Modelling and Dynamic Performance Analysis of the Power System Under Unit Contingency Shutdown Accidents Considering Demand Response

Hongxun Hui[1], Yi Ding[1*], Yonghua Song[2,3,1], Saifur Rahman[4]

1. College of Electrical Engineering, Zhejiang University, Hangzhou, China
2 State Key Laboratory of Internet of Things for Smart City, University of Macau, Macau, China
3 Department of Electrical and Computer Engineering, University of Macau, Macau, China
4 Advanced Research Institute, Virginia Tech, Arlington, VA, USA

August 2019

Contents

1. Background

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

Fig. 2 The blackout in UK on Aug. 9, 2019

- 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 and frequency .

[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

Fig. 3 Traditional generation units

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

https://images.app.goo.gl/RifnP6ZJK7cVs3Fy5

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://images.app.goo.gl/BsbAS8e3F4CuP87V6

Fig. 4 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

- **However, most of papers only focus on the load power disturbance scenarios.**

- **The dynamic performance of the power system with DR has not been studied under unit contingency shutdown accidents.**

[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] Hui H, Ding Y, Zheng M. Equivalent modeling of inverter air conditioners for providing frequency regulation service. IEEE Transactions on Industrial Electronics. 2019 Feb;66(2):1413-23.

[7] Xie D, Hui H, Ding Y, Lin Z. Operating reserve capacity evaluation of aggregated heterogeneous TCLs with price signals. Applied Energy. 2018 Apr 15;216:338-47.

[8] Cai M, Pipattanasomporn M, Rahman S. Day-ahead building-level load forecasts using deep learning vs. traditional time-series techniques. Applied Energy. 2019 Feb 15;236:1078-88.

[9] Shi Q, Li F, Liu G, Shi D, Yi Z, Wang Z. Thermostatic Load Control for System Frequency Regulation Considering Daily Demand Profile and Progressive Recovery. IEEE Transactions on Smart Grid. 2019 Feb 21.

[10] Zhang X, Pipattanasomporn M, Rahman S. A self-learning algorithm for coordinated control of rooftop units in small-and medium-sized commercial buildings. Applied Energy. 2017 Nov 1;205:1034-49.

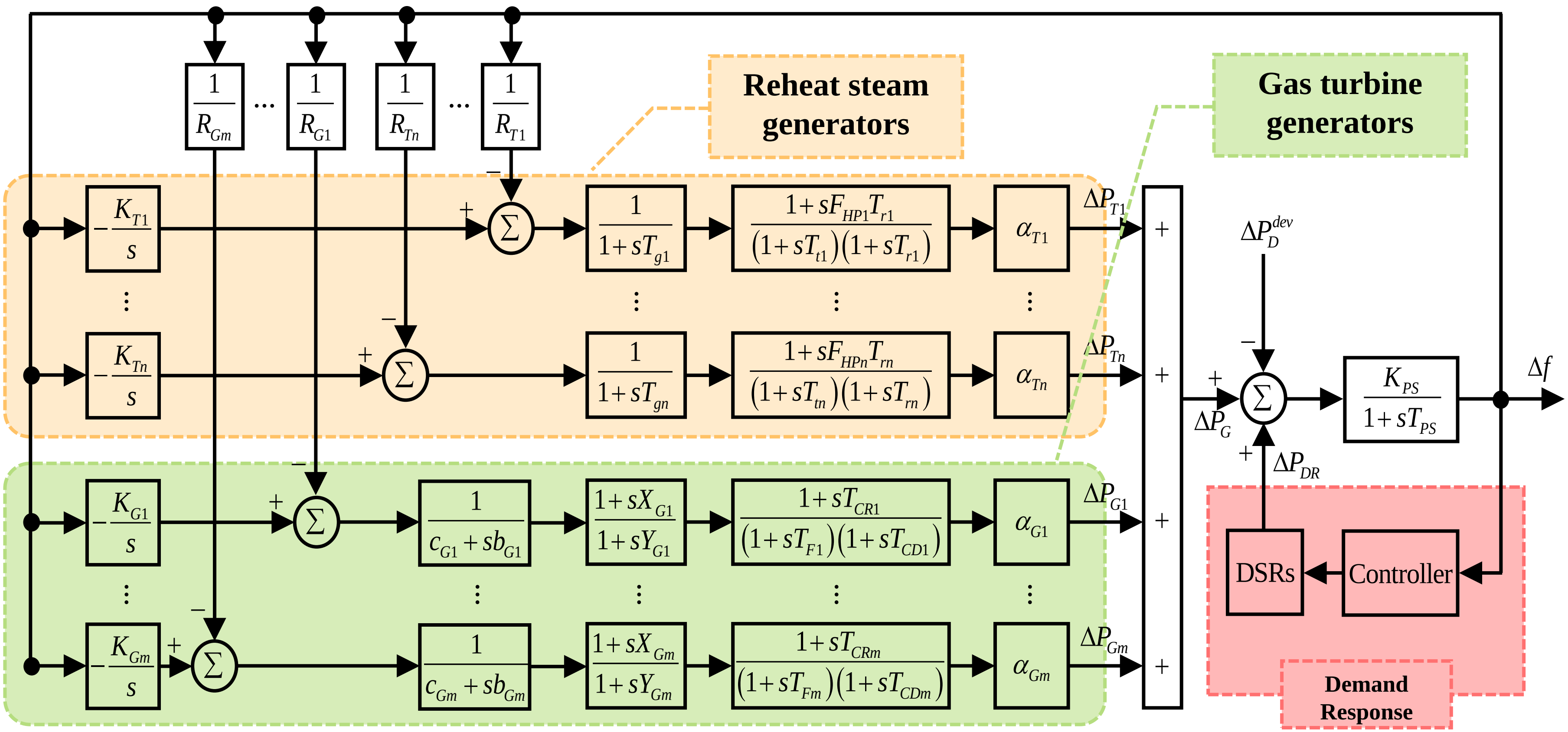
[11] Pourmousavi SA, Nehrir MH. Introducing dynamic demand response in the LFC model. IEEE Transactions on Power Systems. 2014 Jul;29(4):1562-72.

[4] Siano P. Demand response and smart grids—A survey. Renewable and Sustainable Energy Reviews. 2014 Feb 1;30:461-78.

[5] Shi Q, Li F, Hu Q, Wang Z. Dynamic demand control for system frequency regulation: Concept review, algorithm comparison, and future vision. Electric Power Systems Research. 2018 Jan 1;154:75-87.

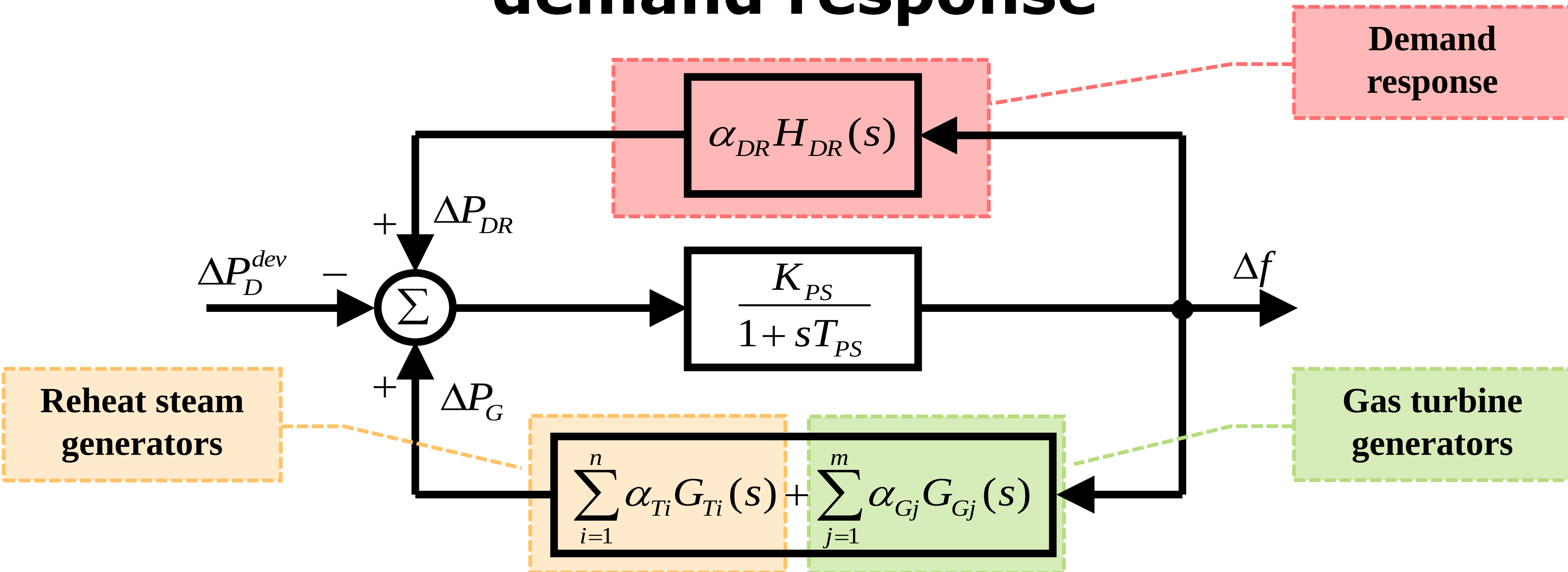
Contents

2. Modelling of the power system considering demand response



[13]Hui H, Ding Y, Luan K, Xu D. Analysis of "815" Blackout in Taiwan and the Improvement Method of Contingency Reserve Capacity Through Direct Load Control. In2018 IEEE Power & Energy Society General Meeting (PESGM) 2018 Aug 5 (pp. 1-5). IEEE.
[14]Mohanty B, Panda S, Hota PK. Controller parameters tuning of differential evolution algorithm and its application to load frequency control of multi-source power system. International Journal of Electrical Power & Energy Systems. 2014 Jan 1;54:77-85.
[15]Parmar KS, Majhi S, Kothari DP. Load frequency control of a realistic power system with multi-source power generation. International Journal of Electrical Power & Energy Systems. 2012 Nov 1;42(1):426-33.

2. Modelling of the power system considering demand response



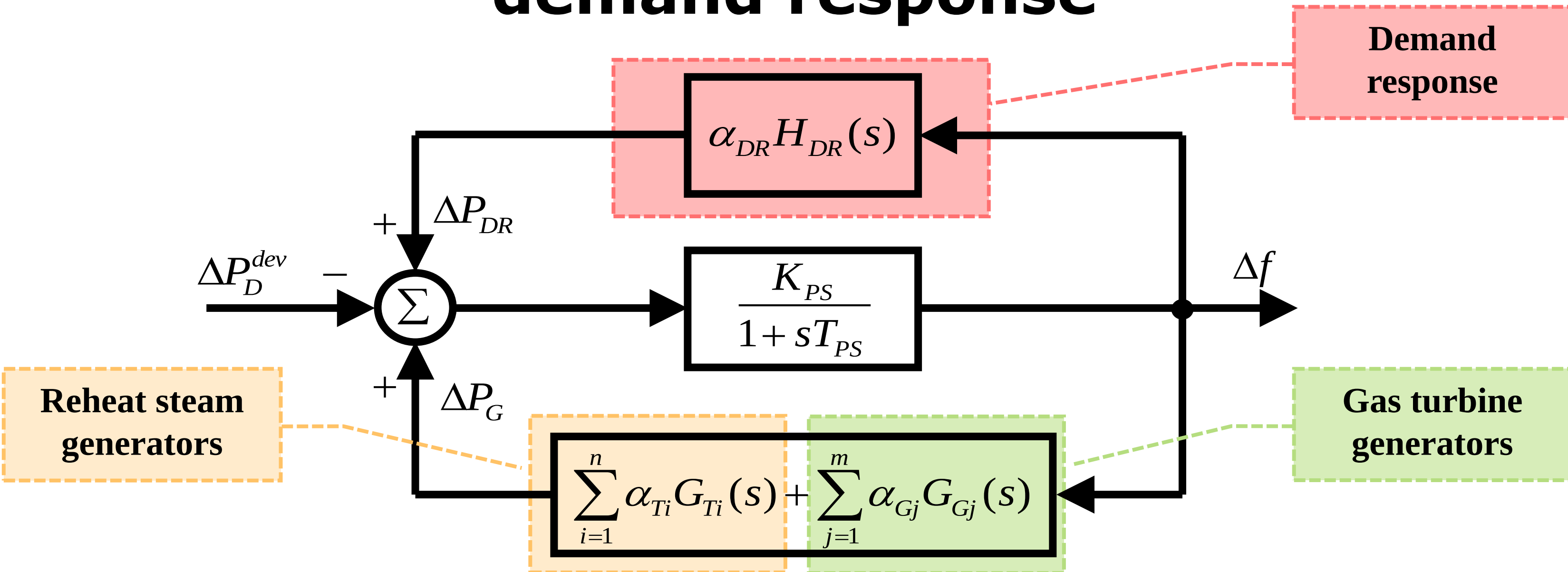
– **Power generation by reheat steam generators :**

$$G_{Ti}(s) = -\left(\frac{1}{R_{Ti}} + \frac{K_{Ti}}{s}\right) \cdot \frac{1}{1+sT_{gi}} \cdot \frac{1+sF_{HPi}T_{ri}}{(1+sT_{ti})(1+sT_{ri})} \quad (1)$$

– **Power generation by gas turbine generators :**

$$G_{Gj}(s) = -\left(\frac{1}{R_{Gj}} + \frac{K_{Gj}}{s}\right) \cdot \frac{1}{c_{Gj}+sb_{Gj}} \cdot \frac{1+sX_{Gj}}{1+sY_{Gj}} \cdot \frac{1+sT_{CRj}}{(1+sT_{Fj})(1+sT_{CDj})} \quad (2)$$

2. Modelling of the power system considering demand response



– **Regulation power by demand side resources :**

$$H_{DR}(s) = -\left(\frac{1}{R_{DR}} + \frac{K_{DR}}{s}\right) \quad (3.1)$$

$$G_{DR}(s) = \alpha_{DR}H_{DR}(s) = -\alpha_{DR}\left(\frac{1}{R_{DR}} + \frac{K_{DR}}{s}\right) \quad (3.2)$$

Contents

3. Stability of the power system with and without demand response

- **The system frequency deviations:**

$$\Delta f(s) = \frac{K_{PS}}{1+sT_{PS}}\left(\Delta P_G(s) + \Delta P_{DR}(s) - \Delta P_D^{dev}(s)\right) \quad (4)$$

Regulation power provided by generators (5)

$$\Delta P_G(s) = \left(\sum_{i=1}^{n}\alpha_{Ti}G_{Ti}(s) + \sum_{j=1}^{m}\alpha_{Gj}G_{Gj}(s)\right)\cdot\Delta f(s)$$

Regulation power provided by DR (6)

$$\Delta P_{DR}(s) = \alpha_{DR}H_{DR}(s)\cdot\Delta f(s)$$

- **The closed-loop transfer function with regard to the disturbance load power:**

$$\Phi(s) = \frac{\Delta f(s)}{\Delta P_D^{dev}(s)} = \frac{-M(s)}{1 - M(s)\underbrace{\left(\sum_{i=1}^{n}\alpha_{Ti}G_{Ti}(s) + \sum_{j=1}^{m}\alpha_{Gj}G_{Gj}(s) + \alpha_{DR}H_{DR}(s)\right)}_{\Psi(s)}} \quad (7)$$

3. Stability of the power system with and without demand response

- **The power generation losses can be regarded as the disturbance power:**

$$\Delta P_D^{dev}(s) = \frac{\left|\alpha_{Tk} G_{Tk}(s)\right|}{s} + \frac{\left|\alpha_{Gl} G_{Gl}(s)\right|}{s} \tag{9}$$

- **The closed- and open-loop transfer functions of the power system will get changed from (7), when the unit contingency shutdown accident occurs:**

$$\Phi(s) = \frac{\Delta f(s)}{\Delta P_D^{dev}(s)} = \frac{-M(s)}{1 - \underbrace{M(s)\left(\sum_{i=1}^{n} \alpha_{Ti} G_{Ti}(s) + \sum_{j=1}^{m} \alpha_{Gj} G_{Gj}(s) + \alpha_{DR} H_{DR}(s)\right)}_{\Psi(s)}} \tag{7}$$

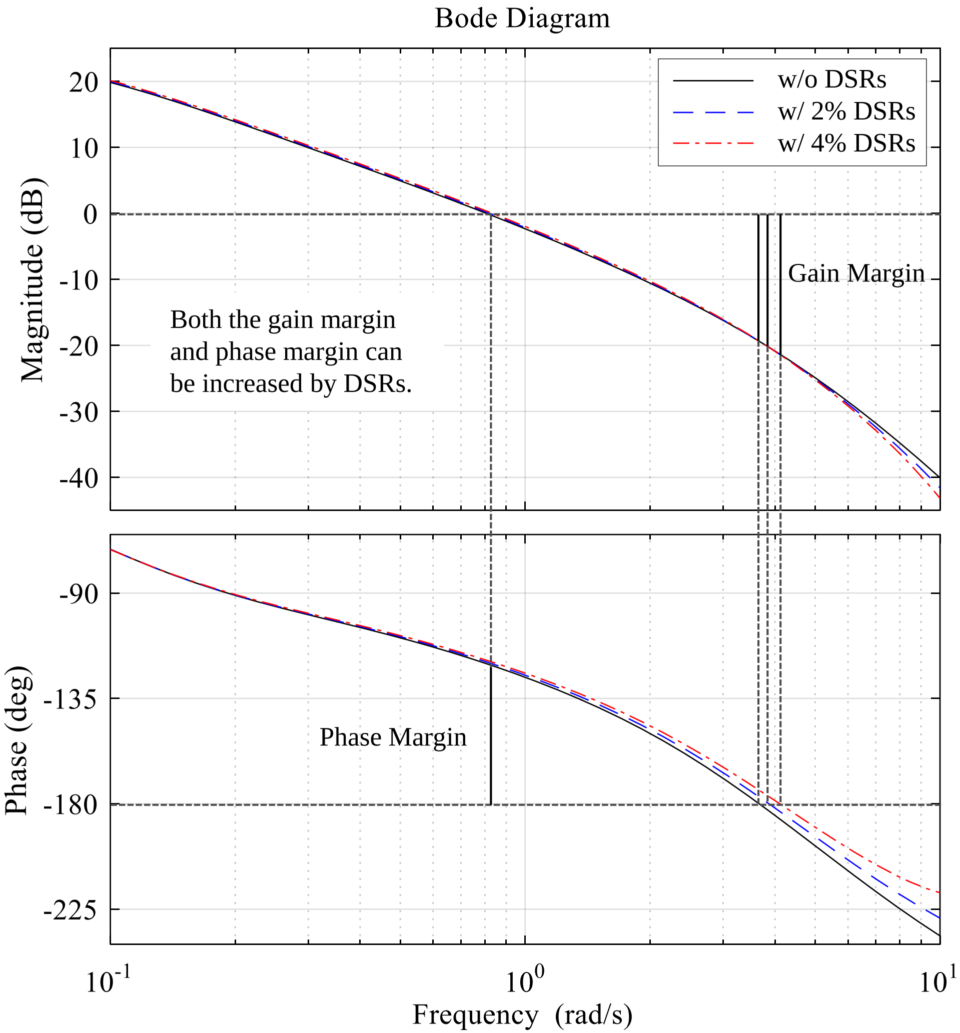
$$\tilde{\Psi}(s) = M(s)\left(\sum_{i=1, i\neq k}^{n} \alpha_{Ti} G_{Ti}(s) + \sum_{j=1, j\neq l}^{m} \alpha_{Gj} G_{Gj}(s) + \alpha_{DR} H_{DR}(s)\right) \tag{10}$$

3. Stability of the power system with and without demand response

– **The power generation losses can be regarded as the disturbance power:**

Table 2 The gain and phase margins of the Bode plots.

Scenarios	Gain Margin	Phase Margin
w/o DSRs	19.4 dB (at 3.67 rad/s)	59.8 deg (at 0.807 rad/s)
w/ 2% DSRs	20.3 dB (at 3.87 rad/s)	60.2 deg (at 0.821 rad/s)
w/ 4% DSRs	21.4 dB (at 4.11 rad/s)	60.5 deg (at 0.835 rad/s)

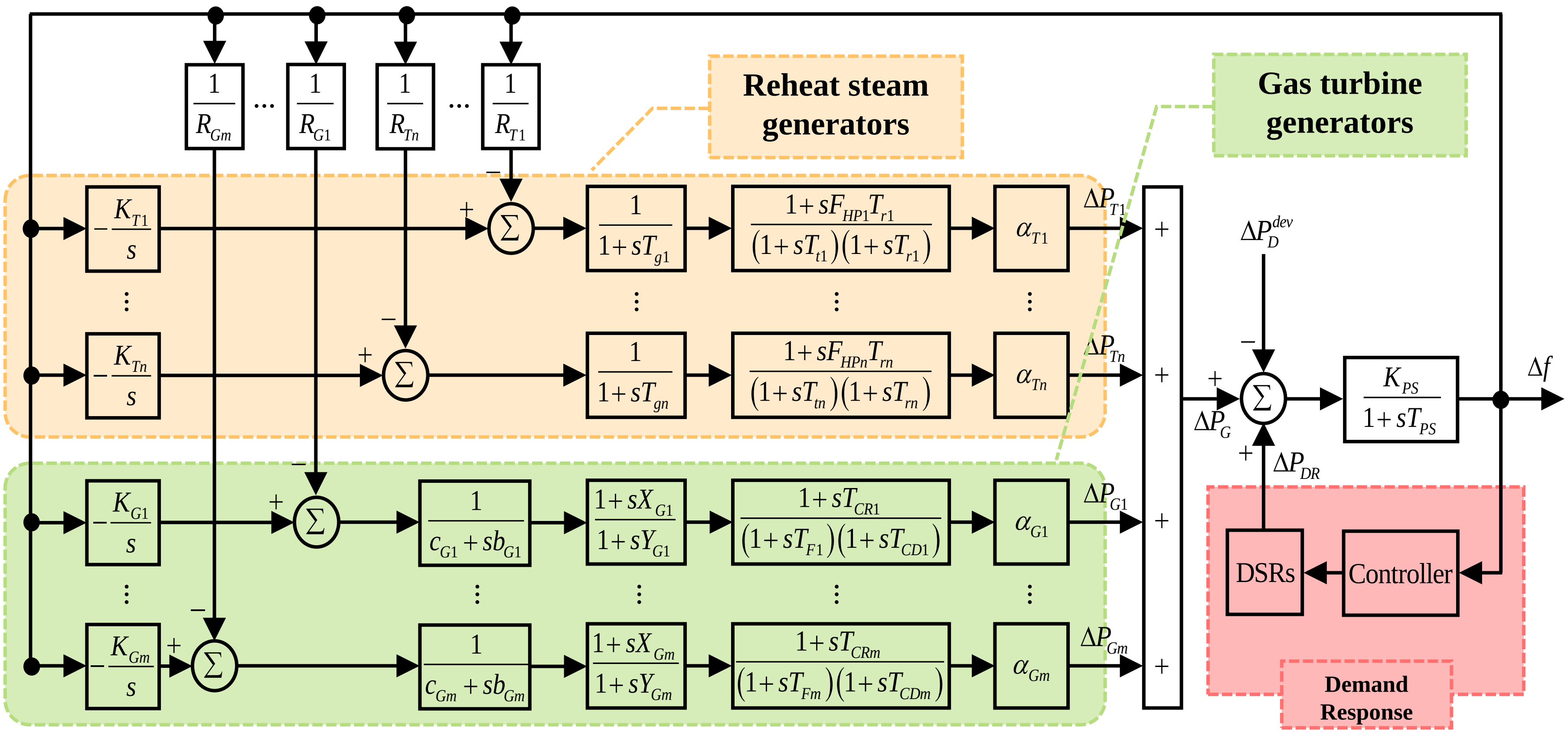


Contents

4. Case Studies

The test system

- **The test system adopts the power system in Fig. 1.**
- **It is assumed that one gas turbine generator is shut down suddenly, which is similar with the actual gas generating plant accident in Taiwan.**



4. Case Studies

The simulation results

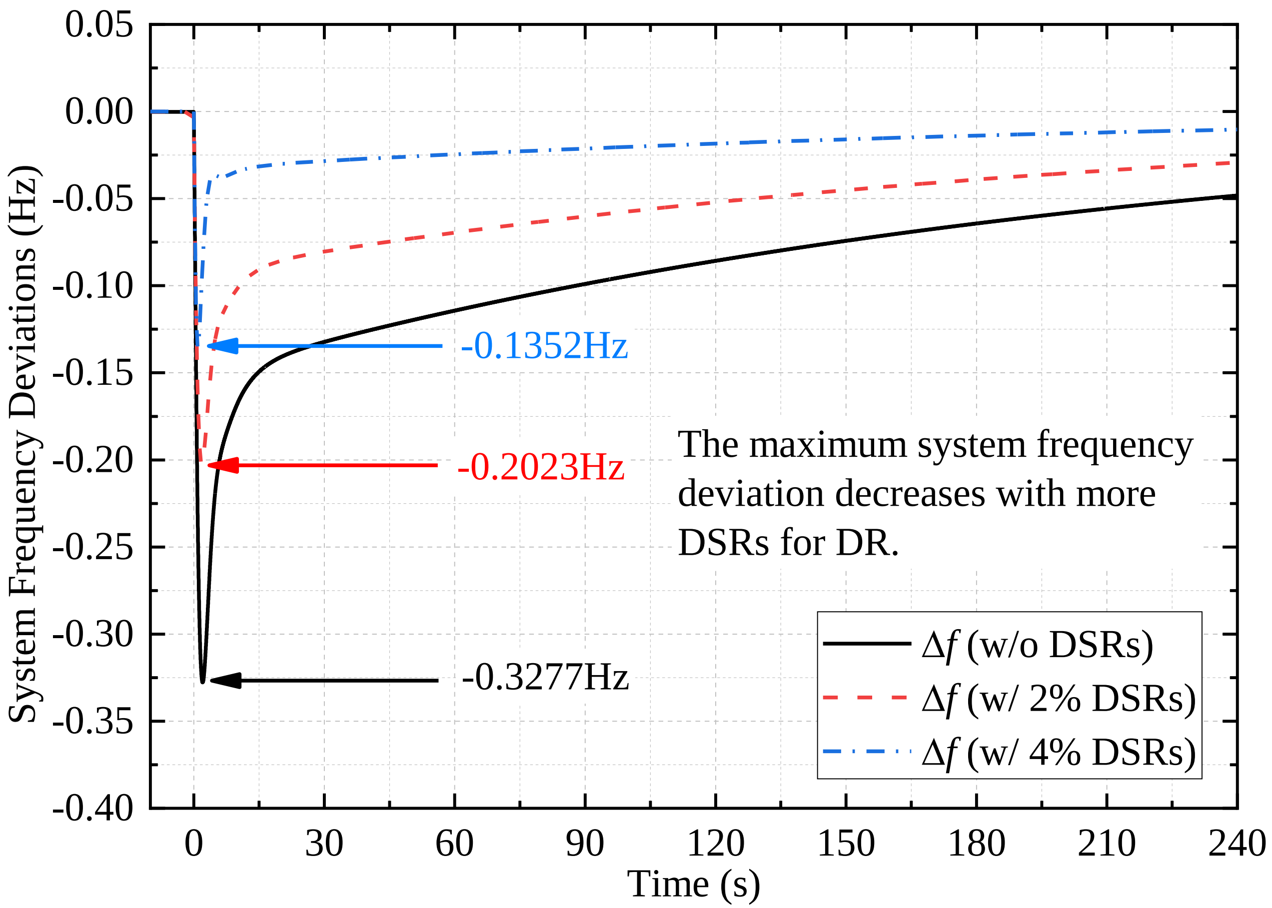


Fig. 4 System frequency deviations in the three cases when one gas turbine generator is shut down.

4. Case Studies

The simulation results

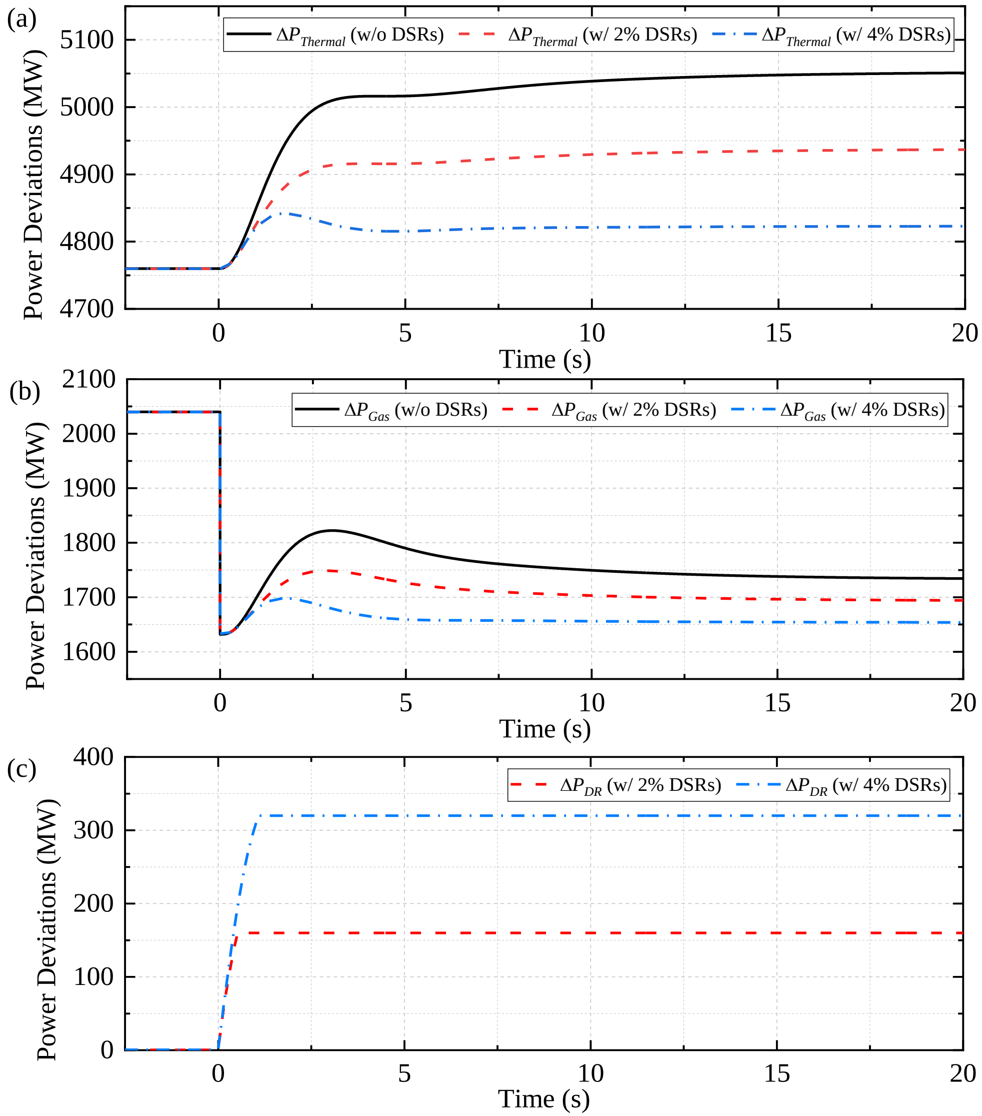


Fig. 5 Power deviations in the three cases:

(a) the total power deviations of the reheat steam generators,

(b) the total power deviations of the gas turbine generators,

(c) the regulation power provided by DSRs.

4. Case Studies

The simulation results

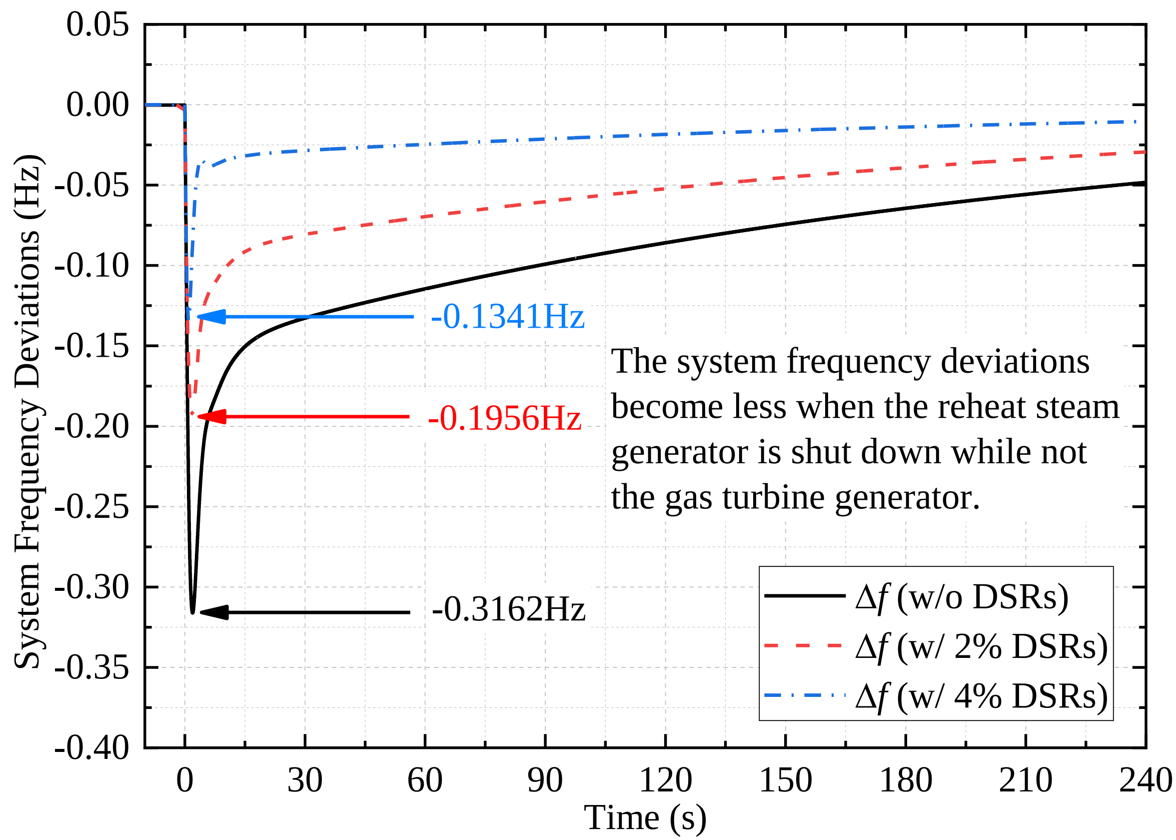


Fig. 6 System frequency deviations in the three cases when one reheat steam generator is shut down.

Contents

5. Discussions and Conclusions

– Faced with the increasing generating unit contingency shutdown accidents, this paper proposes an alternative method of traditional generators to provide regulation power by DSRs.

– Firstly, the power system model considering DR is developed. On this basis, the transformed closed- and open-loop transfer functions are derived.

– Then, the Bode plots are obtained to analyze the dynamic performances of the power system under unit contingency shutdown accidents, which illustrates that the stability of the power system can be enhanced by DR.

– The numerical studies show that the maximum system frequency deviation can be decreased from -0.3277Hz to -0.1352Hz when the DR is considered.

– The proposed models and methods in this paper contribute to guiding the DR in the power systems, especially in the countries and regions where reserve capacities are insufficient.

– Our future work.

Demonstration——Friendly Interactive System of Supply and Demand (FISSD)

It is approved and supported by *Ministry of Science and Technology of the People's Republic of China*.(2016-2020)

Demonstration area in **Suzhou:**

- ➢ Administrative region: 78 km^2
- ➢ Resident population: 780,000
- ✓ Large industry customers： 1420
- ✓ Commercial customers： 32437
- ✓ Residential customers: 352,600
- ➢ Load aggregators: 5

Demonstration area in **Changzhou:**

- ➢ Administrative region: 182 km^2
- ➢ Resident population: 1,600,000
- ✓ Large industry customers： 590
- ✓ Commercial customers： 21755
- ✓ Residential customers: 530,000
- ➢ Load aggregators: 3

Thanks for your attention!