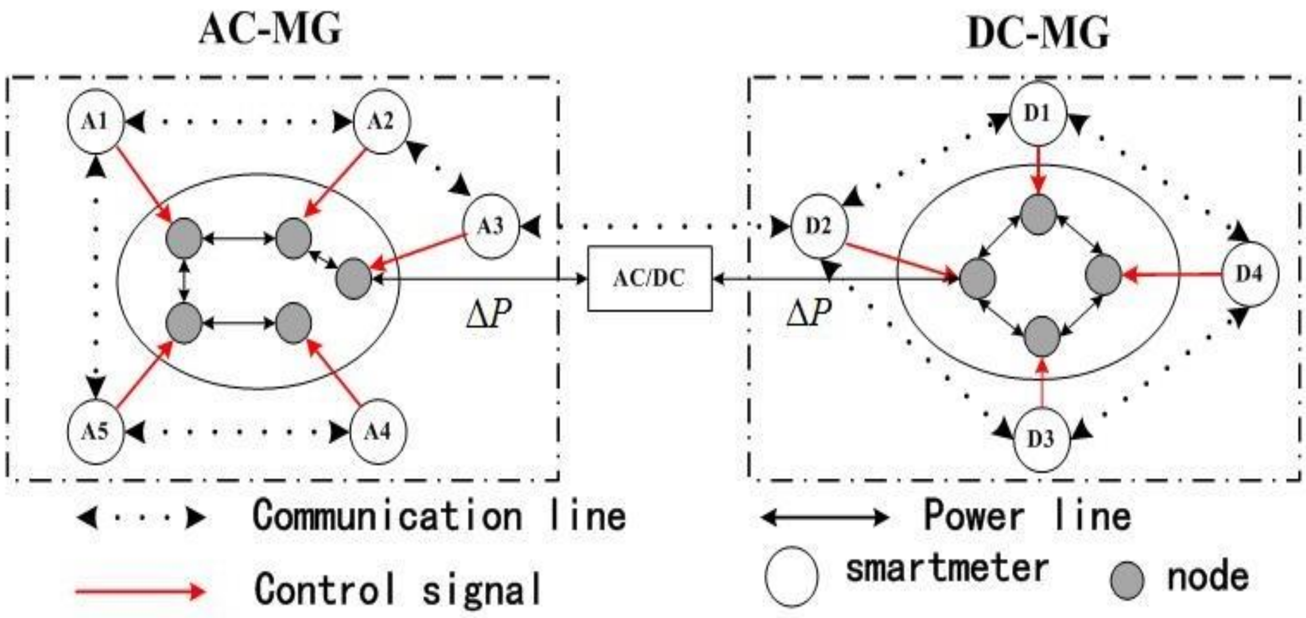
$$\boldsymbol{c} = \mathrm{k}^{U}\boldsymbol{U} + \mathrm{k}^{P}\boldsymbol{P} + \mathrm{k}^{C}\boldsymbol{C}$$



$$\boldsymbol{x}^* = -\boldsymbol{H}^{-1}\boldsymbol{c}$$

$$x^* = \Delta P_i^* = \sum_{j=1}^{N} H_{ij}^{-1}(\mathrm{k}_{ij}^{U} U_j + \mathrm{k}_{ij}^{P} P_j + \mathrm{k}_{ij}^{C} \mathrm{C}_j)$$

Distributed Voltage Regulation Strategy for AC&DC-HMG



Voltage regulation processing :

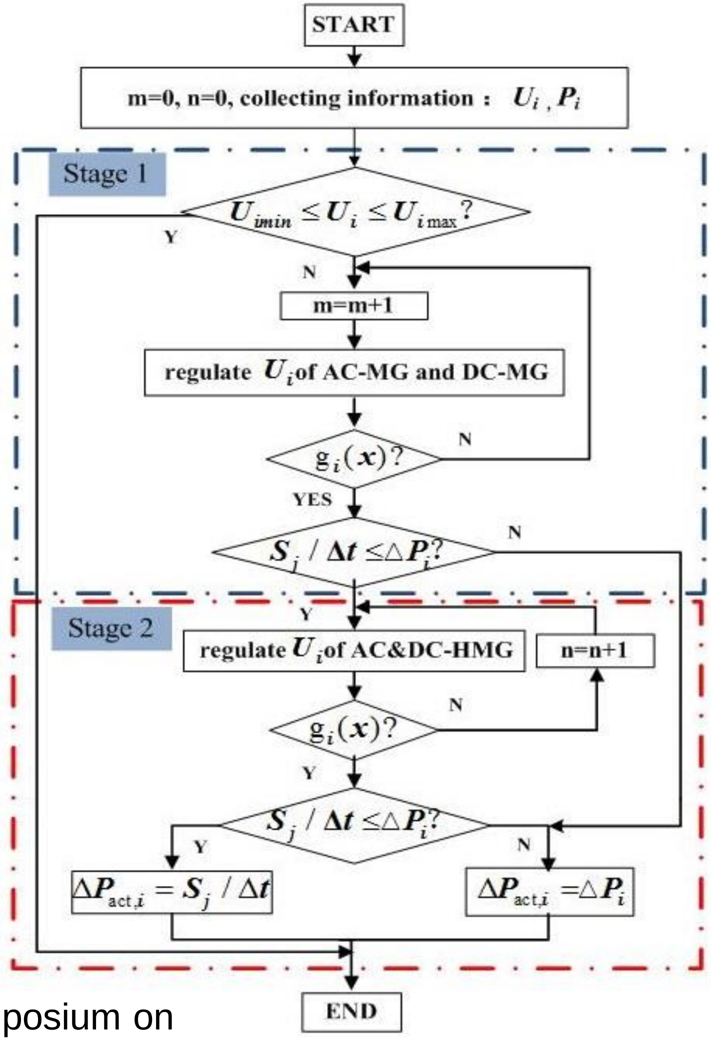
- Internal regulation
- unified regulation

Distributed voltage regulation algorithm

The whole voltage regulation processing

Stage 1: Each MG regulates its voltages by distributed voltage regulation algorithm.

Stage 2: There are six cases of the second stage voltage regulation.



Six cases of the second stage

Six cases of the second step

Scenarios	AC-MG voltages	EVs' scheduling capacity	AC-MG voltages	EVs' scheduling capacity
Case 1	$\leq 5\%$	----	$\leq 5\%$	----
Case 2	$\leq 5\%$	Enough	$> 5\%$	Not enough
Case 3	$\leq 5\%$	Not enough	$> 5\%$	Not enough
Case 4	$> 5\%$	Not enough	$\leq 5\%$	Enough
Case 5	$> 5\%$	Not enough	$\leq 5\%$	Not enough
Case 6	$> 5\%$	Not enough	$> 5\%$	Not enough

Different cases correspond to different solutions.

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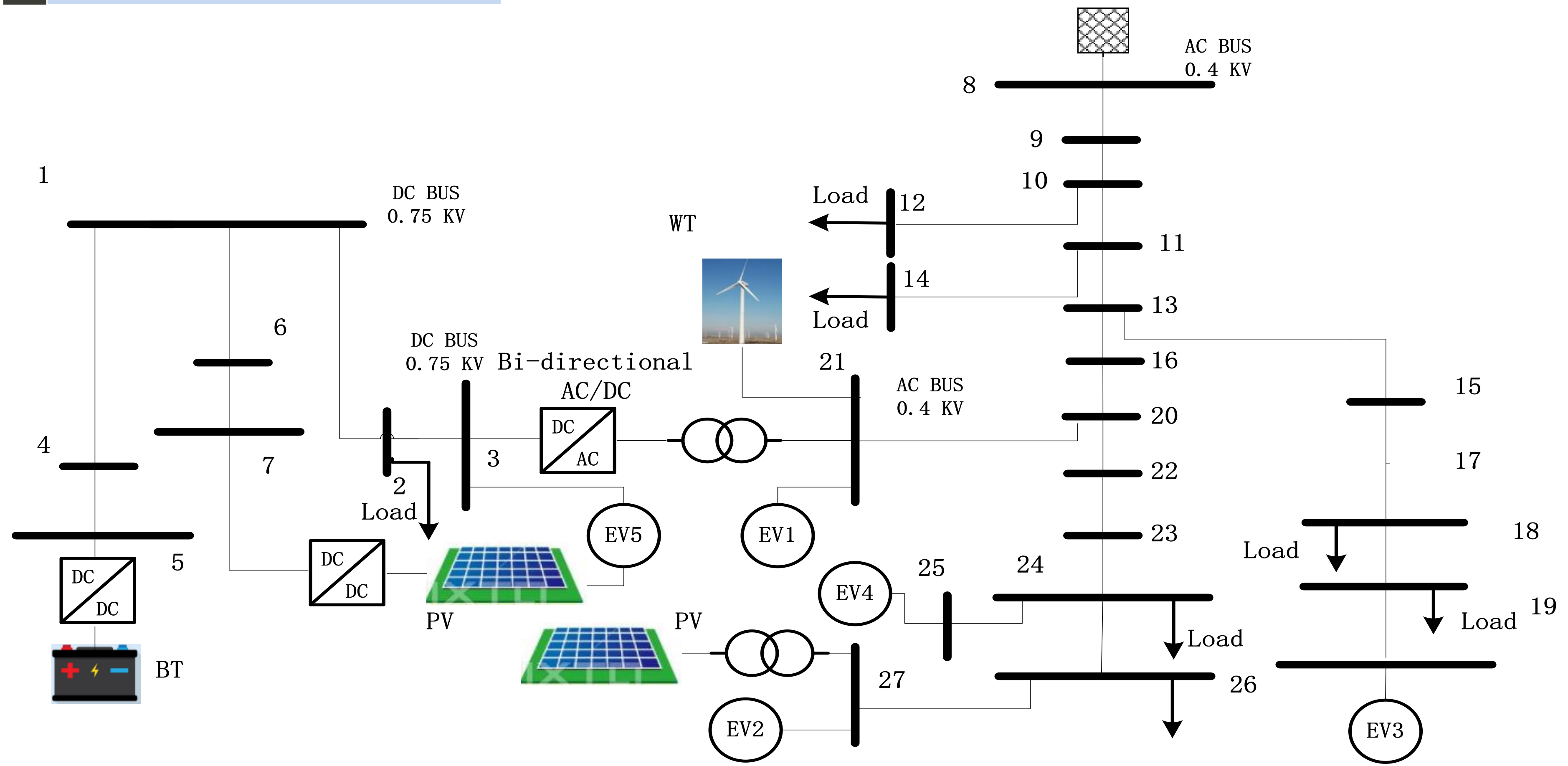
Simulation results and discussion

Microgrids topography



Simulation results and discussion

Parameter setting

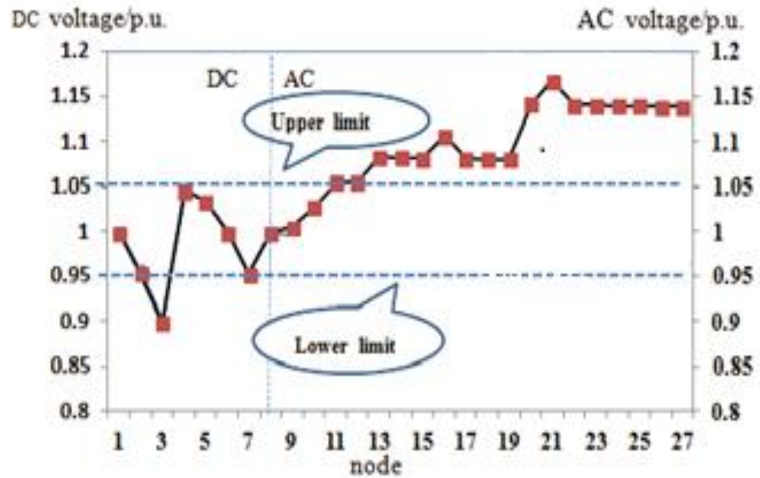
TABLE II. MAXIMUM CONTROLLED EVS POWER

Controllable Component	Maximum power to be dispatched/MW
EV 1	± 0.61
EV 2	± 0.79
EV 3	± 0.96

TABLE III. ACCESS POWER OF EACH NODE

Node	Active power/MW
Node 2 （load）	0.45
Node 5 （BT）	-0.5
Node 7 （PV）	0
Node 12（load）	0.00575
Node 14（load）	0.01395
Node 17（load）	0.0091
Node 18（load）	0.00605
Node 21（WT）	0.62
Node 27 （PV）	0

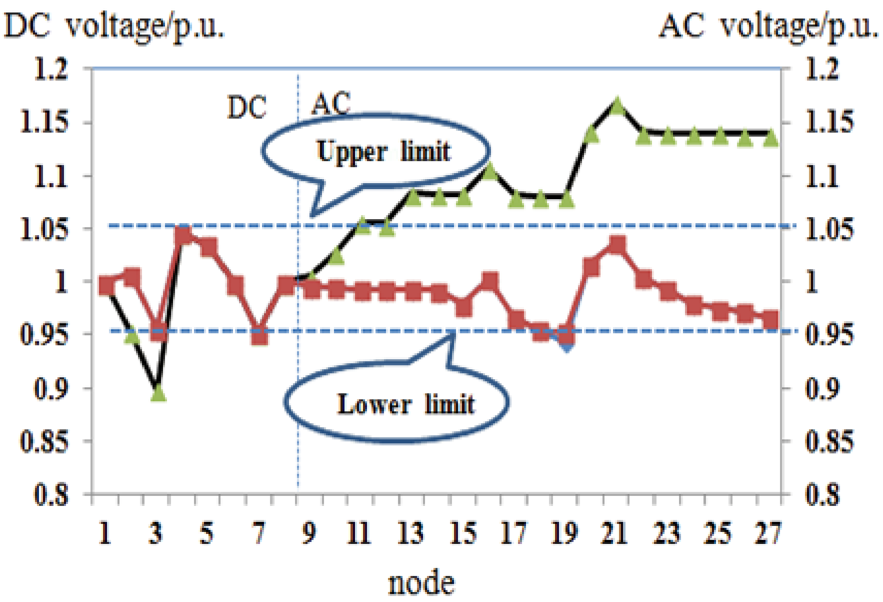
Initial voltages



The initial voltages of AC-MG and DC-MG are mostly over limits

Simulation results and discussion

Case 1

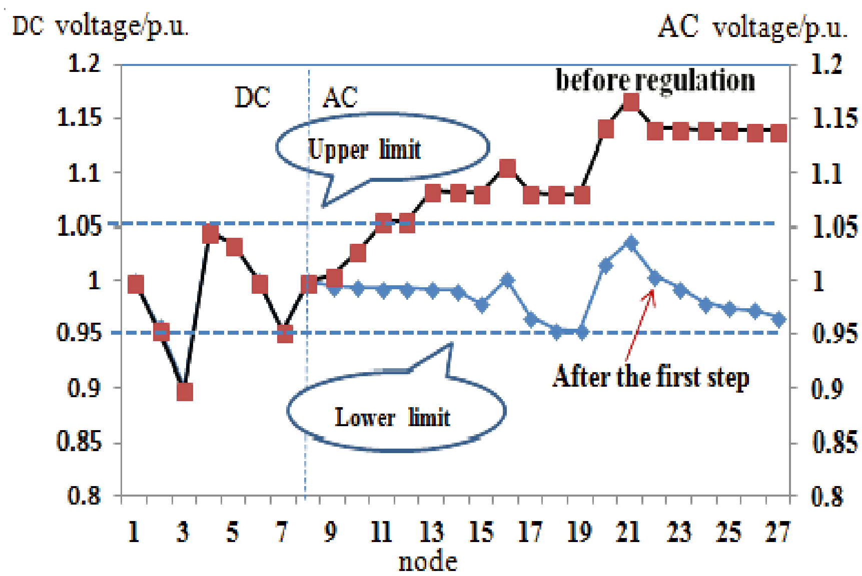


After voltage regulation for the first stage, the voltage fluctuation is within ±5%

$$\Delta P_{EV1} = -0.1843MW$$
$$\Delta P_{EV2} = -0.1056MW$$
$$\Delta P_{EV3} = -0.95MW$$

Simulation results and discussion

Case 2



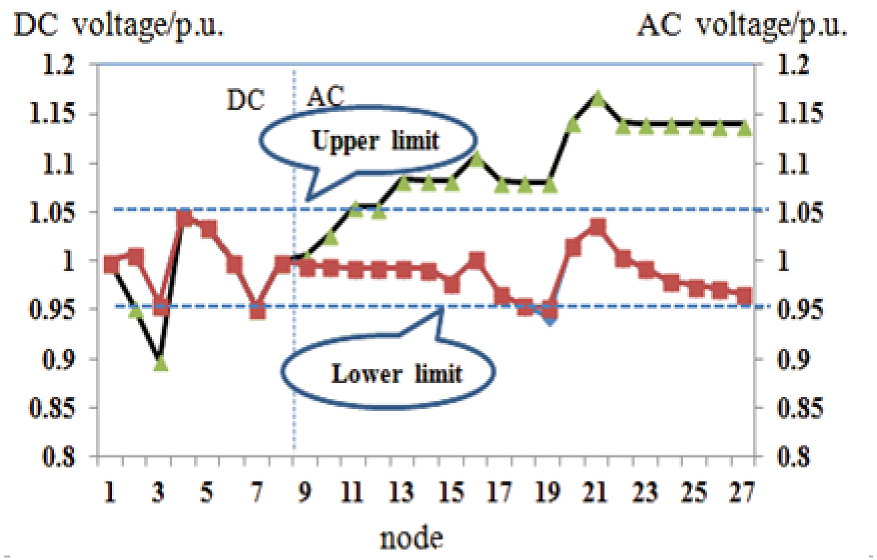
After the first stage regulation, the node voltages are still mostly over the limits in DC-MG.

The solution of case 2 is launched.

Case 2*

Simulation results and discussion

Case 2*



By using the scheme for case 2, the voltage regulation coordinated within AC-MG and DC-MG for the second stage is launched.

Optimal power of EV nodes

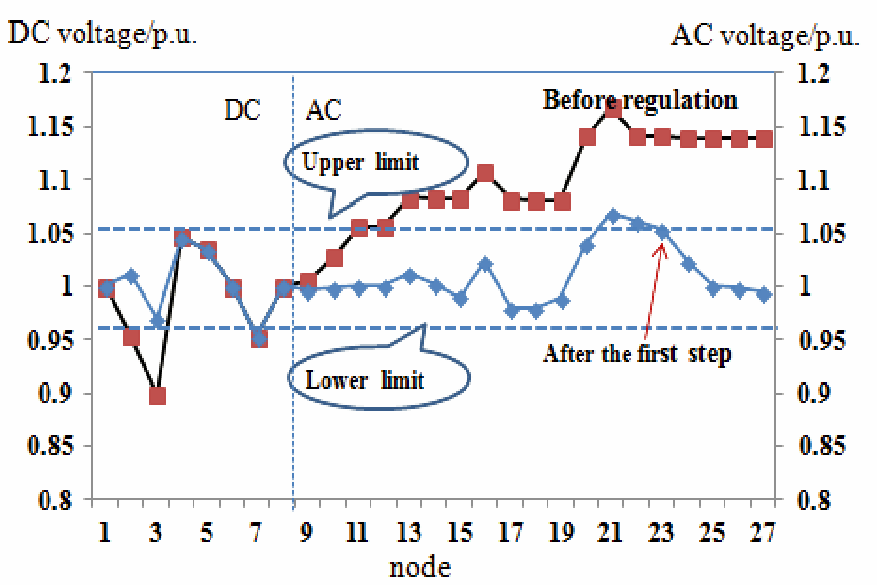
$$\Delta P_{EV1} = -0.8041MW$$

$$\Delta P_{EV2} = 0.0931MW$$

$$\Delta P_{EV3} = -0.4550MW$$

Simulation results and discussion

Case 4



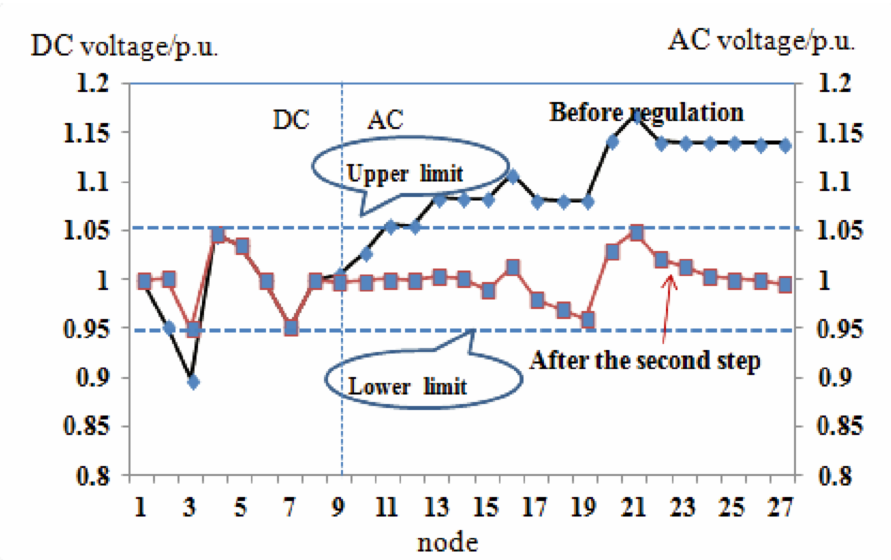
After the first voltage regulation stage, there are still some node voltages over the limits in AC-MG.

The solution of case 4 is launched.

Case 4*

Simulation results and discussion

Case 4*



By using the scheme for case 4, the voltage regulation coordinated within AC-MG and DC-MG for the second stage is launched

Optimal power of EV nodes

$$\Delta P_{EV1} = -0.1355MW$$
$$\Delta P_{EV2} = 0.00956MW$$
$$\Delta P_{EV3} = -0.1566MW$$

Simulation results and discussion

Conclusions

- By the proposed method, the voltage deviation of the AC&DC-HMG can be stabilized within 5% with power coordination between AC-MG and DC-MG with EVs connected the related nodes.
- In addition, each node regulates its voltage based on communication only within neighboring nodes, thus reducing the burden for communications.

Future works

- We only considered the grid connection situation, and did not consider the situation when the EVs was connected in the island mode.
- The scheduling of electric vehicles can be optimized.

Thank you!