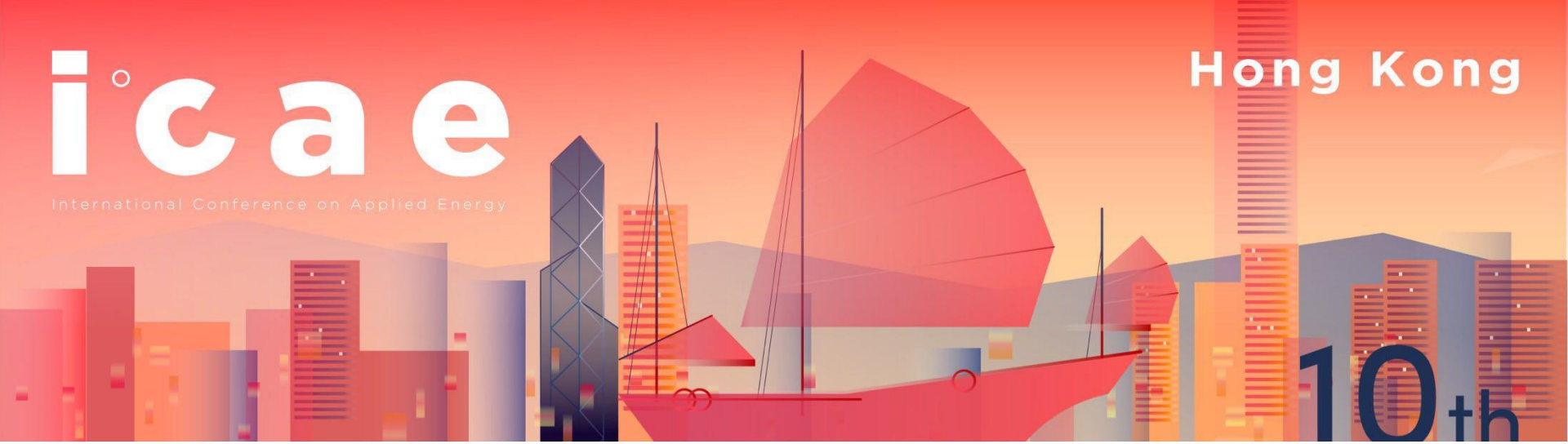

Modeling and analysis of inverter air conditioners for primary frequency control considering signal delays and detection errors

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Contents

1. Background (I)

https://www.economist.com/asia/2017/08/17/a-massive-blackout-prompts-questions-about-taiwans-energy-policy

Fig. 1 The blackout in Taiwan on Aug. 15, 2017

- The large-scale blackouts are increasing.

The blackout in Taiwan on Aug. 15, 2017 affected about 6.68 million customers[1].

The blackout in Brazil on Mar. 21, 2018 resulted in 22.5% failure of power output[2].

- The fundamental reason is the shortage of the operating reserve.

[1] Wu H, et al. Administrative investigation report on the 815 power failure. Executive Yuan, Taiwan, Republic of China, Tech. Rep. 1060907, Sep. 2017. <http://www.ey.gov.tw>

[2] U.S. News. Tens of Millions in Northern Brazil Hit by Massive Power Outage. <https://www.usnews.com/news/world/articles/2018-03-21/tens-of-millions-in-northern-brazil-hit-by-massive-power-outage>

1. Background (Ⅱ)

Fig. 2 Traditional generation units

Conventionally, the operating reserve is provided by traditional generation units, such as the thermal power plants or hydro turbines[3].

https://image.baidu.com

The development of the information and communication technology makes it easier for household appliances to provide operating reserve, which we can call smart home[4].

https://image.baidu.com

Fig. 3 Smart home system

[3] Rebours YG, Kirschen DS, Trotignon M, Rossignol S. A survey of frequency and voltage control ancillary services—Part I: Technical features. IEEE Trans. Power Syst., vol. 22, no. 1, pp. 350-357, Feb. 2007.

[4] Siano P. Demand response and smart grids—A survey. Renew. Sustain. Energy Rev., vol. 30, pp. 461-478, Feb. 2014.

1. Background (Ⅲ)

Air conditioners (ACs) account for a large share in the power consumption[5].

ACs can be regulated in a short time without much influence on the customer comfort[6].

https://image.baidu.com

Fig. 4 Air conditioners

- **Regular fixed speed air conditioners.**

- **Inverter air conditioners (IAC).**
- Can be adjusted more flexibly.
- Have little influence on the IAC life time.

[5] Hui H, Ding Y, Liu W, Lin Y, Song Y. Operating reserve evaluation of aggregated air conditioners. Appl. Energy, vol. 196, pp. 218-228, Jun. 2017.

[6] What is Inverter Technology AC, Bijli Bachao, Tech. Rep., 2017. <https://www.bijlibachao.com>

2. Modeling of the inverter air conditioner (IAC)

- **The thermal model of a room[8]:**

$$c_A \rho_A V \frac{dT_A}{dt} = H_{gain}(t) - H_{IAC}(t) \quad (1)$$

- **Heat gains of the room:**

$$H_{gain}(t) = \left(U_{O-A} A_S + c_A \rho_A V \xi\right)\left(T_O(t) - T_A(t)\right) + H_{dis}(t) \quad (2)$$

- **The refrigerating capacity:**

$$H_{IAC}(t) = l_Q P_{IAC}(t) + \sigma_Q \quad (3)$$

- **The operating power of an IAC:**

$$P_{IAC}(t) = \kappa_P f_c(t) + \mu_P \quad (4)$$

Compressor's operating frequency

[7] Shao S, Shi W, Li X, Chen H. Performance representation of variable-speed compressor for inverter air conditioners based on experimental data. Int. Journ. Refrig., vol. 27, no. 8, pp. 805-815, Dec. 2004.

[8] Hui H, Ding Y, Zheng M. Equivalent Modeling of Inverter Air Conditioners for Providing Frequency Regulation Service. IEEE Trans. Ind. Electron. doi: 10.1109/TIE.2018.2831192, in press, 2018.

3. The control method of IACs (I)

The basic control method

- **The basic control strategy of an IAC (PI controller):**

$$\Delta f_c(t) = \theta \cdot \Delta T_{dev}(t) + \eta \cdot \int \Delta T_{dev}(t) dt$$

- **Temperature deviation of the indoor temperature and the set temperature:**

$$\Delta T_{dev}(t) = \Delta T_A(t) - \Delta T_{set}(t)$$

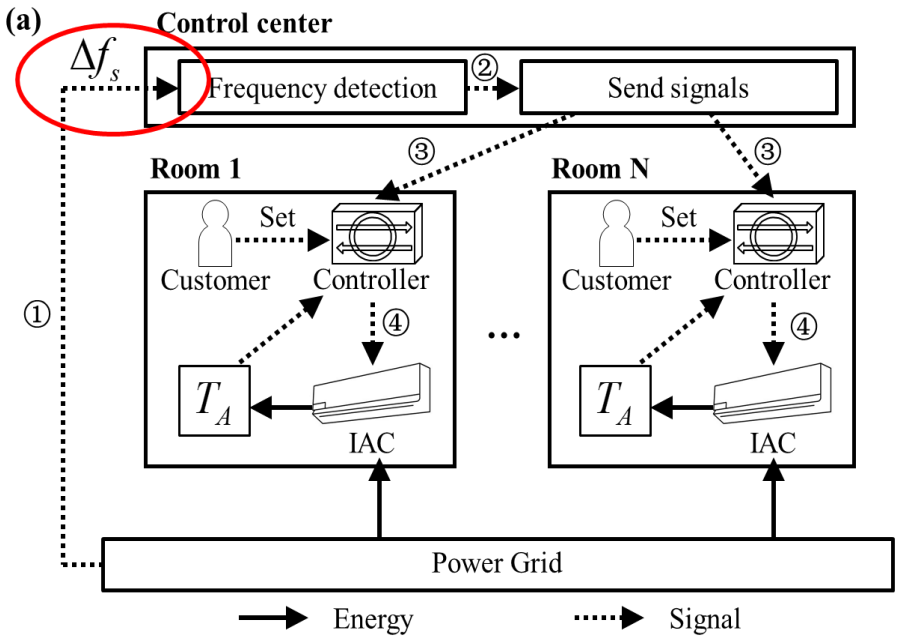
- **The improved control strategy of an IAC (PI controller + P controller):**

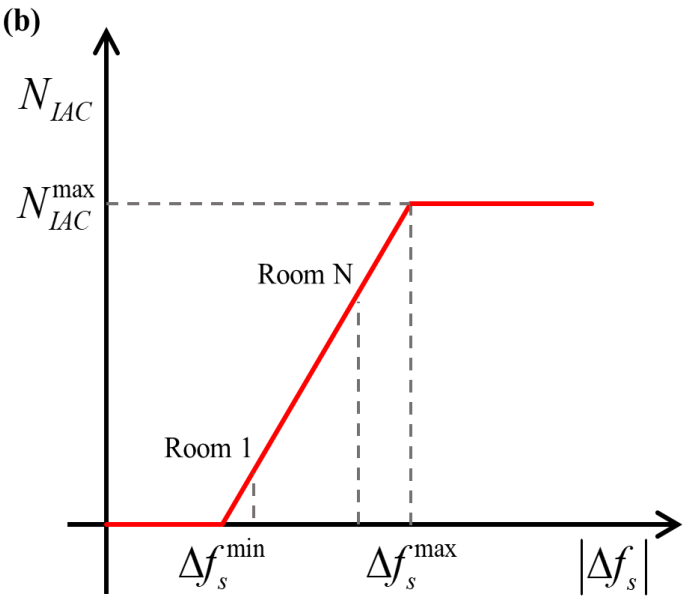
$$\Delta f_c(t) = \theta \cdot \Delta T_{dev}(t) + \eta \cdot \int \Delta T_{dev}(t) dt + \delta \cdot \Delta f_s(t) \quad (5)$$

Power system's frequency deviation

3. The control method of IACs (Ⅱ)

The centralized detection control (CDC) of aggregated IACs





- **The control strategy of an IAC:**

$$\Delta f_c(t) = \theta \cdot \Delta T_{dev}(t) + \eta \cdot \int \Delta T_{dev}(t)dt + \delta \cdot \Delta f_s(t)$$

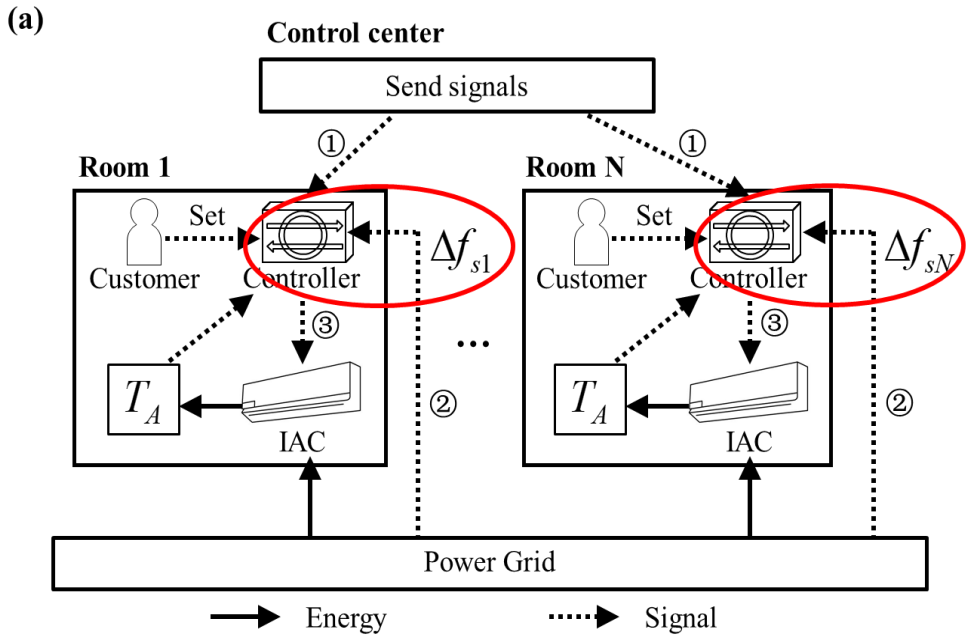
$$\Delta T_{dev}(t) = \Delta T_A(t) - \Delta T_{set}(t)$$

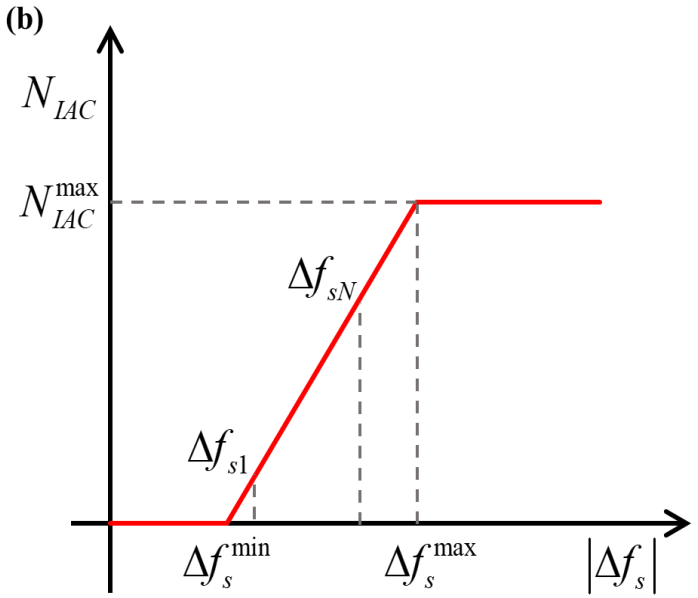
- **More IACs will be dispatched:**

$$N_{IAC} = \begin{cases} 0 & ,|\Delta f_s| \le \Delta f_s^{min} \\ \dfrac{N_{IAC}^{max}}{\Delta f_s^{max} - \Delta f_s^{min}} \Delta f_s & , \ \Delta f_s^{min} \le |\Delta f_s| \le \Delta f_s^{max} \\ N_{IAC}^{max} & ,|\Delta f_s| \ge \Delta f_s^{max} \end{cases}$$

3. The control method of IACs (Ⅲ)

The distributed detection control (DDC) of aggregated IACs





- **The control strategy of an IAC:**

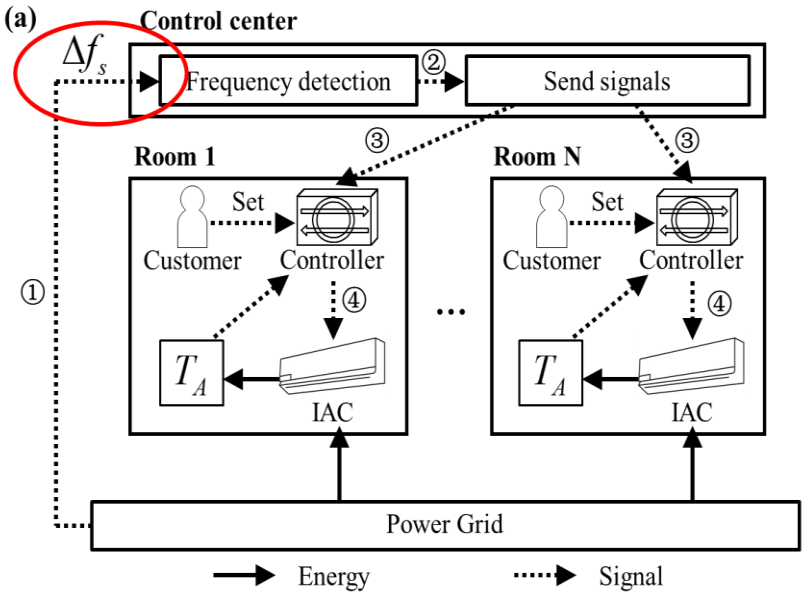
$$\Delta f_c(t) = \theta \cdot \Delta T_{dev}(t) + \eta \cdot \int \Delta T_{dev}(t)dt + \delta \cdot \Delta f_s(t)$$

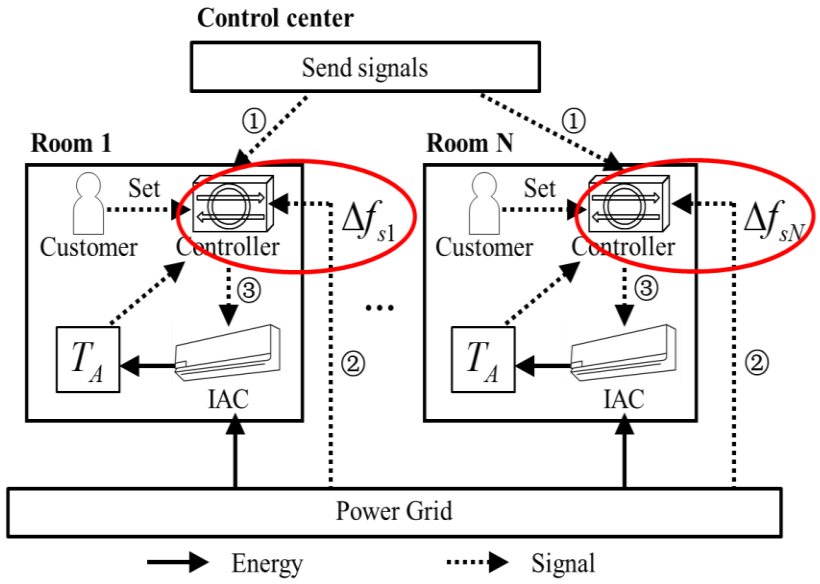
$$\Delta T_{dev}(t) = \Delta T_A(t) - \Delta T_{set}(t)$$

- **The IACs are set different frequency thresholds to realize the same effect.**

3. The control method of IAC (IV)

The comparison of the two detection control methods



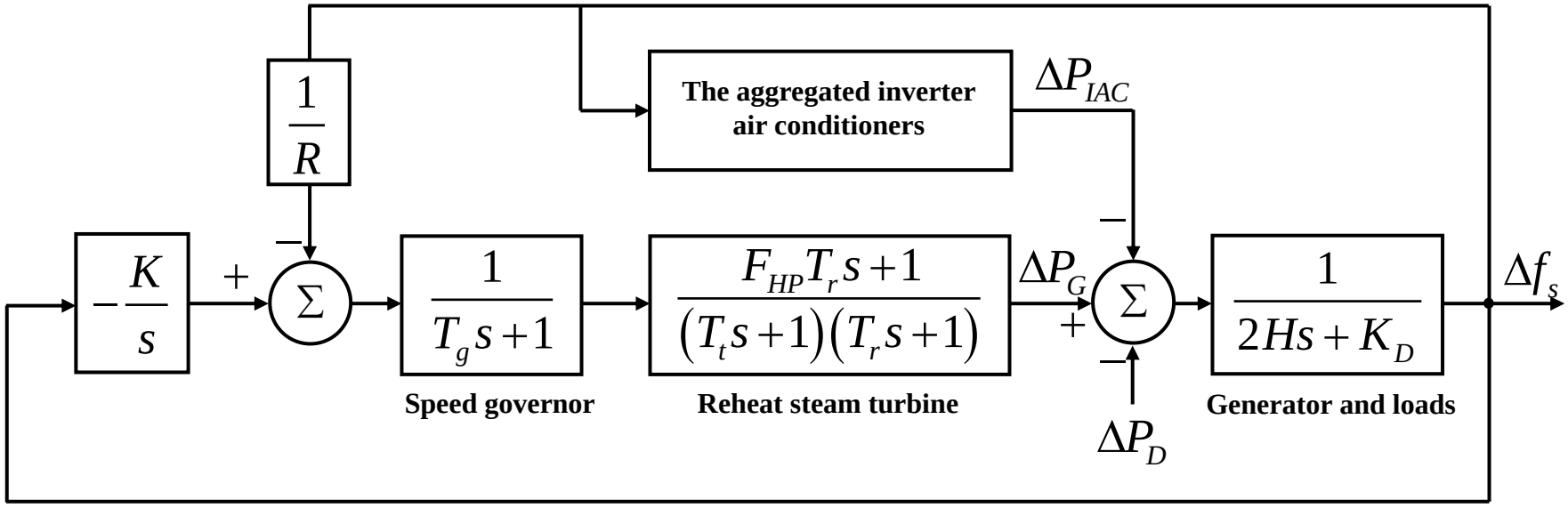


	Centralized detection method	Distributed detection method
Number of detection devices	fewer	more
Accuracy	better	lower
Communication time	longer	shorter

4. Case Studies (I)

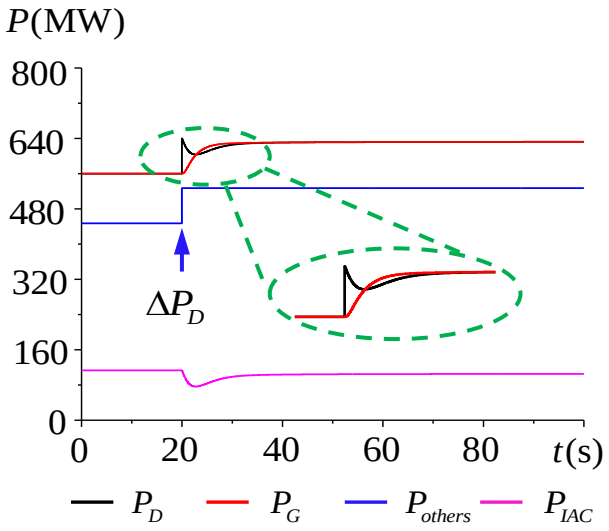
The test system

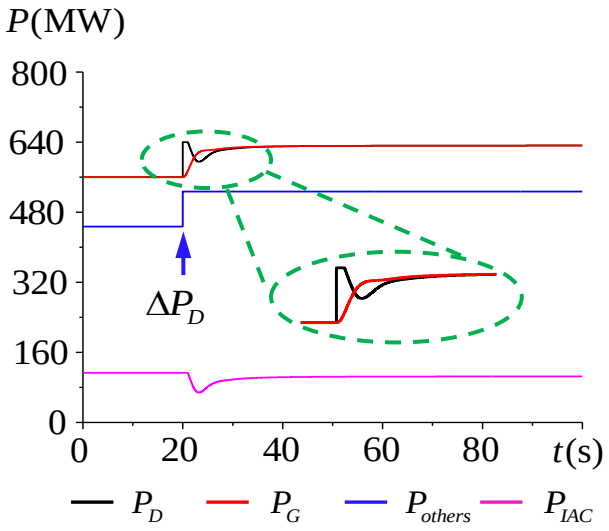
- **The initial parameters:**
  - The initial loads of the power system are 560MW.
  - The number of the aggregated IACs is 30,000.
  - The ambient temperature and the set temperature of the IAC are 33℃ and 26℃, respectively.
  - The minimum and maximum thresholds of the system frequency deviation are 0.01Hz and 0.03Hz, respectively.
  - It's assumed that the load deviation is 80MW.
- **The system:**

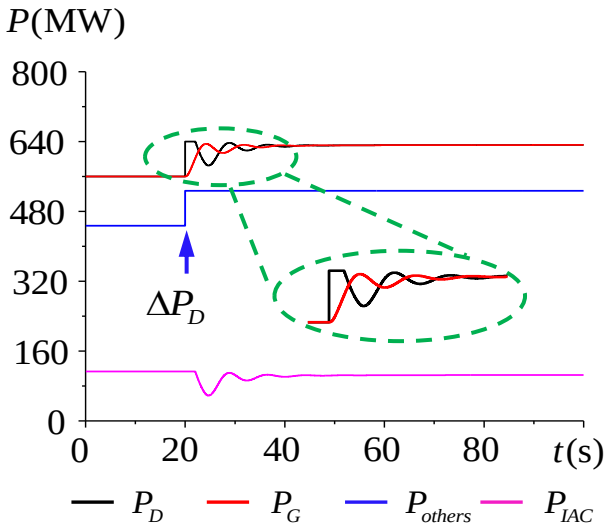


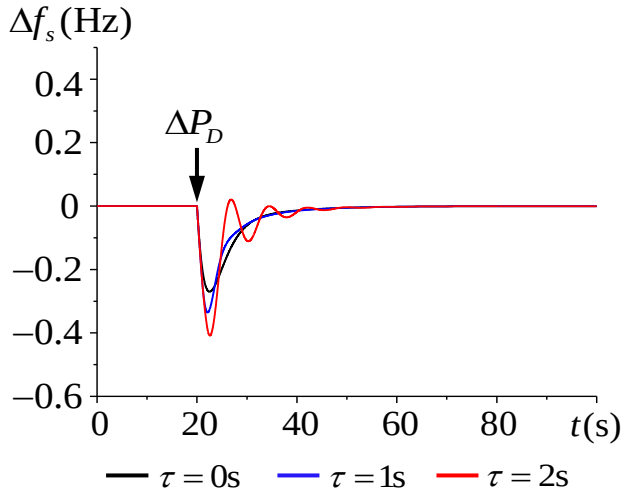
4. Case Studies (Ⅱ)

The simulation results - The centralized detection control





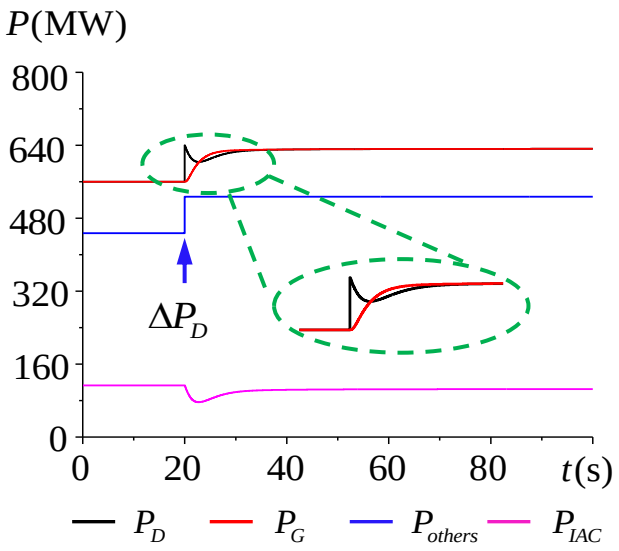


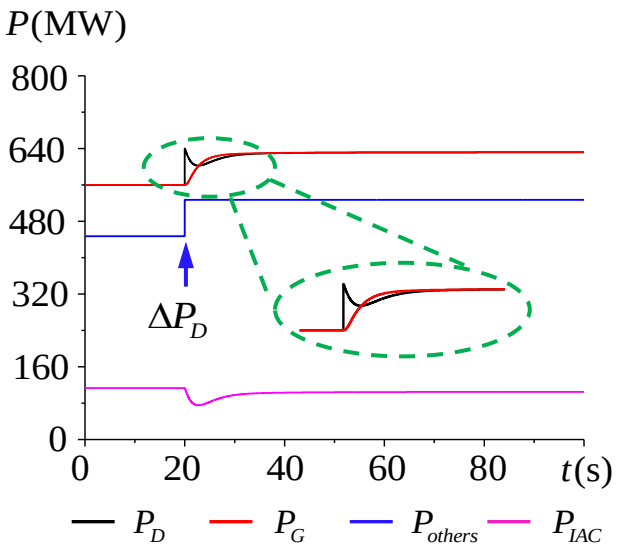


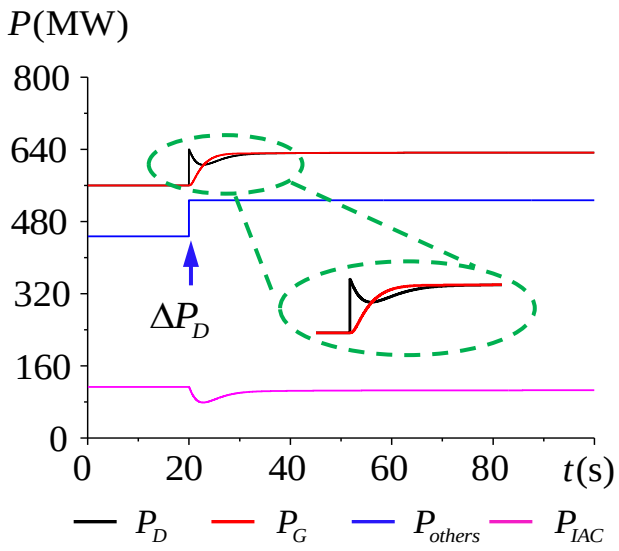
CASE	$\Delta f_s^{\max}$ (Hz)	$\Delta P_{IAC}^{\max}$ (MW)
Case 1	-0.270	-36.56
Case 2	-0.335	-44.80
Case 3	-0.409	-55.04

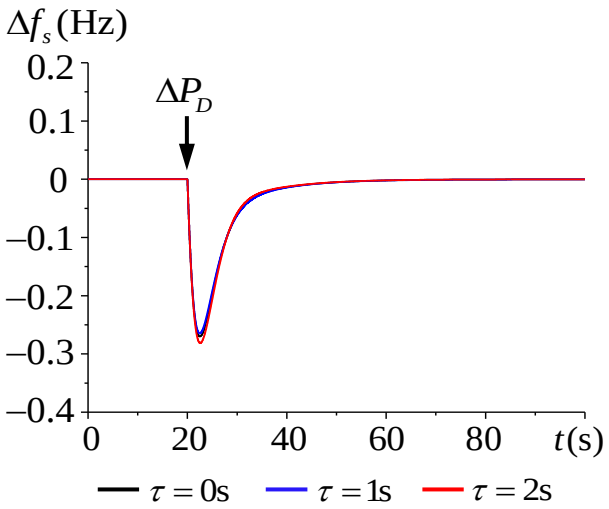
4. Case Studies (Ⅲ)

The simulation results - The distributed detection control





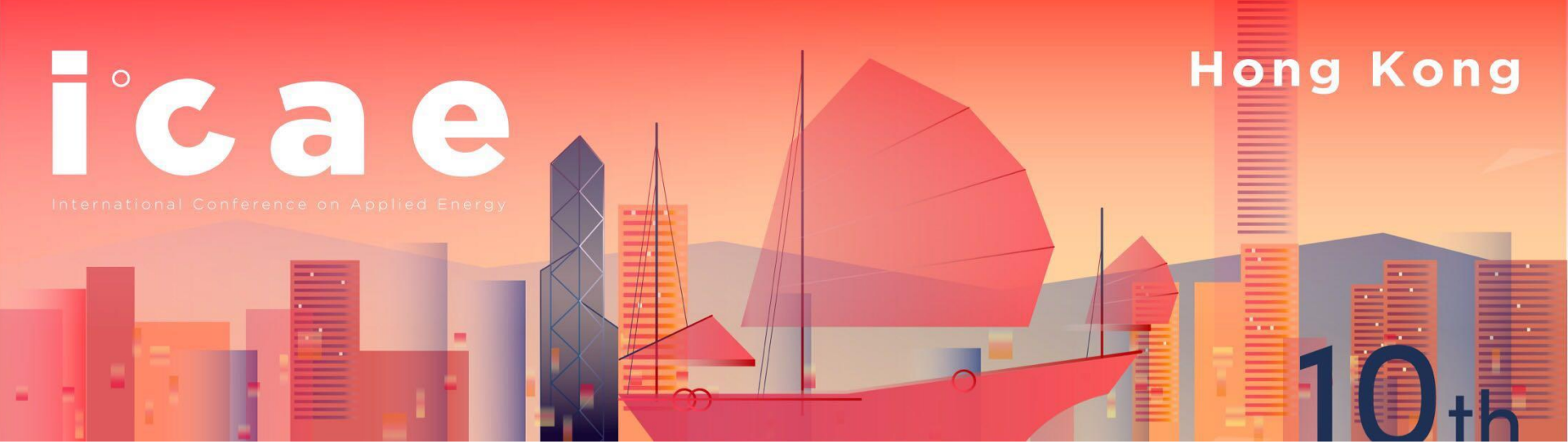




CASE	$\Delta f_s^{\max}$ (Hz)	$\Delta P_{IAC}^{\max}$ (MW)
Case 1	-0.270	-36.56
Case 2	-0.265	-37.60
Case 3	-0.281	-34.32

5. Discussions and Conclusions

- The model of the inverter air conditioner (IAC) is developed in this paper.
- Two detection control methods are proposed, the centralized detection control (CDC) method and the distributed detection control (DDC) method.
- The IACs have been proved to be able to provide operating reserve for the power system.
- The communication delays in the CDC method will enlarge the system frequency deviations and even bring frequency oscillations, while the detection errors in the DDC method have less influences on the system frequency deviation.
- Therefore, as for the large-scale aggregated IACs, the DDC method may be more appropriate than the CDC method.



Thanks for your attention!