Cooperation of Demand Response and Traditional Power Generations for Providing Spinning Reserve

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Introduction

UHV penetration

- Aug.14th, 2017 at 11:00, Yuheng-Weifang 1000kv UHVAC transmission system successfully completed 72 hours test run, and has been officially put into operation.
- Until september,2016, there are 21 UHV projects that have started construction or operation, including 7 UHVACs and 14 UHVDCs.
- In Jiangsu Province of China, it is estimated that 45% electricity consumption will be transmitted by the UHVDC from other provinces.

UHVDC sudden drop

Before	**Load of Suzhou area**	**power transmitted UHVDC transmission system**	**frequency**	**500kV bus voltage of Suzhou converter station**
	17936MW	3066MW	50.05HZ	505.93kV
After	**time**	**UHVDC transmission loss**	**Frequency drop**	**Load curtailment**
	13:39:10, June 17, 2016	3066MW	0.41HZ	0

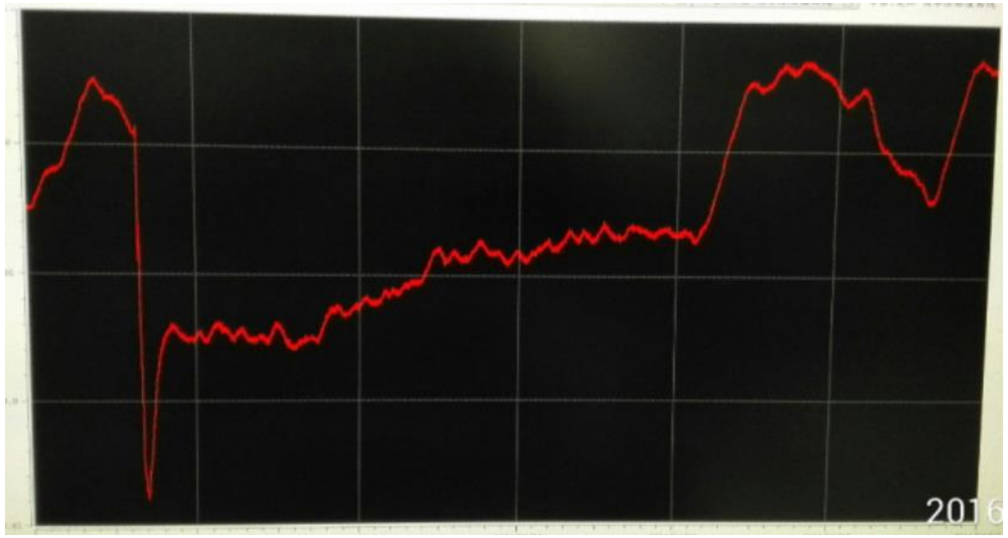


Fig1. Frequency curve of Suzhou substation

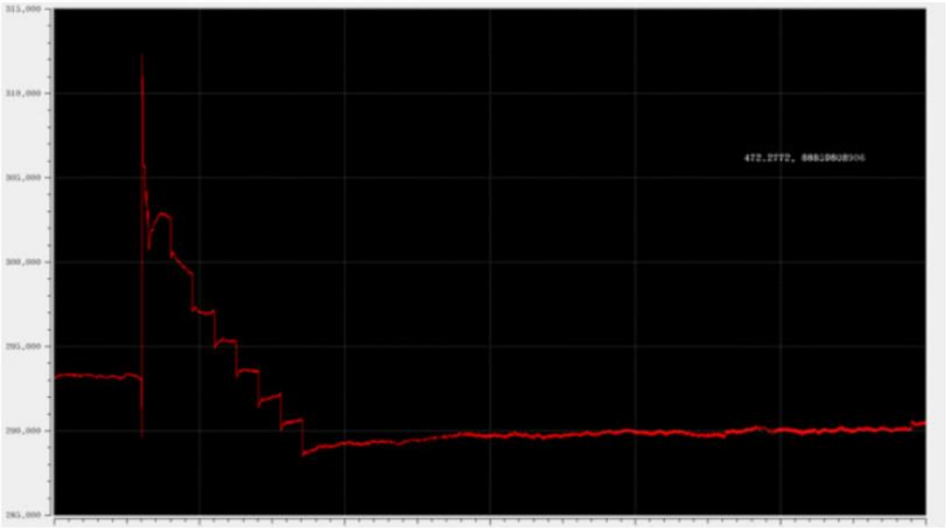


Fig2. voltage of Suzhou converter station

The existing cooperation strategy

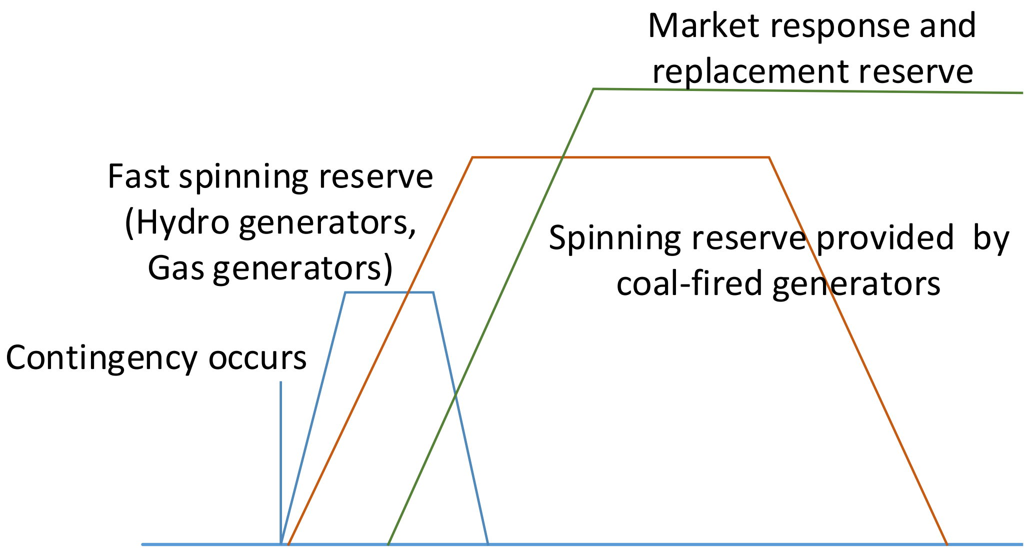


Fig3. Cooperation of different kinds of spinning reserve

UHVDC blocking

- Rapid power drop
- Large power shortage

Hydro generators

- Not enough capacity

Coal-fired generators

- Not enough ramping rate

Load curtailment

- Do not convey economic signal

Cooperation of DR and traditional spinning reserve providers

Growing of air conditions

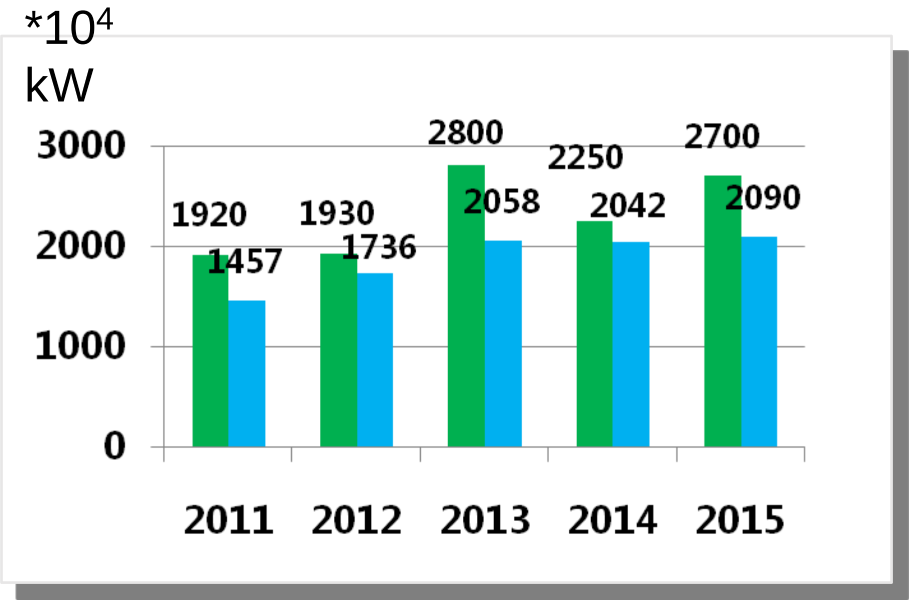


Fig4. The Trends of Max AC Load and Max Peak - valley Difference in Jiangsu in Recent 5 Years

In 2015, air-conditioning load in the power system of Jiangsu, reaching to 27 million kilowatts, almost 1/3 of the year's maximum loads; peak-valley difference is also reaching to 21 million kilowatts, accounting for about 1/4 of the maximum load.

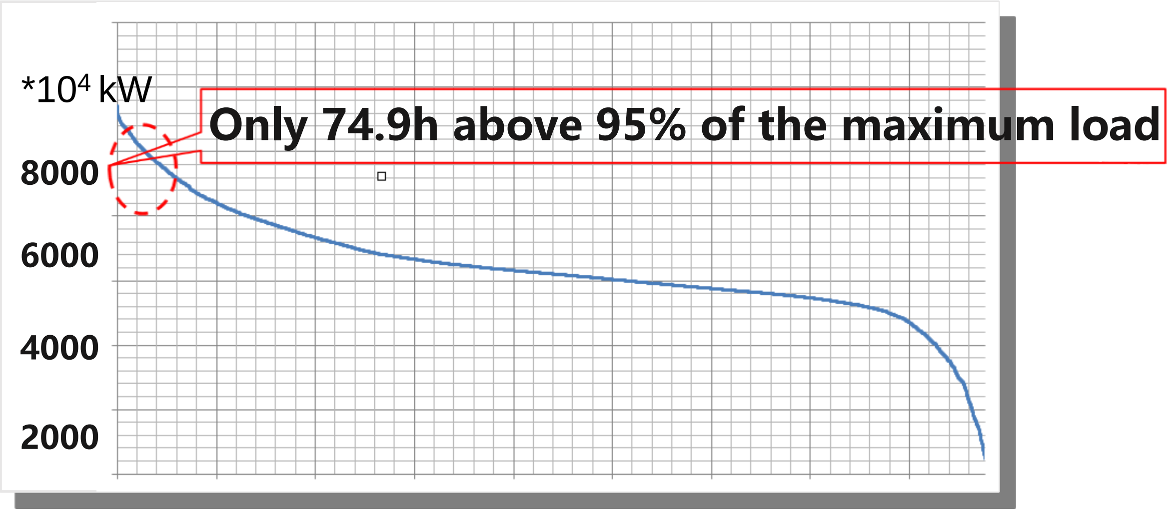


Fig5. Load-Hours Curve of Jiangsu Province in 2015

Air conditioning and other non-productive loads have obviously seasonal and time characteristics, and a strong correlation with the peak-valley difference.

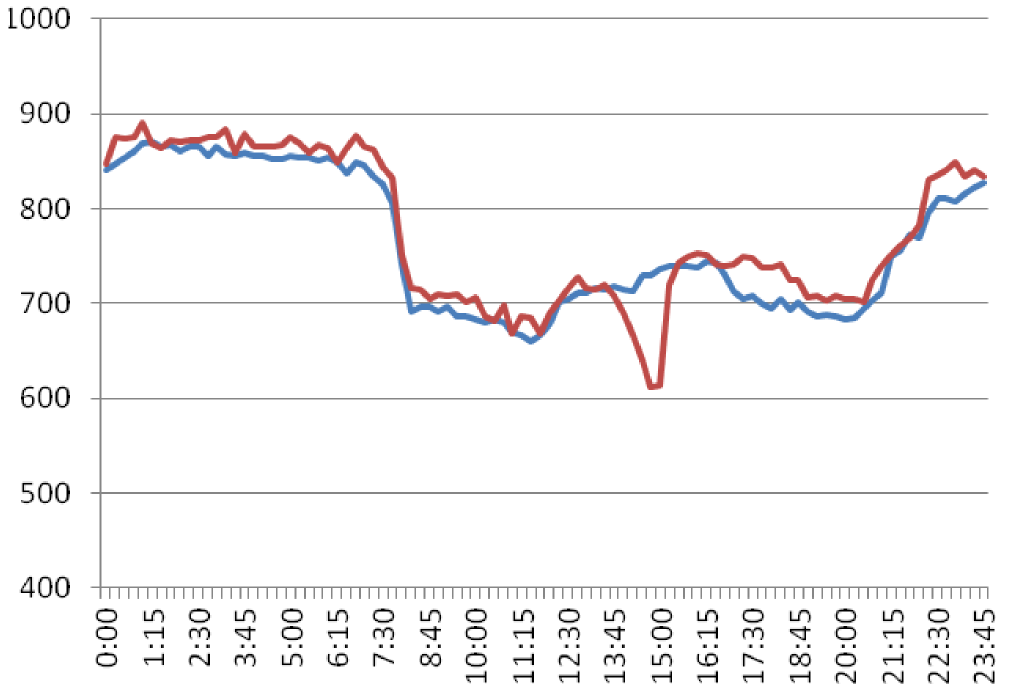
Practical experience of AC control

Systems

- Demand-response business support platform
- Smart Home Energy Efficiency Management System
- Interactive simulation software of electricity supply and demand

Devices

- DR in Jiangsu province



Practical experiences

Methodology

AC model

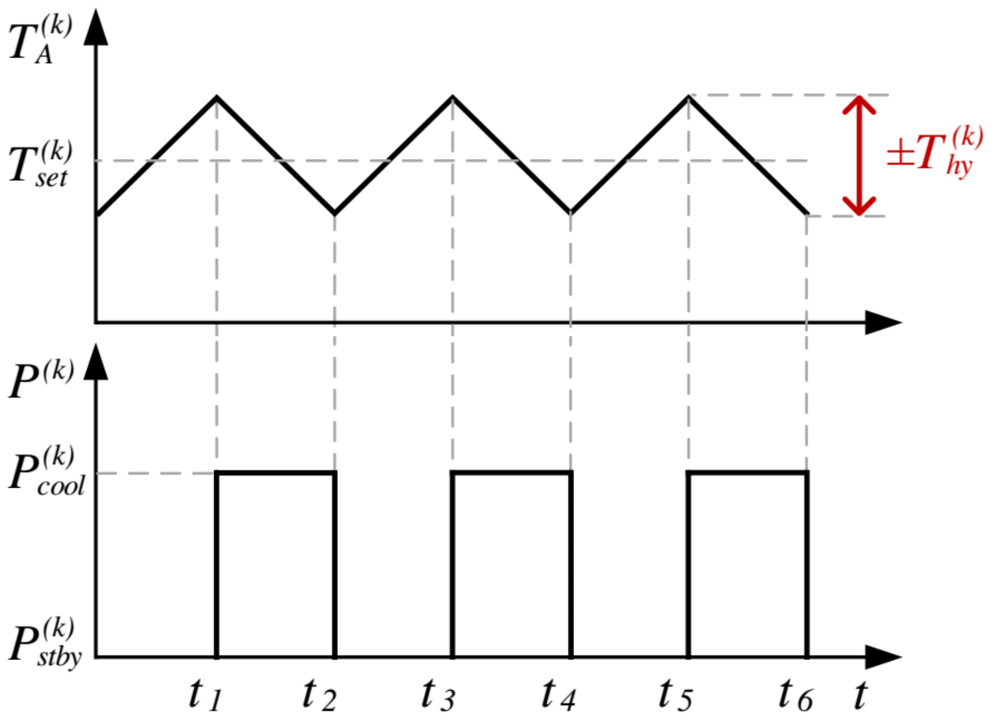


Fig6(a). the variation curve of the temperature in the room. Fig6(b). the operating power variation curve of AC.

ENERGY EQUIVALENT

$$c_a \rho_a V \frac{dT_r}{dt} = H_{gain} - H_{loss}$$

HEAT GAIN

$$H_{gain} = P * COP + H_{internal}$$

HEAT LOSS

$$H_{loss} = KS_w (T_r - T_0) + c_a \rho_a V_{ex} (T_r - T_0)$$

In order to maintain a stable temperature of the room, the temperature and the power of AC is shown in the fig6.

Dynamic AC model

Receive the DR signal

Set a new temperature of AC(increase the setting temperature

The AC stands by, and the temperature increases.

Reaches a new stable state.

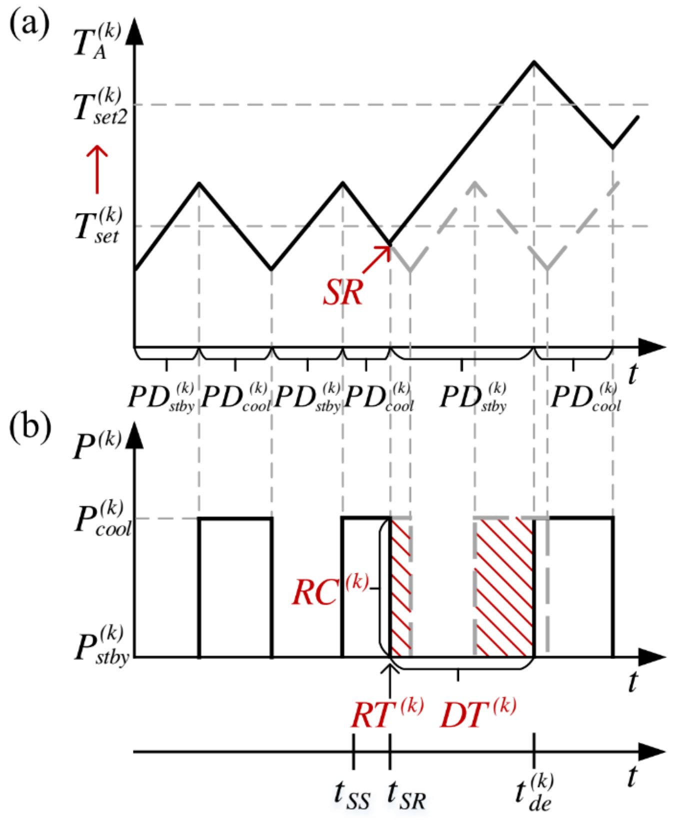


Fig7. Operating reserve provided by the kth AC when receiving the control signal in cooling state

AC aggregation

Micro performance

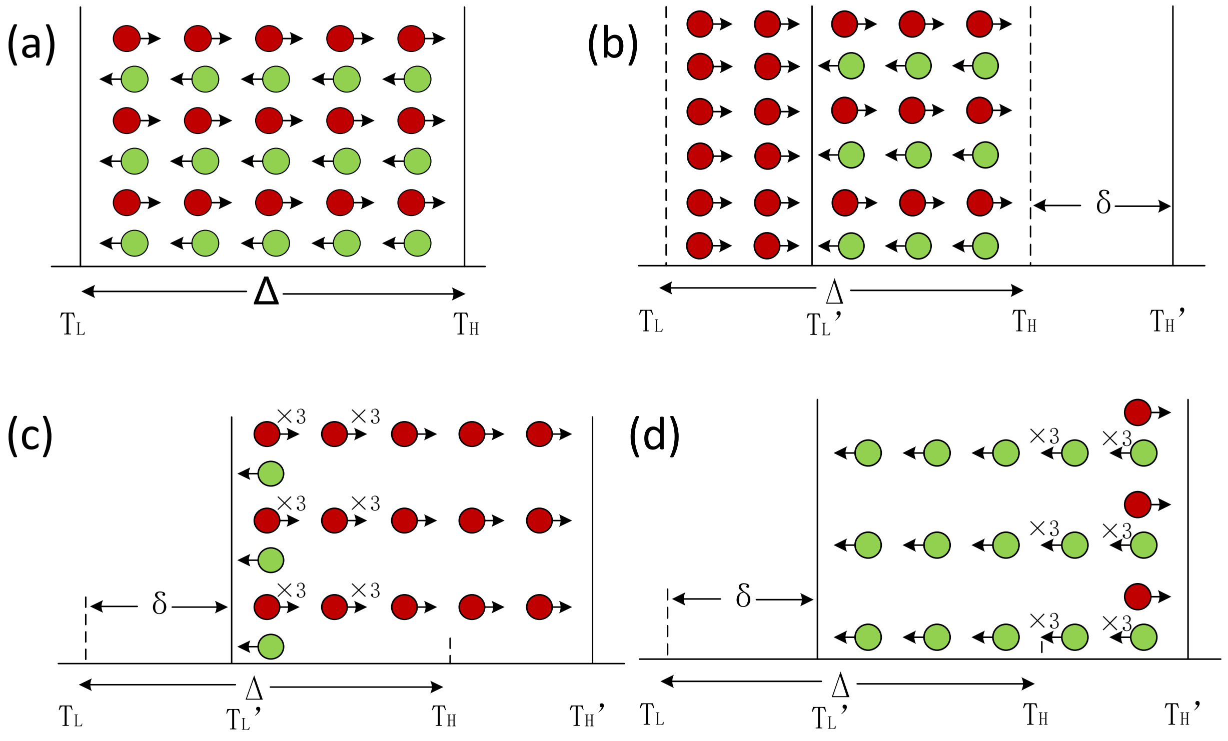


Fig8(a). Normal states of ACs. Fig8(b)(c)(d). Performance of ACs when setting temperatures change

Macro performance

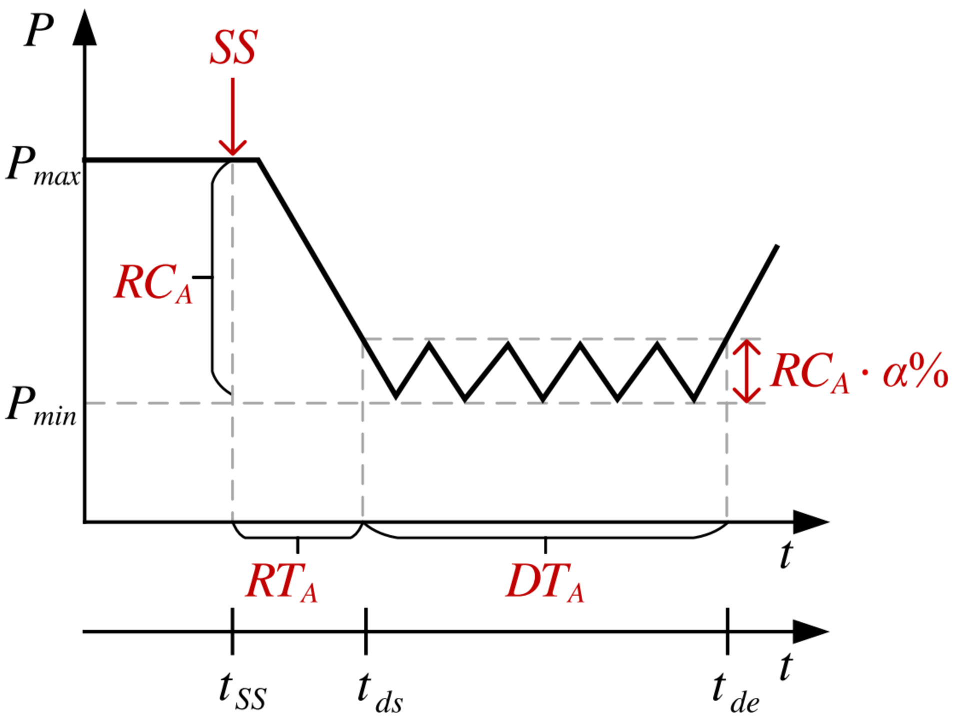


Fig9. Operating reserve provided by aggregated ACs

PRS phenomenon

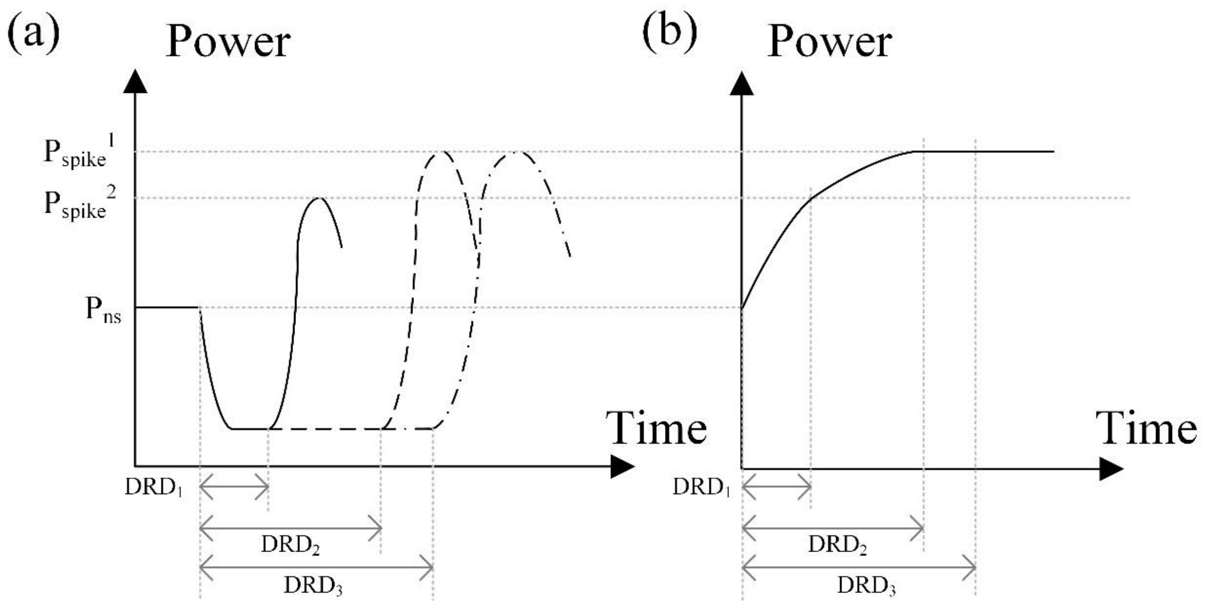


Fig10 (a) Several PRS phenomena;Fig10 (b). the relationship of maximum power of PRS and DR duration

As the DR duration increases, the maximum power of RPS increases first, and then remain a constant.

reason

- maintain the satisfaction of the customers
- no regulation of ACs re-commitment

restart during a very short time interval

factors

- **duration of DR**
- heat capacity of rooms
- ambient temperatures
- rated power of the ACs

Control strategy for DR

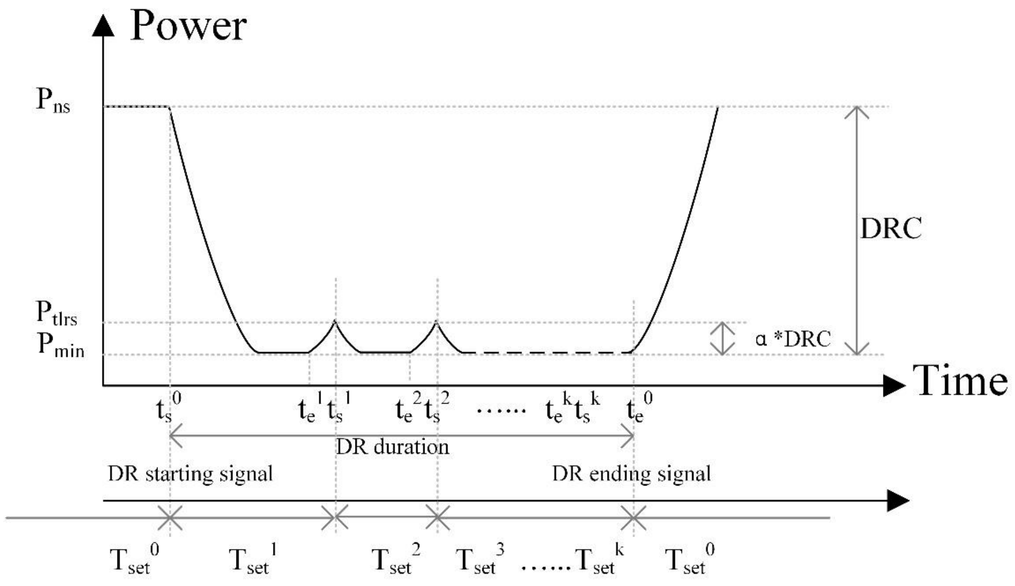
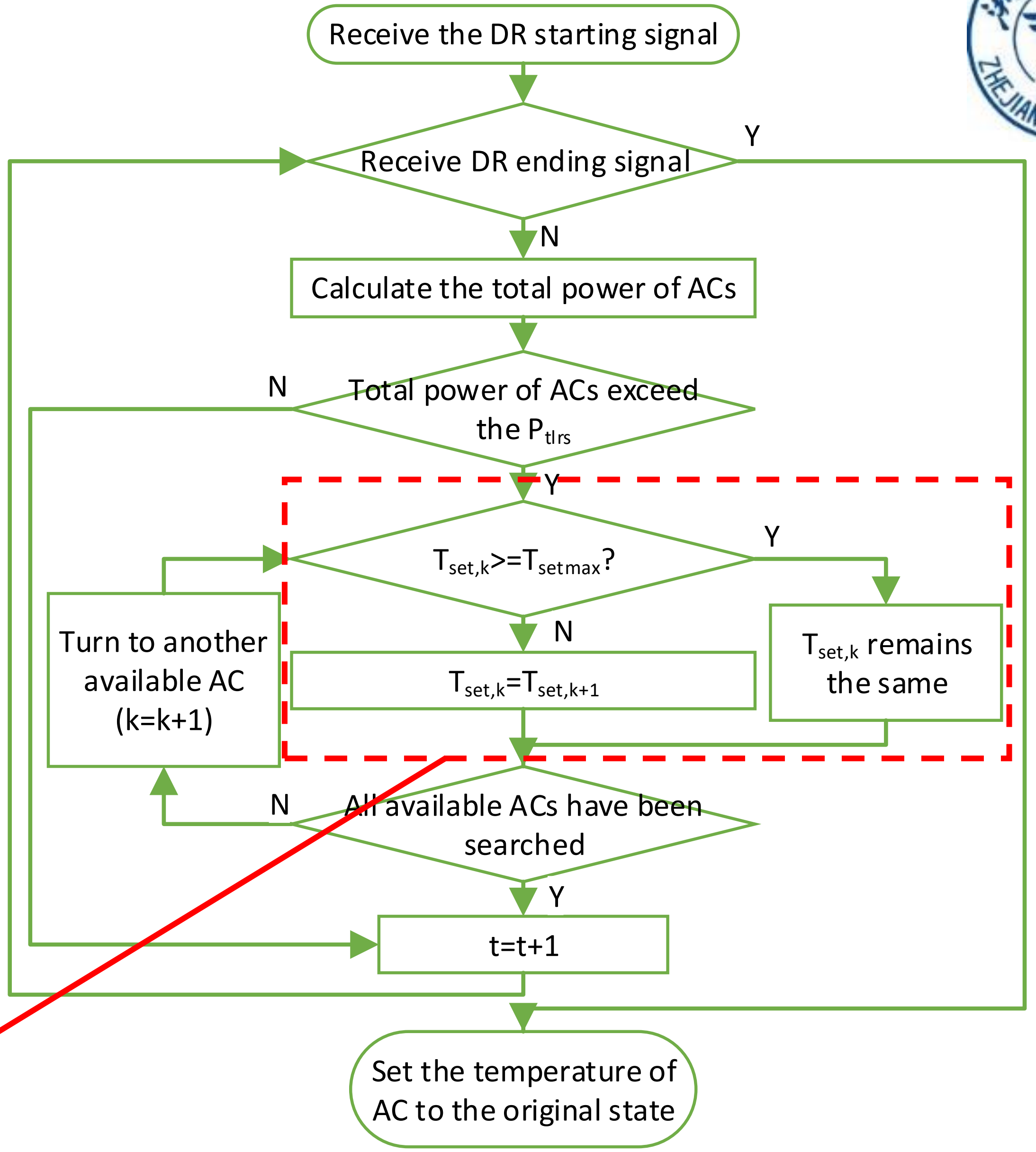


Fig11. The operating power curve of ACs in proposed strategy

$$T_{set}^{k+1} = \begin{cases} T_{set}^{k} + 1, P_{AC} > \alpha * DRC \,\&\&\, T_{set}^{k} < T_{set\max} \\ T_{set}^{k}, P_{AC} \le \alpha * DRC \,\|\, T_{set}^{k} \ge T_{set\max} \end{cases}$$



Cooperation strategy

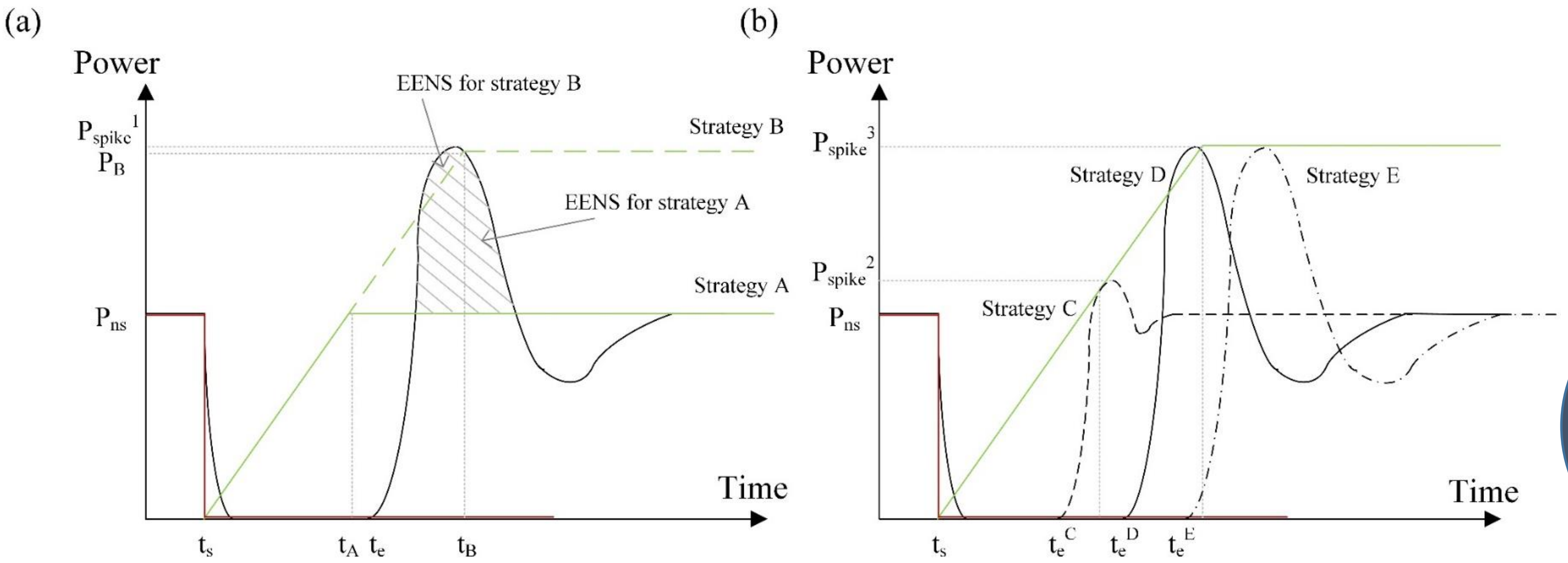
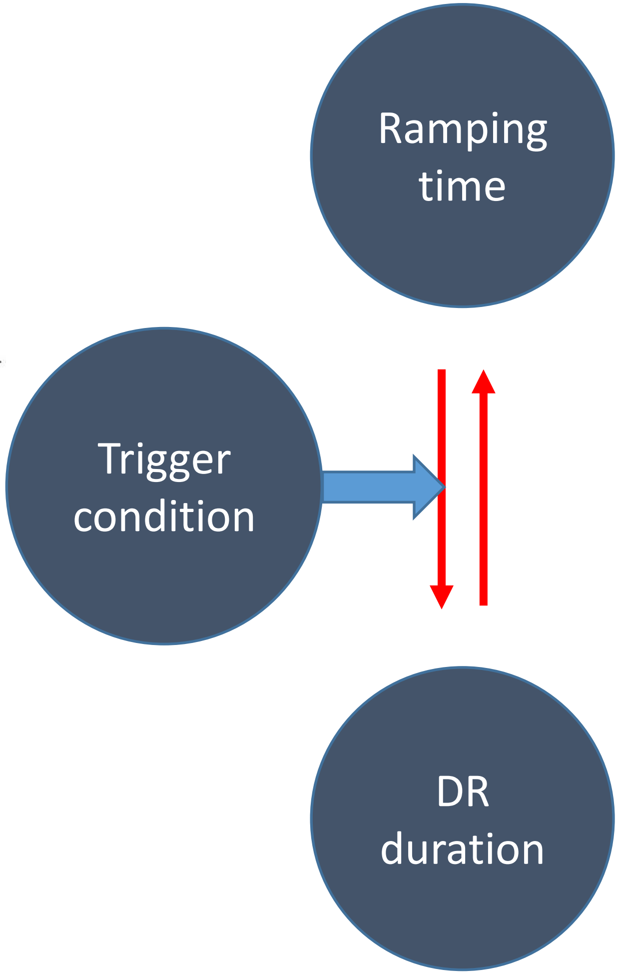


Fig12(a). Cooperation of TSRPs-ACs system with different ramp strategies;
Fig12(b). Cooperation of TSRPs-ACs system with different DR strategies



Expected Energy Not Supplied

$$EENS = \frac{1}{n}\sum_{k=1}^{n}\sum_{i\in T}\varepsilon_i * (P_{load,i} - P_{gen,i}) * t_i$$

Cooperation strategy

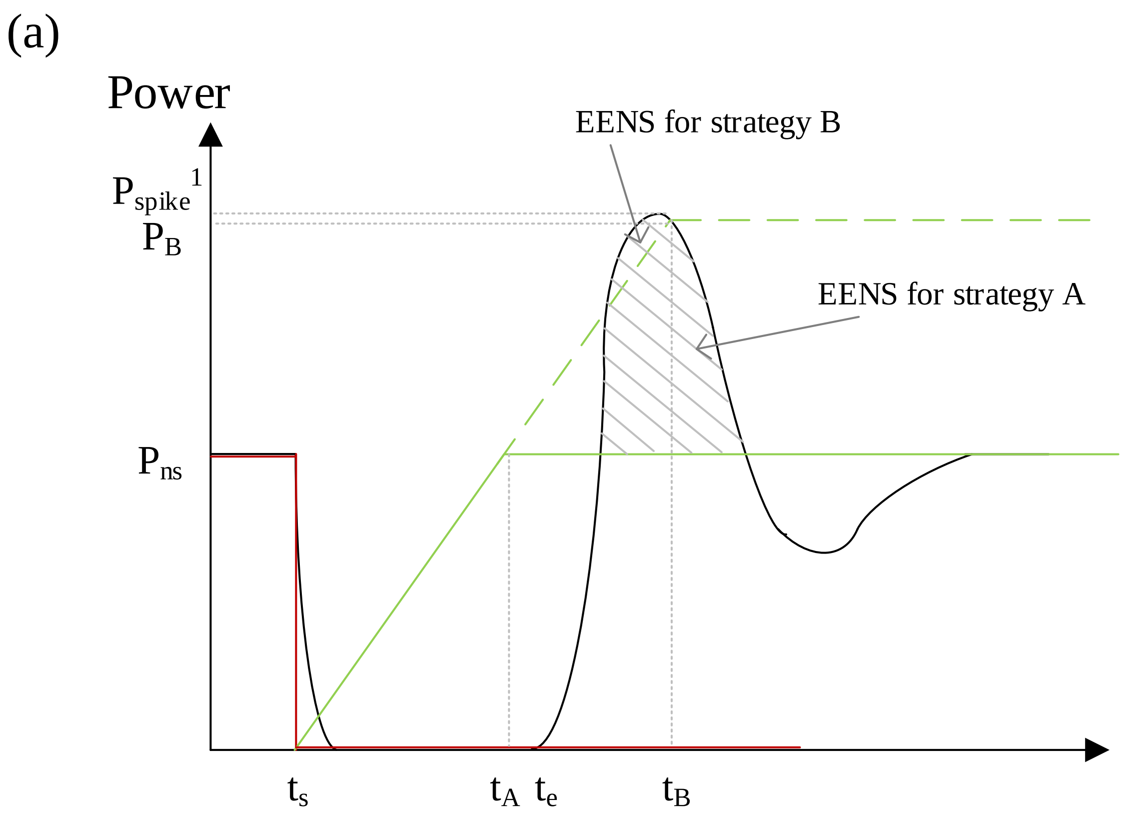


Fig12(a). Cooperation of TSRPs-ACs system with different ramp strategies;

Control variable:

- Ramping time of the traditional generators.
- Trigger condition for the traditional generators to stop ramping.

Constant:

- DR duration of ACs.

Strategy A:

- traditional generators stop ramping when their power output reaches to the power of ACs in normal state.

Strategy B:

- traditional generators stop ramping when their power output reaches to the maximum power of ACs considering the RPS phenomenon.

Cooperation strategy

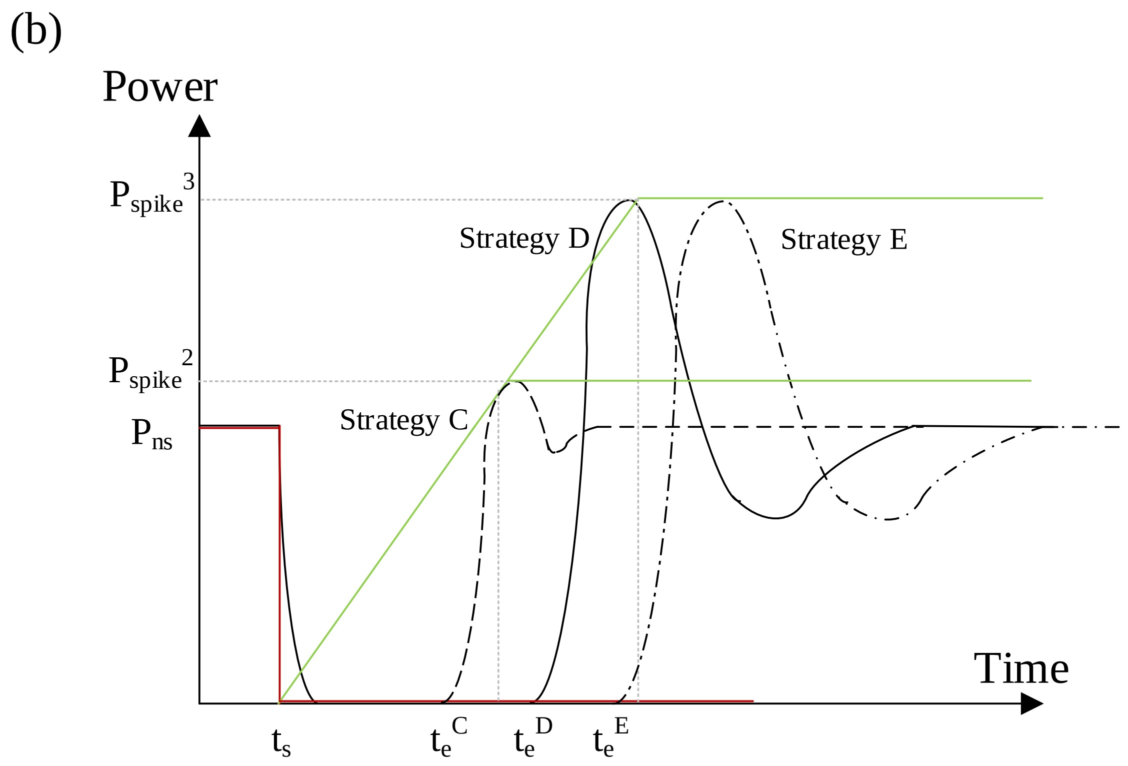


Fig12(b). Cooperation of TSRPs-ACs system with different DR strategies

Control variable:

- DR duration for ACs
- Ramping time of the traditional generators.

Constant:

- Trigger condition for the traditional generators to stop ramping.

■ Compared between strategy C and strategy D, former strategy has both shorter DR duration and better reliability performance.

■ Strategy E over responses.

DR duration and ramp time can be co-optimized to achieve both the best reliability performance and relatively low DR cost.

Simulation

Parameters of ACs and TSRPs

Table 1. The parameters of ACs and TSRPs

	Amount of ACs	Tolerance parameter	COP	Air temperatures (℃)	Ambient temperature (℃)	Heat capacity of air (kJ/kg*℃)
distribution	constant	constant	normal	uniform	constant	constant
value/range	500	0.3	(3,3.7)	(28,34)	32	1.5
	Hysteresis temperature(℃)	Rated power (W)	Max setting temperature(℃)	Setting temperature(℃)	Capacity of TSRPs(MW)	Ramp rate (percentage of capacity/min)
distribution	uniform	constant	constant	normal	constant	constant
value/range	(1,2)	6000	30	(24,26)	3	case2: 6%

Simulation results

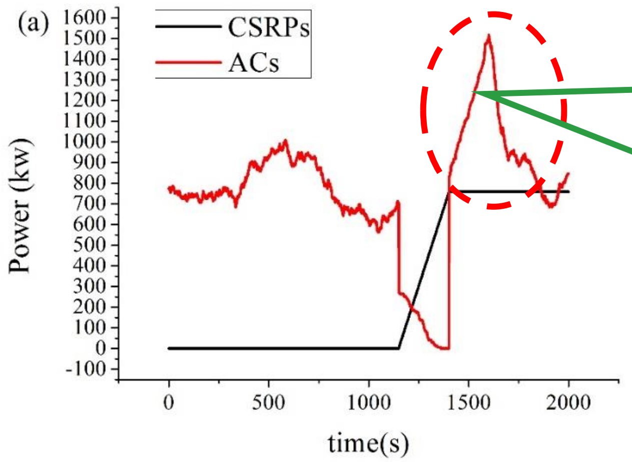


Fig13. cooperation of TSRPs-ACs system without considering PRS

DR duration (HOUR)	Relative value of max power of RPS
0	0.36
0.31	1

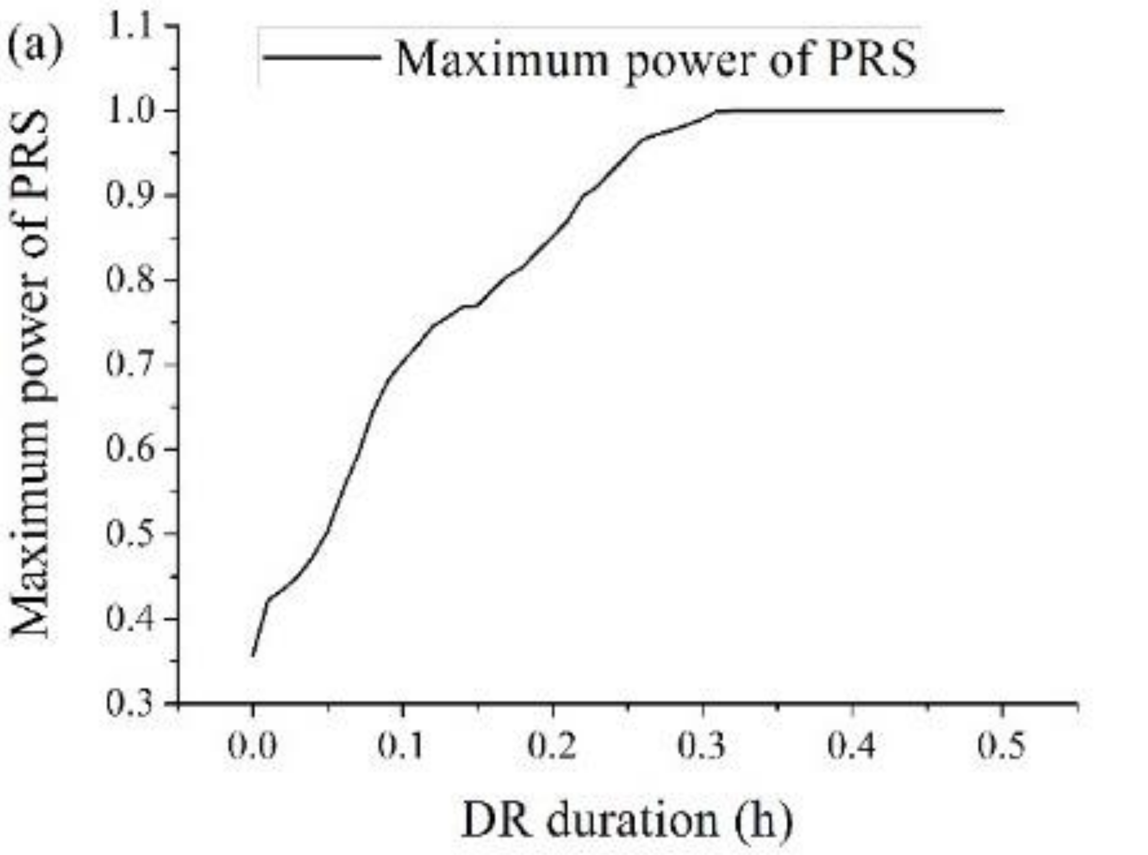


Fig14. Relationship of DR duration and maximum power of PRS

Simulation results

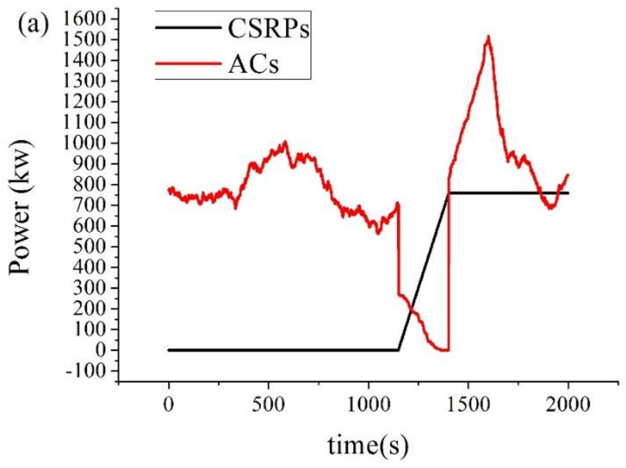


Fig13. Stage 1: cooperation of TSRPs-ACs system without considering PRS

Table2. Comparison of reliability performances

		DR duration	EENS(kW*h)	LOLP
stage1			43.489	0.568
stage2	Case 1	0.23	1.927	0.004
	Case 2	0.13	17.489	0.017
	Case 3	0.06	8.726	0.018

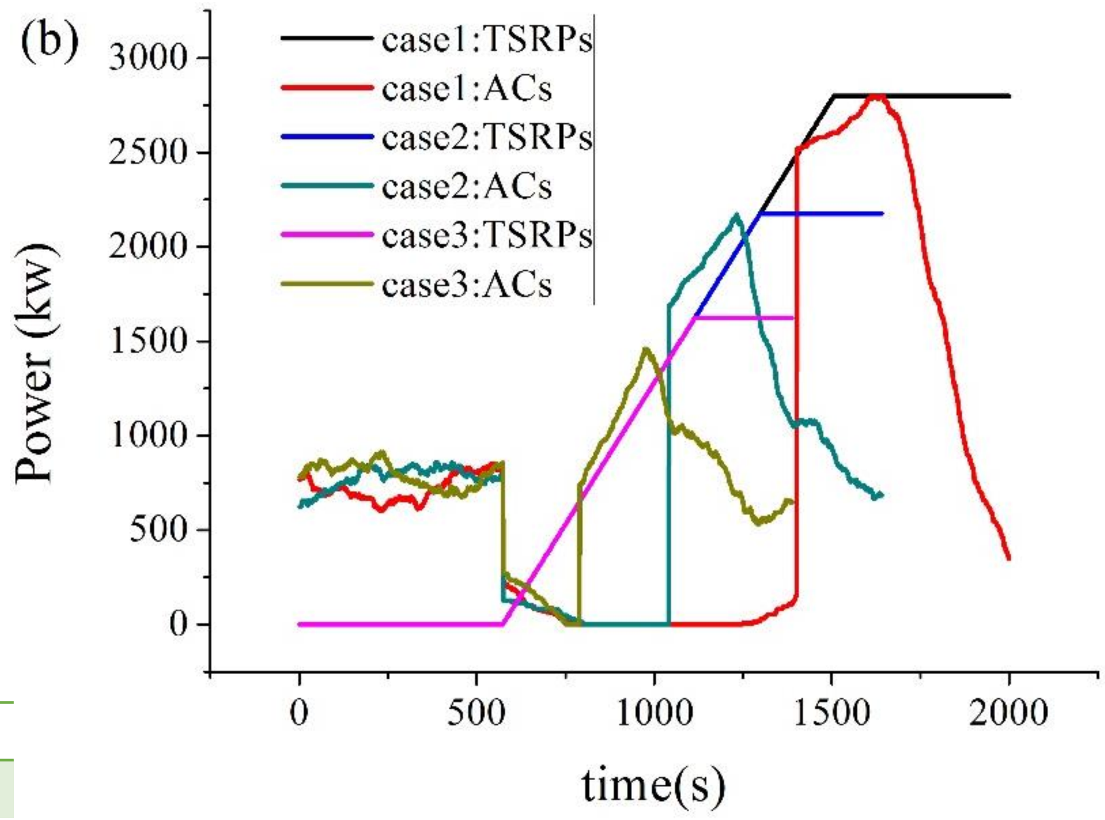


Fig15. Stage 2: Cooperation of TSRPs-ACs system with different DR strategies considering PRS

Simulation results

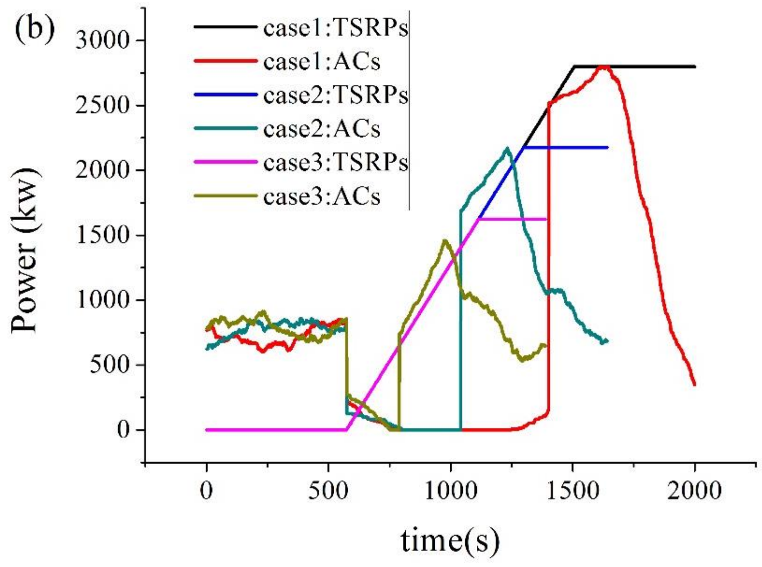


Fig15. Cooperation of TSRPs-ACs system with different DR strategies considering PRS

Take continuous values of DR duration

Monte-Carlo simulation for 1000 times

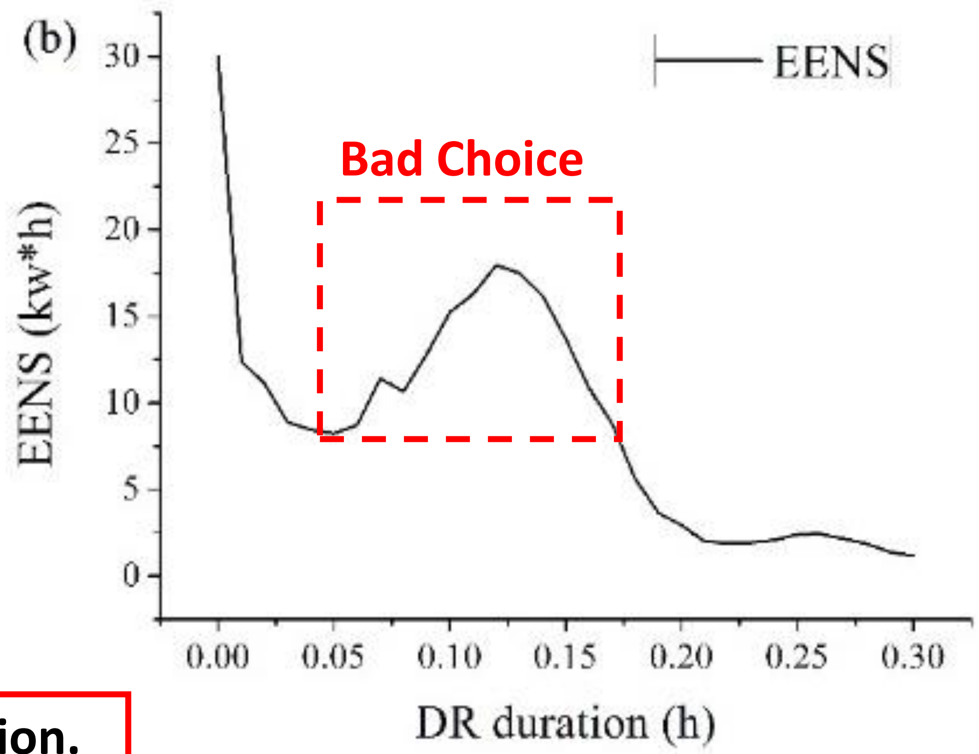


Fig16. Relationship of DR duration and EENS

- ✓ **EENS is not monotonic with the increase of DR duration.**
- ✓ **Improper extension of DR duration will lead to worse reliability performance of TSRPs-ACs system rather than improve it.**

Thanks!

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