III International Scientific Conference **“Sustainable and efficient use of energy, water and natural resources – SEWAN-2021”**

Synthesis of Cooling Water System under Varied Design Parameters

Authors: Yufei WANG

Affiliations: China University of Petroleum (Beijing)

Saint-Petersburg, April 19-24, 2021

Names: Yufei WANG

Affiliations: China University of Petroleum (Beijing)

Outline

1. Background
2. Synthesis under uncertainty
3. Bi-multiperiod optimization
4. Flexible topology optimization

Synthesis of Cooling Water System under Varied Design Parameters

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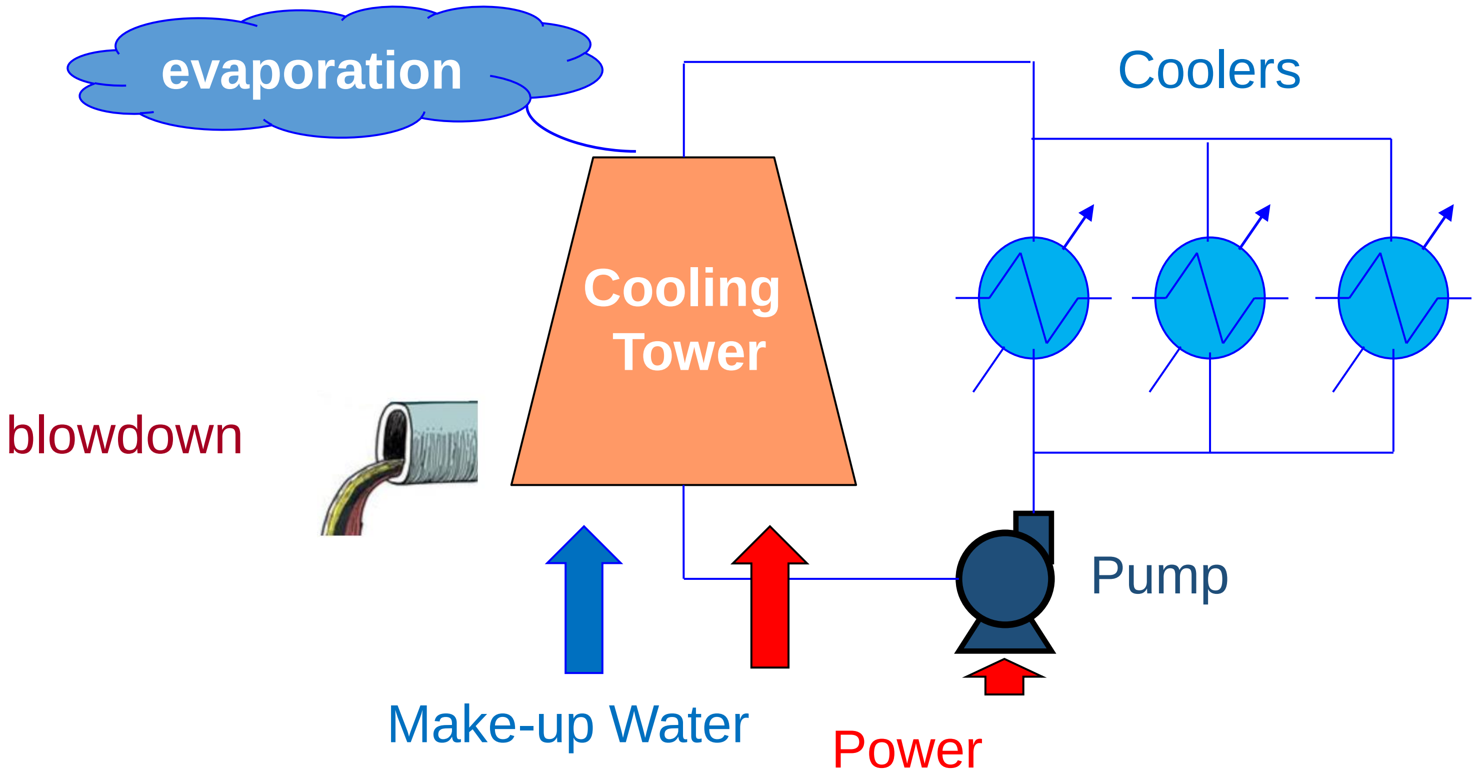
Background



An efficient CWS can save both power and water

Synthesis of Cooling Water System under Varied Design Parameters

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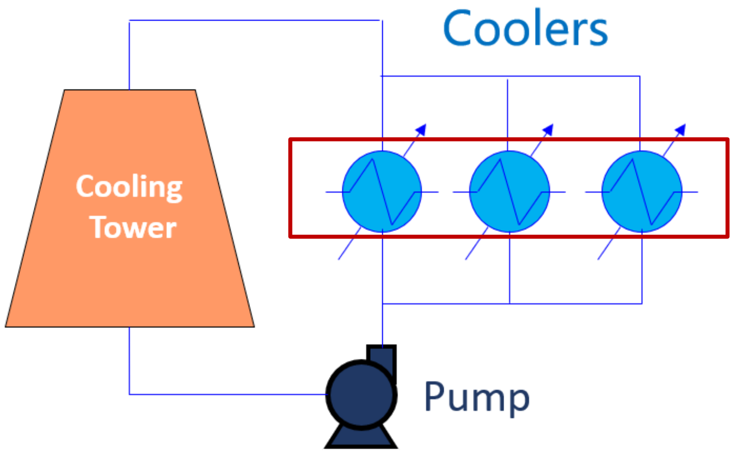
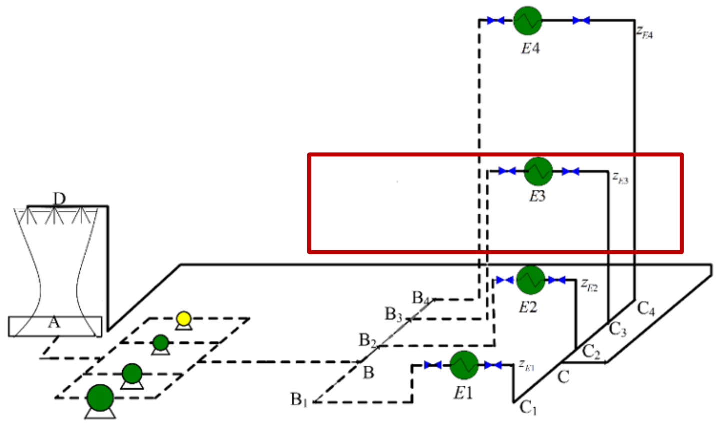
Affiliations: China University of Petroleum (Beijing)

Background — Faced problems in a CWS



1. Ignore the difference in cooling requirement

Higher flow rate !



2. Ignore the difference in pump head requirement

Higher pump head!

Higher Power consumptions !

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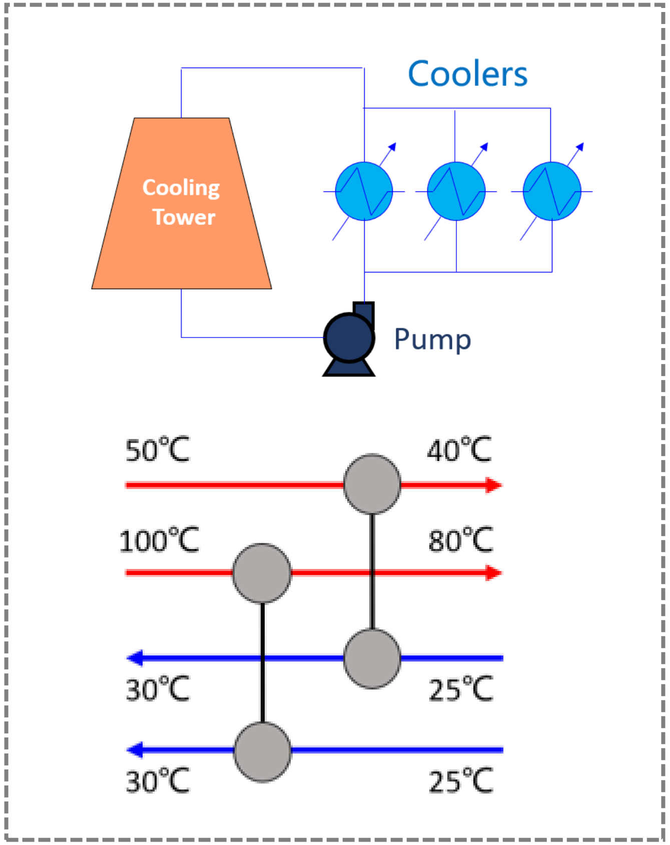
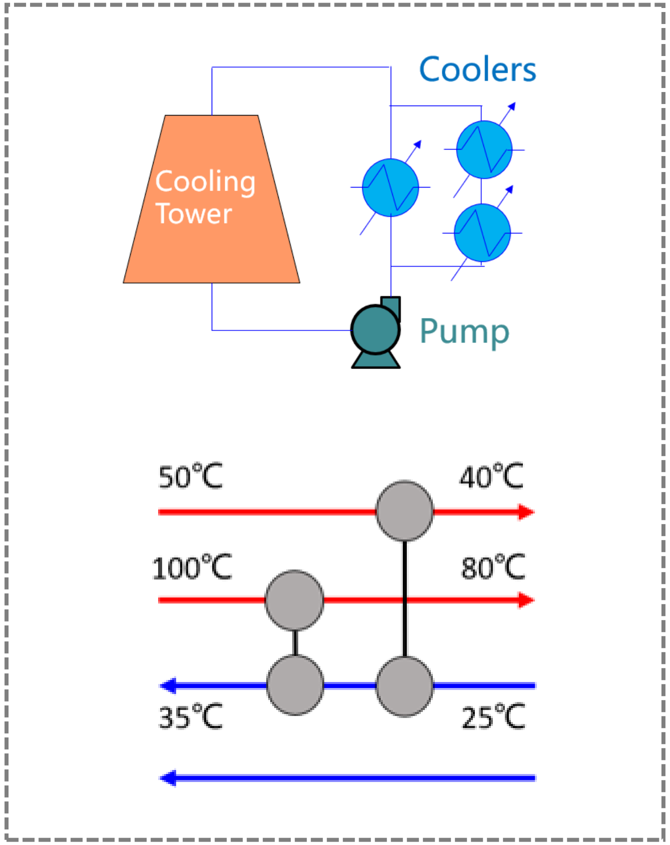
Background — Traditional way out (1)



Series Structure



Return temperature ↑ Flow rate ↓ Pressure drop ↑

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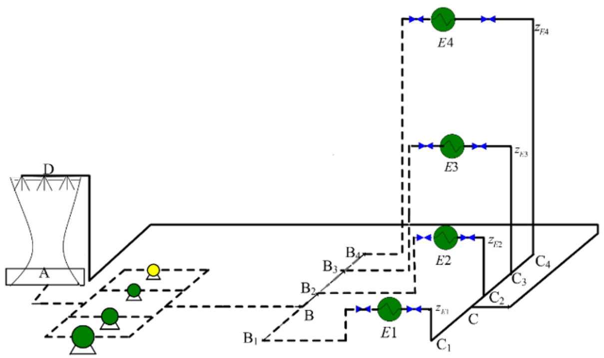
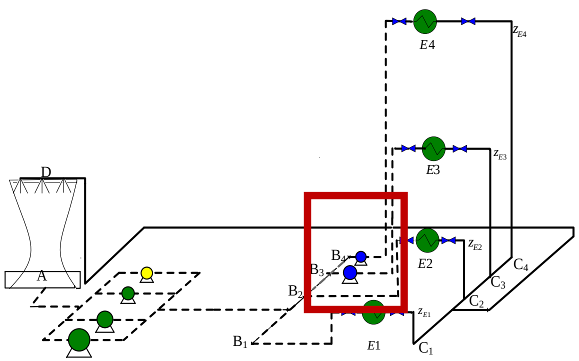
Background — Traditional way out (2)



Main pump structure



Main-auxiliary pump structure

Main pump head ↓ Power ↓ Investment ↑

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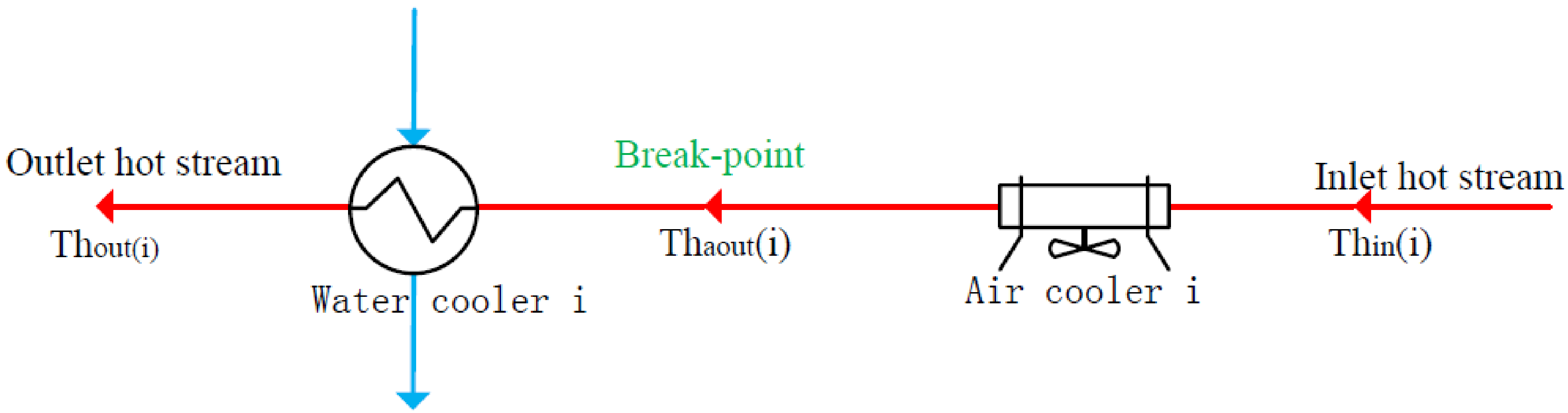
Background — Traditional way out (3)

Consider air cooling in CWS synthesis



Find the best cooling duty distribution between air cooling and water cooling to reduce total cost

Names: Yufei WANG
Affiliations: China University of Petroleum (Beijing)

Background — Unsolved problems

- A number of parameters vary with time
- Most studies considered CWS synthesis under stable condition

Weather condition

Peak/off peak power price

Working fluctuation

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Affiliations: China University of Petroleum (Beijing)

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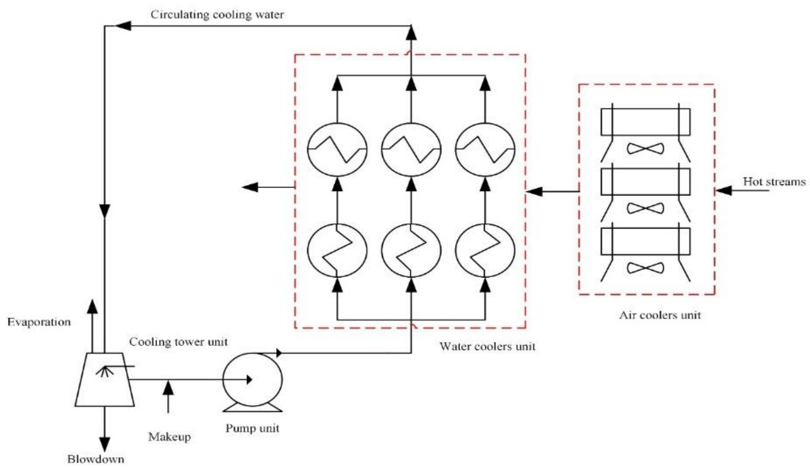
Synthesis under uncertainty

In real industries, a number of uncertain factors exist

Optimal design under uncertainty



All traditional methods are involved

- Air cooling
- Series structure
- Main-auxiliary pumps

Uncertainty parameters

Weather condition

Working fluctuation

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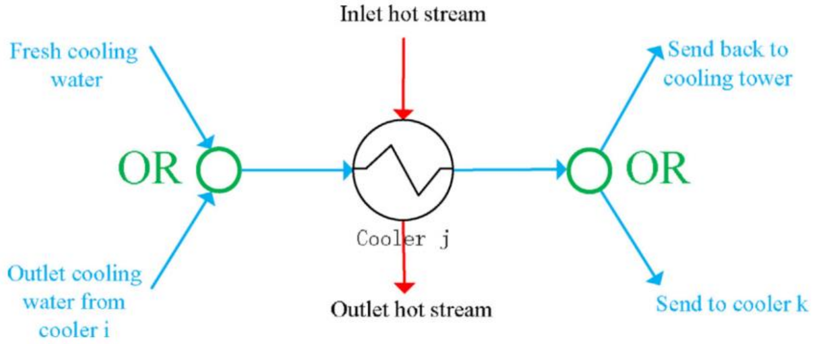
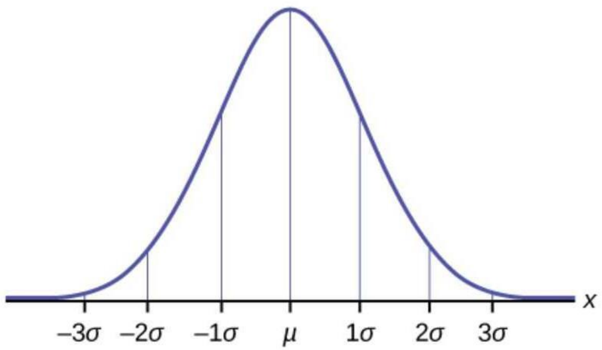
Synthesis under uncertainty

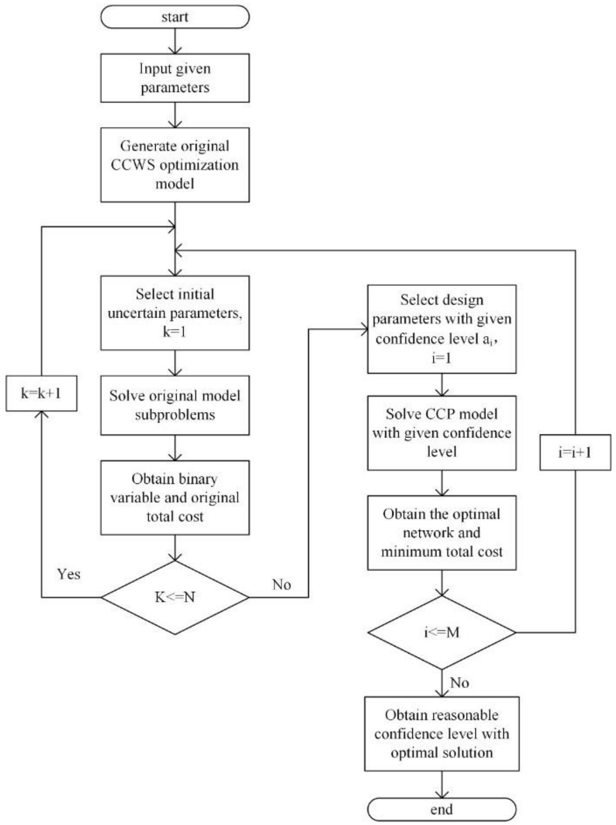


Generalized superstructure



Confidence level

Objective: Minimum Total Annual cost



Monte Carlo based algorithm

Names: Yufei WANG

Affiliations: China University of Petroleum (Beijing)

Synthesis under uncertainty — Case study

Four conditions are considered:

- Initial case with stable condition
- Optimization under uncertain hot streams flow rates
- Optimization under uncertain ambient temperature
- Optimization under uncertain ambient temperature and uncertain flow rates

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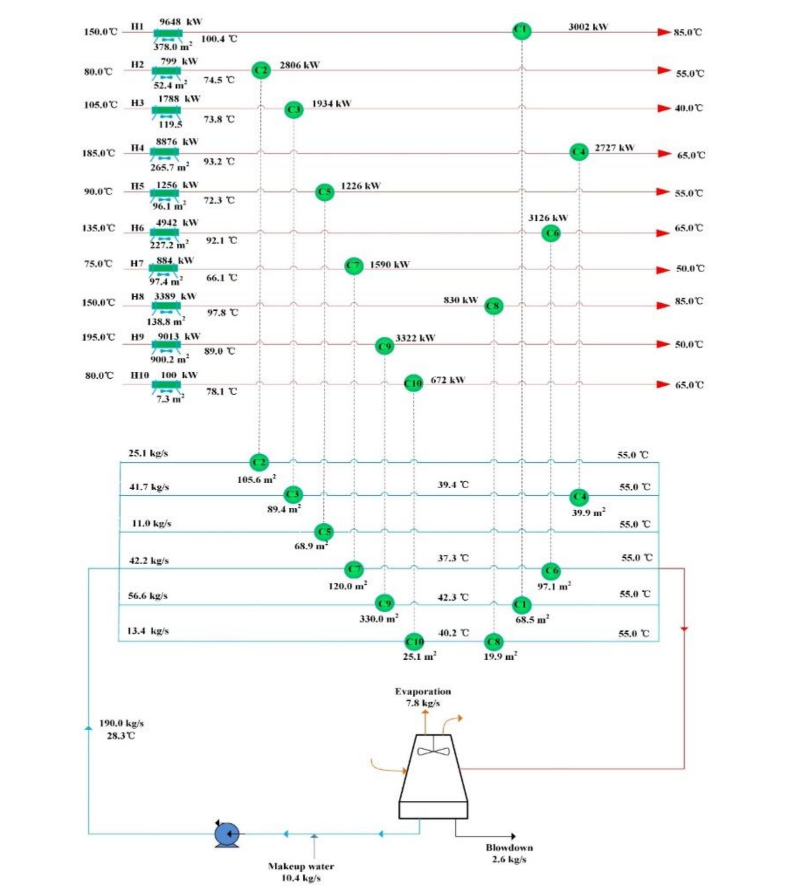
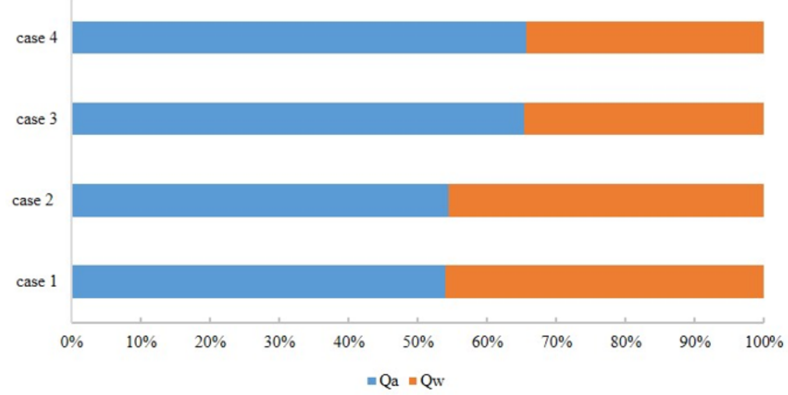
Affiliations: China University of Petroleum (Beijing)

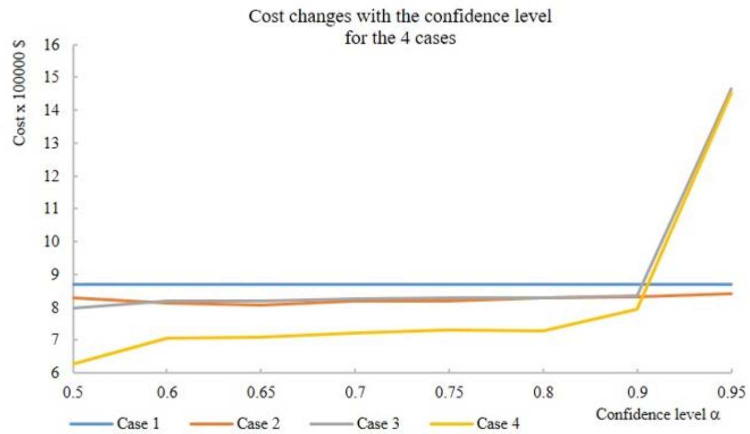
Synthesis under uncertainty — Case study



Optimal design can be obtained



Cooling duty distribution



Confidence level

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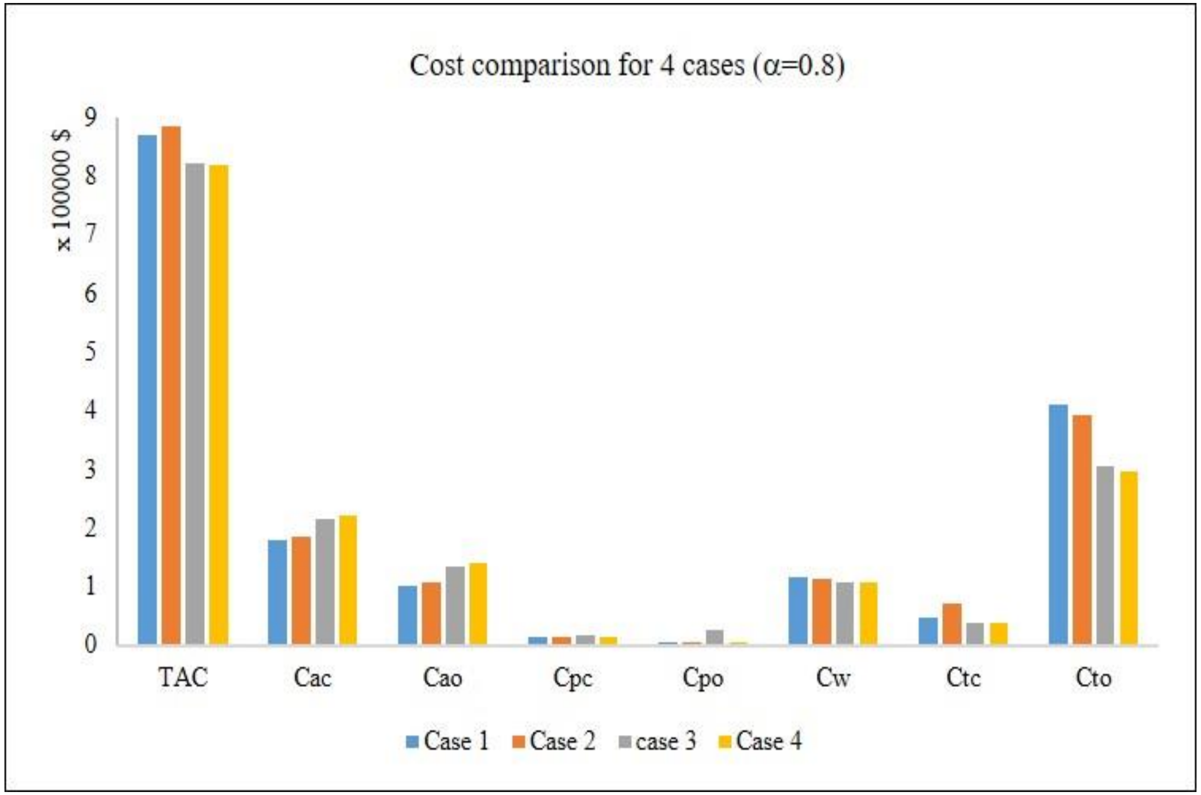
Synthesis under uncertainty — Case study



Cost comparison for the 4 cases

Names: Yufei WANG

Affiliations: China University of Petroleum (Beijing)

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Bi-multiperiod optimization

In real industries, some parameters periodically change in different time scale.

Day time scale

Year time scale

Peak/off peak power price
Weather condition…

Weather condition…

A method is proposed to design the system under Bi-multiperiod condition

Synthesis of Cooling Water System under Varied Design Parameters

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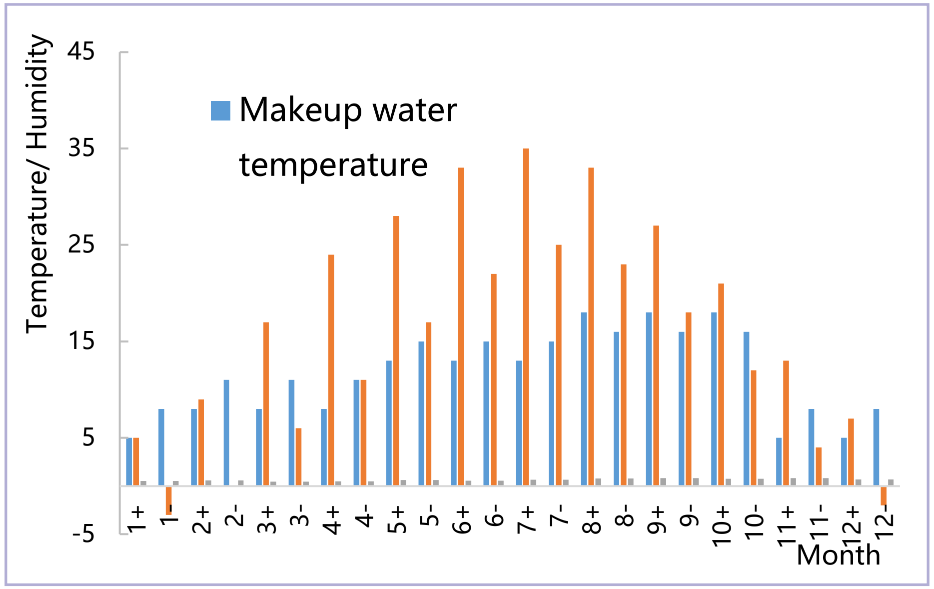
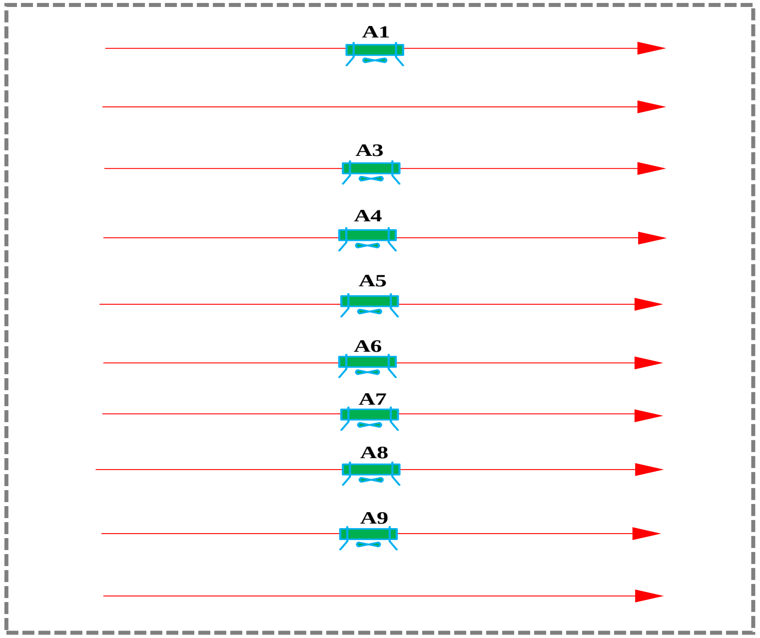
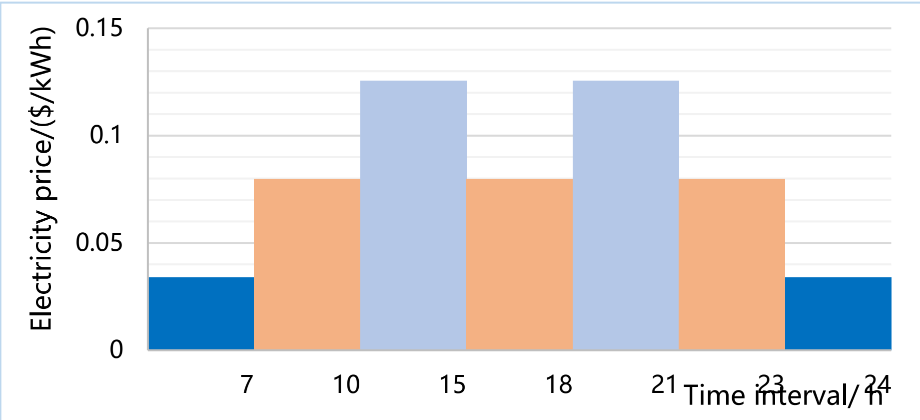
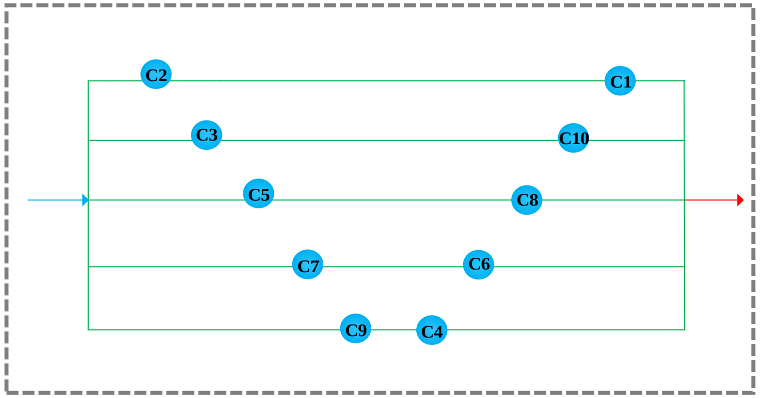
Bi-multiperiod optimization









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Affiliations: China University of Petroleum (Beijing)

Bi-multiperiod optimization — Case study

Three conditions are considered:

- Case 1: All design parameters are constant
- Case 2: Year time scale multiperiod optimization
- Case 3: Bi-multiperiod optimization

	Case 1	Case 2	Case 3
Number of air coolers	9	9	10
Total area of air coolers (m^2)	1824	2495	2629
Total area of water coolers (m^2)	1120	1330	1283
Total water flow rate ($kg{\cdot}s^{-1}$)	205	187~237	174~211
Makeup water flow rate ($kg{\cdot}s^{-1}$)	14.5	2.0~12	1.1~10.8
Blowdown water flow rate ($kg{\cdot}s^{-1}$)	3.6	0.5~3.0	0.3~2.7
Evaporation water flow rate ($kg{\cdot}s^{-1}$)	10.9	1.5~9.0	0.8~8.1
Total cost ($)	9.06×10^6	8.82×10^5	8.22×10^5

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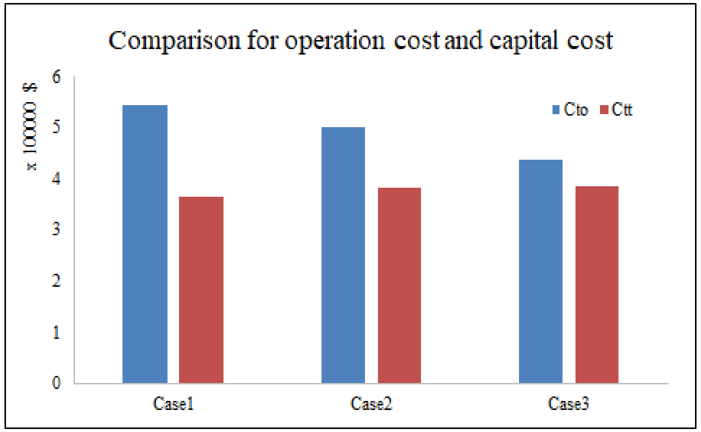
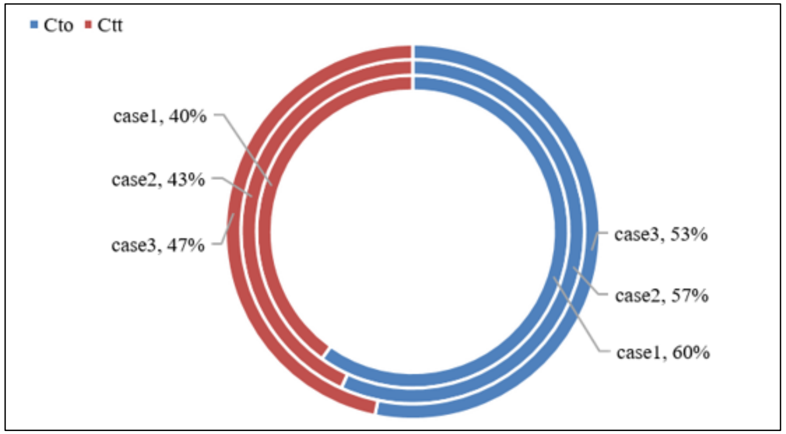
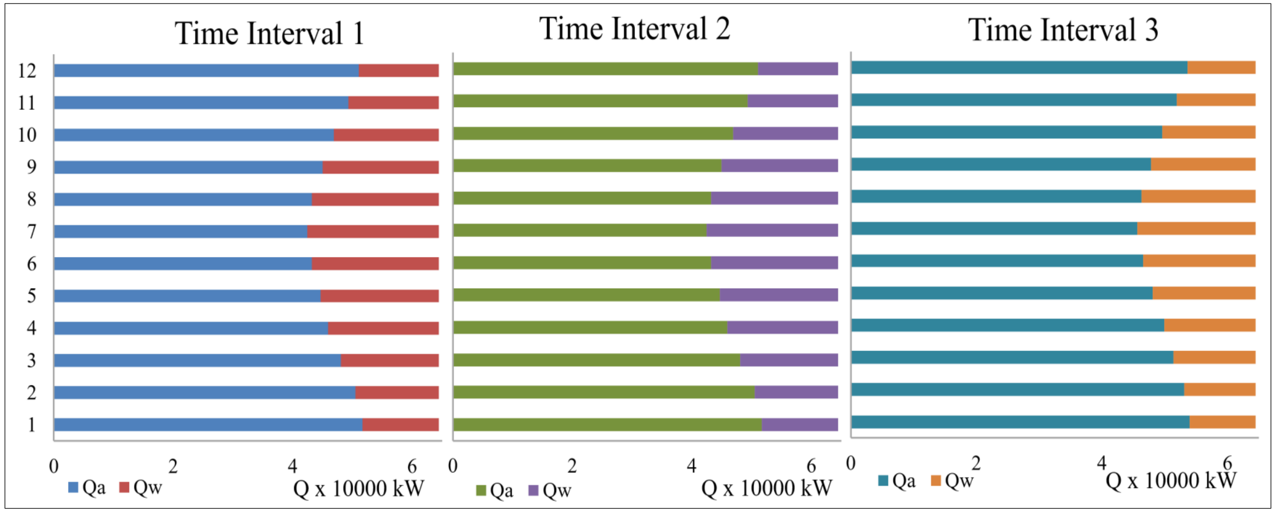
Bi-multiperiod optimization — Case study



Operation and capital cost



Cost comparison



Heat load distribution in condition 3

Names: Yufei WANG
Affiliations: China University of Petroleum (Beijing)

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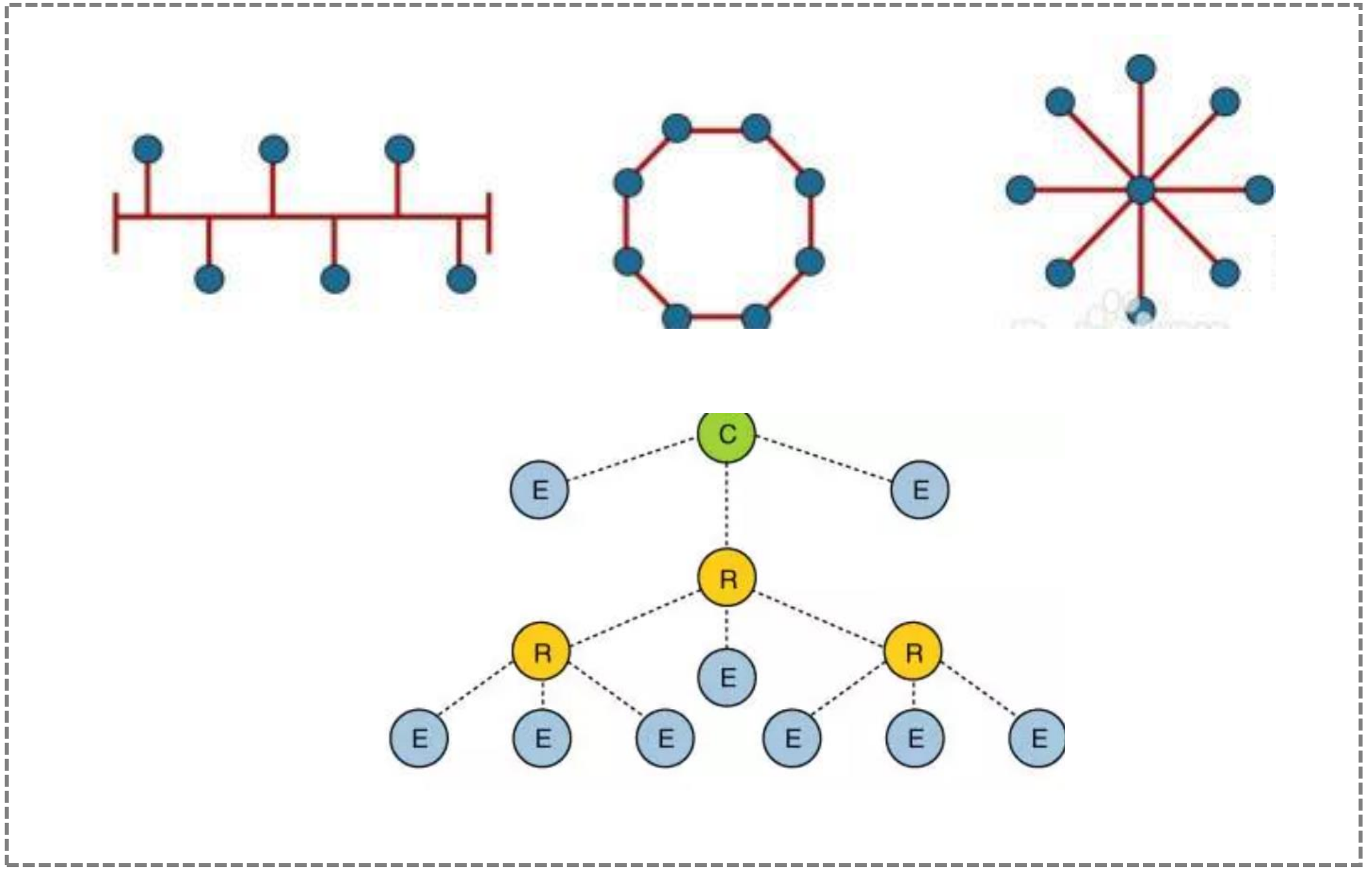
Flexible topology optimization

- Previous studies design system with fixed structure
- Structure may vary to better fit the varied parameters



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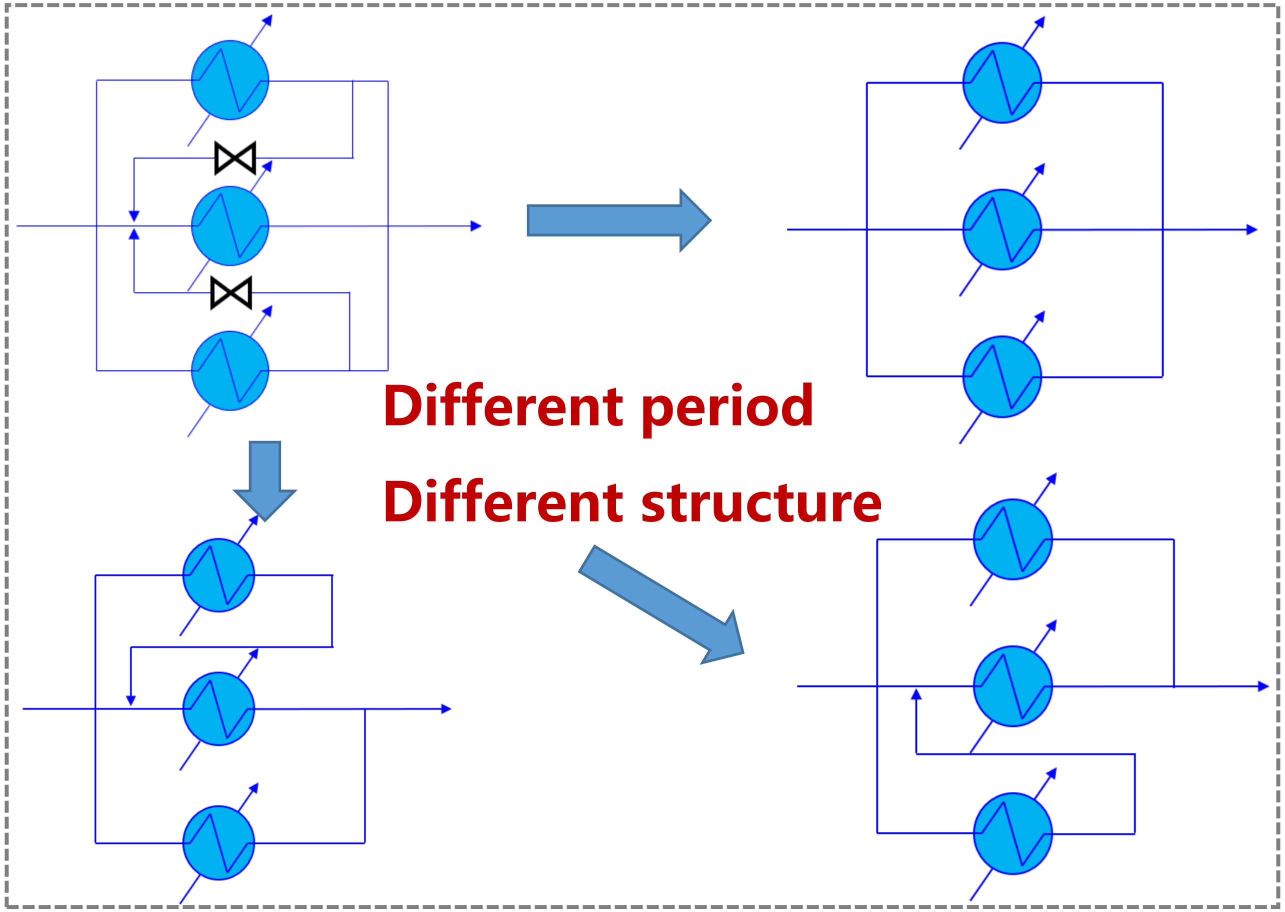
Flexible topology optimization



Key constraints

$$\sum_{i=1}^{n} Z(i,j,p) \leq 1$$

$$\sum_{j=1}^{n} Z(i,j,p) \leq 1$$

$$\sum_{i=1}^{n} Y(i,j) \leq p$$

$$\sum_{j=1}^{n} Y(i,j) \leq p$$

$$Z(i,j,p) \leq Y(i,j) \cdot p \,/\, p$$

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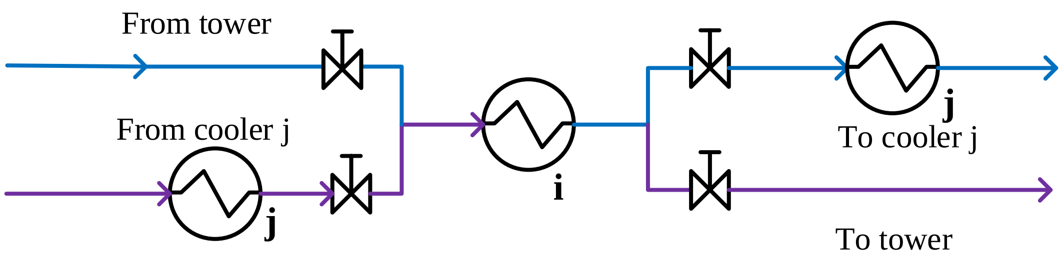
Flexible topology optimization— Case study



No constraints on how many coolers are connected to 1 cooler in all periods.

Sensitivity analysis

Node numbers	Computation time	Total cost	Structure
2 ★	11 mins	923,543 $	simple
3	18 mins	926,032 $	harder
4	31 mins	925,370 $	harder
5	39 mins	916,295 $	hardest
6	60 mins	920,765 $	hardest

At most 2 coolers are connected to 1 cooler in all periods.

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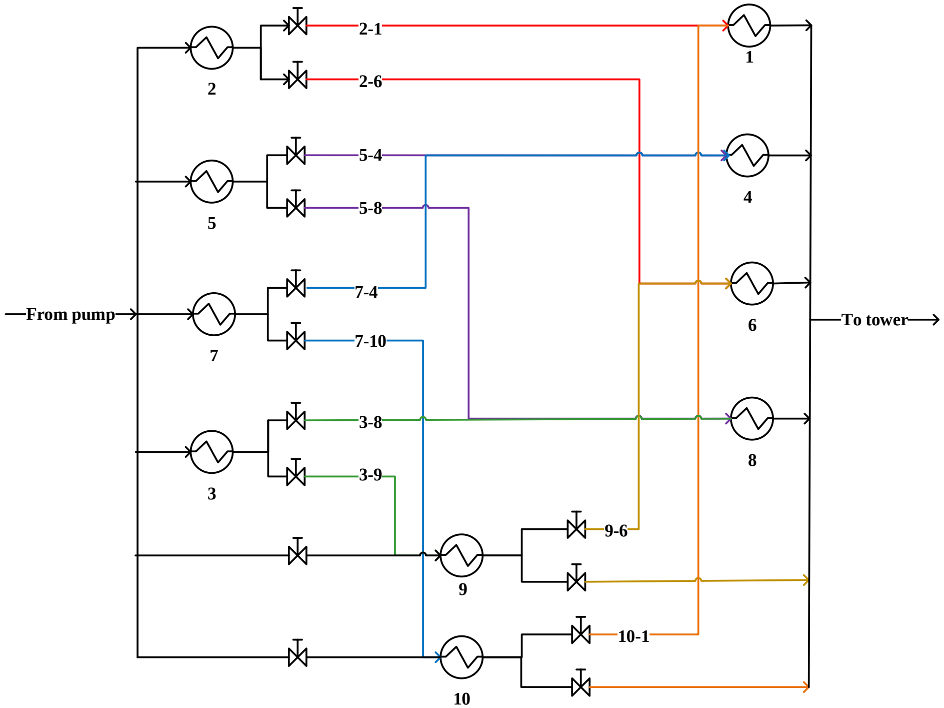
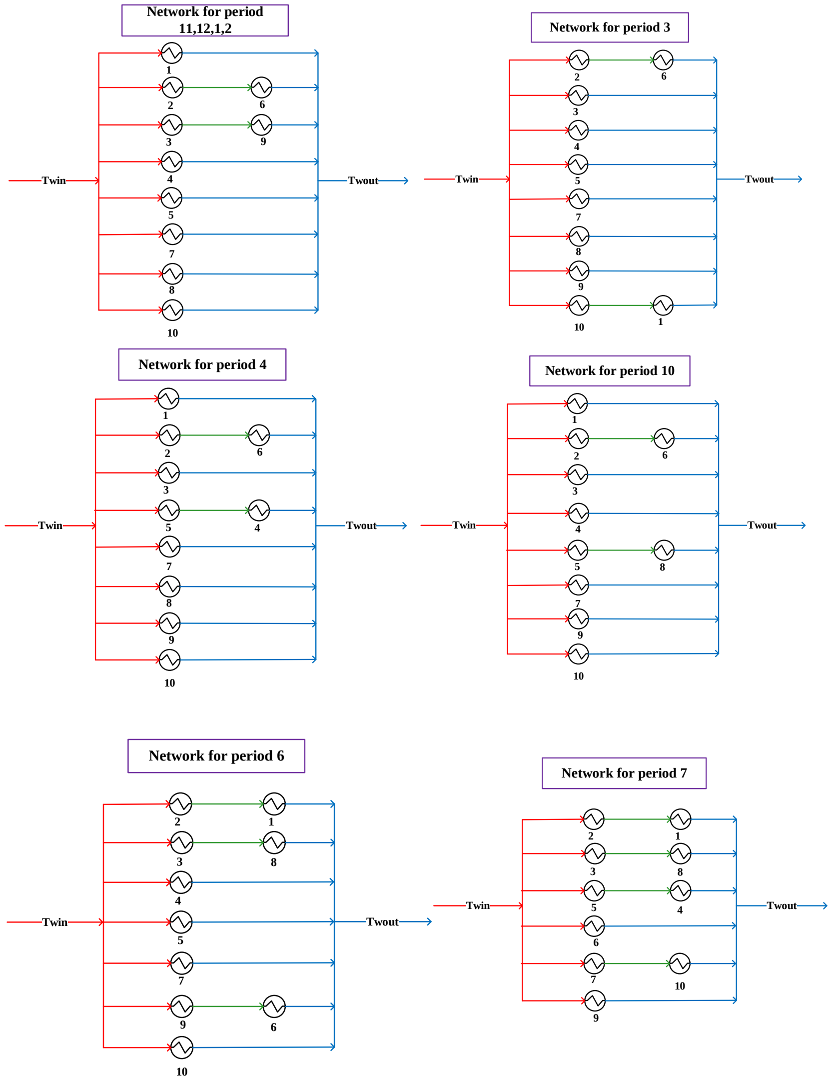
Flexible topology optimization

—Case study



Optimal design with flexible structure (8 nodes)



Optimal structure in periods

Names: Yufei WANG
Affiliations: China University of Petroleum (Beijing)

Flexible topology optimization —Case study

Period	Ambient temperature (℃)	Water temperature (℃)	Total water flowrate (kg/s)	Evaporation (kg/s)	Blowdown (kg/s)	Makeup (kg/s)
1	5	20	98.161	5.257	1.752	7.009
2	9	20	109.711	5.875	1.958	7.833
3	17	20	132.477	7.094	2.364	9.459
4	24	22	160.072	8.572	2.857	11.429
5	28	26	192.018	10.282	3.427	13.71
6	33	30	245.888	12.492	4.164	16.656
7	38	34	372.119	16.797	5.588	22.355
8	35	31	243.805	12.999	4.332	17.331
9	27	25	183.517	9.827	3.275	13.103
10	21	20	143.695	7.695	2.565	10.26
11	13	20	121.149	6.488	2.162	8.65
12	7	20	103.95	5.567	1.855	7.422

Names: Yufei WANG

Affiliations: China University of Petroleum (Beijing)

Flexible topology optimization —Case study

	Flexible network	Fixed network
Ambient temperature (℃)	5~38	38
Water temperature (℃)	20~35	35
Total water cooler area (m^2)	1290	1022
Total air cooler area (m^2)	2509	2858
Capital cost ($)	442,328	417,036
Operation cost ($)	401215 ★	601,957
Total cost ($)	923,543	1,018,993

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Conclusions

CWS optimization under uncertainty variables.

CWS optimization integrated bi-multiperiod parameters.

CWS optimization considering flexible topology .

An efficient CWS can save both power and water and minimize total cost.

Future work

CWS optimization integrated the above factors.

Names: Yufei WANG

Affiliations: China University of Petroleum (Beijing)

Thank you for your attention!

Authors: Yufei WANG
Affiliations: China University of Petroleum (Beijing)

Contact details: wangyufei@cup.edu.cn