Energy and Power Engineering, 2025, 17(8), 241-247
https://www.scirp.org/journal/epe
ISSN Online: 1947-3818
ISSN Print: 1949-243X

A New Algorithm for Optimal Design of the Recirculating Cooling Water System of Thermal Power Plants Part II: Case Study 2

Aleksa V. Popadić

Independent Researcher, Gacko, Bosnia & Herzegovina
Email: nauka25ap@gmail.com

How to cite this paper: Popadić, A.V. (2025) A New Algorithm for Optimal Design of the Recirculating Cooling Water System of Thermal Power Plants Part II: Case Study 2. *Energy and Power Engineering*, **17**, 241-247.
https://doi.org/10.4236/epe.2025.178013

Received: July 7, 2025
Accepted: August 17, 2025
Published: August 20, 2025

Abstract

An innovative approach to the optimization of process parameters and equipment sizes of the recirculating cooling water system for various types of thermal power plants (TPPs) with natural draft wet cooling towers is presented in this paper. This article is organized into several parts to illustrate the application of the proposed optimization method using case studies. Case Study 2 is intended to demonstrate how different combinations of the decision variables affect the optimization results compared to the optimal base case when all decision variables are optimized.

Keywords

Thermal Power Plant, Cooling Water System, Cold End System, Natural Draft Cooling Tower, Steam Condenser, Optimization

1. Introduction

This article is organized into several parts to illustrate the application of the proposed optimization method using case studies. The case studies are related to the cold end system of a 300 MW TPP. The objective of the studies is to find an optimal design of the system that will perform its task at the lowest possible annual cost (capital and operating) while satisfying the specified input design conditions and operating conditions, as well as the imposed constraints.

In Part I of the article [1], a detailed description of the methodology is included, and Case Study 1 is presented as the base case study. The decision variables are: cooling water approach to the ambient wet bulb temperature (ΔT_{app}), cooling water range (ΔT_{cw}), steam condenser terminal temperature difference (ΔT_{TTD}), cooling water velocity in the steam condenser tubes (v_{SCt}), hydraulic water load on the cooling tower fill (q_{CTf}), height of the cooling tower fill (H_{CTf}), and height of the cooling tower air inlet opening (H_{CTi}). The annual cost (capital and operating) of the cooling water system (AC_{CWS}) is chosen as the objective function. The optimal values of the decision variables and parameters of the cold end system equipment (SC, CT and CWPs and CWPLs) are determined on the basis that the AC_{CWS} is minimal. The exhaustive search algorithm [2] [3] is used to find the optimal values.

In this part (Part II) of the article, Case Study 2 is presented to investigate the effect of reducing the global optimization of the system to partial optimization by different combinations of the decision variables.

2. Case Study 2

Case Study 2 is intended to demonstrate how different combinations of the decision variables affect the optimization results compared to the optimal base case OPT-0 when all decision variables are optimized.

Table 1. Optimization cases for Case Study 2.

Optimization Case No.	Design values of the decision variables						
	ΔT_{app} (K)	ΔT_{cw} (K)	q_{CTf} (m^3/m^{2}h)	H_{CTi} (m)	H_{CTf} (m)	ΔT_{TTD} (K)	v_{SCt} (m/s)
OPT-0	optimize	optimize	optimize	optimize	optimize	optimize	optimize
OPT-1	5.5	optimize	10.0	9.0	1.5	optimize	1.5
OPT-2	6.0	optimize	9.0	8.0	1.4	optimize	optimize
OPT-3	optimize	optimize	optimize	8.5	1.4	4.0	1.9
OPT-4	optimize	optimize	optimize	optimize	optimize	4.0	2.0
OPT-5	6.2	8.0	9.0	optimize	optimize	3.5	optimize
OPT-6	optimize	optimize	optimize	optimize	1.5	4.0	2.0
OPT-7	optimize	8.5	9.5	optimize	optimize	4.0	2.0
OPT-8	5.5	8.5	9.0	9.0	1.4	4.0	2.0
OPT-9	optimize	9.0	9.0	8.5	1.3	4.0	1.8

Ten characteristic optimization cases, with different subsets of fixed and free decision variables, as shown in **Table 1**, are compared at an assumed LCOE of 100 €/MWh. The various scenarios were selected on the following basis:

a) Optimization Case OPT-0: All the decision variables are free (subject to optimization).

b) Optimization Case OPT-8: All the decision variables are fixed.

c) Optimization Case OPT-9: All the decision variables are fixed except the cooling water approach to the ambient wet bulb temperature (ΔT_{app}), which is subject to optimization.

d) Optimization Case OPT-4: The decision variables related to the design of the cooling tower are free, and the decision variables related to the design of the steam condenser are fixed.

e) Optimization Case OPT-2: The decision variables related to the design of the cooling tower are fixed, and the decision variables related to the design of the steam condenser are free.

f) Optimization Cases OPT-1, OPT-3, OPT-5, OPT-6, and OPT-7: Combination of the scenarios d) and e).

Note: The cooling water range (ΔT_{cw}) is a common decision variable for the design of the cooling tower and steam condenser.

All design/operating conditions and constraints for Case Study 2 are the same as for Case Study 1, except for the following:

- Average annual ambient wet bulb temperature: Twb-amb = 7.4˚C (Tdb-amb = 10˚C @ RH = 70%). This average (day and night) annual ambient temperature is typical for most parts of Europe and North America.

3. Numerical Results

Based on the input parameters, the optimal results for the decision variables and equipment sizes of the cold end system components are presented in Annex, **Tables A1-A4**. The optimal results are shown as a function of the average annual ambient wet bulb temperature and the LCOE.

The decision variables that are not subject to optimization in the tables are marked in bold font.

4. Conclusions

Based on the optimization results given in the tables in Annex A, the following conclusions can be drawn:

a) The results show that full optimization (OPT-0) yields the lowest annual cost of the cooling water system and demonstrate the limitations of partial optimization approaches.

b) More optimal is the combination of decision variables that results in a combination of ΔP_{LPST} and P_{CWPs} for which AC_{CWS} is smaller. It is important to note that smaller cooling tower and steam condenser sizes do not necessarily result in more optimal solutions. The same applies to steam condensation pressure.

c) Based on the above stated, the shortcomings of partial optimization methods of cooling water systems that do not include LPST are obvious. The same applies to optimization methods that are based on minimizing capital investment cost in the cooling water system.

d) Significant savings (measured in millions of €) can be achieved, on each project, by properly optimizing the decision variables. The greater the installed power of the TPP, the greater the savings.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Popadić, A.V. (2025) A New Algorithm for Optimal Design of the Recirculating Cooling Water System of Thermal Power Plants Part I: Description of the Methodology & Case Study 1. *Energy and Power Engineering*, **17**, 217-240. https://doi.org/10.4236/epe.2025.178012

[2] Black, A.P. (2019) CS 350 Algorithms and Complexity, Lecture 6: Exhaustive Search Algorithms. Department of Computer Science, Portland State University. https://web.cecs.pdx.edu/~black/cs350/Lectures/lec06-Exhaustive%20Search.pdf

[3] Lincke, T.R. (2002) Exploring the Computational Limits of Large Exhaustive Search Problems. Ph.D. Thesis, Swiss Federal Institute of Technology. https://doi.org/https://doi.org/10.3929/ethz-a-004442444

Nomenclature

Symbol	Definition	Unit
A	Area	m^2
D, d	Diameter	m
D_{CTb}	Diameter of CT at base	m
D_{CTe}	Diameter of CT at exit	m
D_{CTft}	Diameter of CT at fill top	m
D_{CTt}	Diameter of CT at throat	m
H	Height or CWP head	m or mH_2O
H_{CT}	Height of CT, m	m
H_{CTf}	Height of CT fill	m
H_{CTi}	Height of CT air inlet	m
$H_{CTft\text{-}t}$	Height of CT from top of fill to throat	m
$H_{CTt\text{-}e}$	Height of CT from throat to exit	m
p	Pressure	N/m^2
P	Electric power	MW
q	Hydraulic water load on CT fill	m^3/m^2h
Q	Flow capacity of CWPs	m^3/s
T	Temperature	˚C, K
v	Velocity	m/s
	Abbreviations	
AC	Annual cost	
CC	Capital cost	
CT	Cooling tower	
CWP	Cooling water pump	
CWPL	Cooling water pipeline	
CWS	Cooling water system	
LCOE	Levelized cost of energy	
LPST	Low pressure steam turbine	
RH	Relative humidity	
SC	Steam condenser	
ST	Steam turbine	
TPP	Thermal power plant	
TTD	Terminal temperature difference	
	Subscripts	
a	Air	
amb	Ambient	
app	Approach	
cond	Condensation	
cw	Cooling water	
cwc	Cooling water cold	
db	Dry bulb	
wb	Wet bulb	
	Greek symbols	
Δ	Increment	-

Annex

Table A1. Optimal values of the decision variables at LCOE of 100 € per MWh.

OPT-No	ΔT_{app} (K)	ΔT_{cw} (K)	q_{CTf} (m^3/m^{2}h)	H_{Cti} (m)	H_{CTf} (m)	ΔT_{TTD} (K)	v_{SCt} (m/s)	AC_{CWS} (€)
Average annual ambient air temperature: $T_{db\text{-}amb}$ = 10˚C @ RH = 70%								
OPT-0	5.0	7.5	8.6	8.6	1.6	3.0	1.3	3,904,152.80
OPT-1	**5.5**	6.8	**10.0**	**9.0**	**1.5**	3.0	**1.5**	4,230,540.50
OPT-2	**6.0**	7.1	**9.0**	**8.0**	**1.4**	3.0	1.3	4,252,994.50
OPT-3	5.0	7.1	8.1	**8.5**	**1.4**	**4.0**	**1.9**	4,512,757.50
OPT-4	5.0	7.2	8.8	8.8	1.6	**4.0**	**2.0**	4,545,819.50
OPT-5	**6.2**	**8.0**	**9.0**	9.0	1.2	**3.5**	1.2	4,811,910.50
OPT-6	5.4	8.0	8.8	8.6	**1.5**	**4.0**	**2.0**	4,843,852.00
OPT-7	5.0	**8.5**	**9.5**	9.5	1.9	**4.0**	**2.0**	4,892,203.00
OPT-8	**5.5**	**8.5**	**9.0**	**9.0**	**1.4**	**4.0**	**2.0**	5,122,864.00
OPT-9	5.9	**9.0**	**9.0**	**8.5**	**1.3**	**4.0**	**1.8**	5,498,763.00

Table A2. Optimal values of the p_{cond} at LCOE of 100 € per MWh.

OPT-No.	T_{cwc} (˚C)	ΔT_{cw} (K)	ΔT_{TTD} (K)	T_{cond} (˚C)	p_{cond} (kPa)	ΔP_{LPST} (MW)	P_{CWPs} (MW)
Average annual ambient air temperature: $T_{db\text{-}amb}$ = 10˚C @ RH = 70%							
OPT-0	17.8	7.5	3.0	28.3	3.85	1.969	2.535
OPT-1	18.2	6.8	3.0	28.0	3.79	2.176	2.941
OPT-2	18.8	7.1	3.0	28.9	3.98	1.533	2.527
OPT-3	17.7	7.1	**4.0**	28.8	3.96	1.618	2.952
OPT-4	17.8	7.2	**4.0**	29.0	4.00	1.469	3.079
OPT-5	19.1	**8.0**	**3.5**	30.6	4.38	0.077	2.322
OPT-6	18.3	8.0	**4.0**	30.3	4.32	0.321	2.772
OPT-7	18.1	**8.5**	**4.0**	30.6	4.39	0.059	2.817
OPT-8	17.8	**8.5**	**4.0**	30.3	4.33	−0.285	2.683
OPT-9	18.9	**9.0**	**4.0**	31.9	4.74	−1.172	2.333

Table A3. Optimal dimensions of the CT at LCOE of 100 € per MWh.

OPT-No.	H_{CT} (m)	H_{CTi} (m)	H_{CTf} (m)	$H_{CTft\text{-}t}$ (m)	$H_{CTt\text{-}e}$ (m)	D_{CTb} (m)	D_{CTft} (m)	D_{CTt} (m)	D_{CTe} (m)
Average annual ambient air temperature: $T_{db\text{-}amb} = 10^{\circ}C$ @ RH = 70%									
OPT-0	107.0	8.6	1.6	72.2	24.6	89.1	82.4	50.5	55.2
OPT-1	116.1	**9.0**	**1.5**	78.9	26.8	87.1	80.2	49.2	53.7
OPT-2	106.8	**8.0**	**1.4**	72.7	24.7	89.0	828	50.7	55.4
OPT-3	113.1	**8.5**	**1.4**	77.0	26.1	93.8	87.3	53.5	58.4
OPT-4	108.4	8.8	1.6	73.1	24.9	90.0	83.1	51.0	55.7
OPT-5	101.8	9.0	1,2	68.4	23.2	84.7	78.0	47.8	52.2
OPT-6	102.7	8.6	**1.5**	69.1	23.5	85.5	78.9	48.3	52.8
OPT-7	98.3	9.5	1.9	64.7	22.2	81.2	73.6	45.1	49.4
OPT-8	105.1	**9.0**	**1.4**	70.7	24.0	82.4	75.7	46.4	50.6
OPT-9	108.7	**8.5**	**1.3**	73.9	25.1	79.9	73.5	45.1	49.2

Table A4. Optimal parameters for the SC and CWPs at LCOE of 100 € per MWh.

OPT-No.	A_{SC} (m^2)	N_{SCt}	L_{SCt} (m)	ΔH_{SC} (mH_2O)	z	ΔH_{CWPL} (mH_2O)	H_{CWP} (mH_2O)	Q_{CWP} (m^3/s)	P_{CWP} (MW)
Average annual ambient air temperature: $T_{db\text{-}amb} = 10^{\circ}C$ @ RH = 70%									
OPT-0	27,236	36,959	8.4	2.1	2	1.6	16.4	6.4	1.267
OPT-1	26,822	35,331	8.6	2.7	2	1.5	17.2	7.0	1.471
OPT-2	27,679	39,048	8.1	2.0	2	1.5	15.5	6.7	1.264
OPT-3	20,452	26,711	8.7	4.1	2	1.5	18.1	6.7	1476
OPT-4	19,958	25,024	9.1	4.6	2	1.6	19.1	6.6	1.540
OPT-5	24,639	37,545	7.5	1.6	2	1.7	16.0	6.0	1.161
OPT-6	19,022	22,524	9.6	4.8	2	1.7	19.1	6.0	1.386
OPT-7	18,624	21,198	10.0	5.0	2	1.7	20.6	5.6	1.408
OPT-8	18,687	21,197	10.0	5.0	2	1.7	19.6	5.6	1.342
OPT-9	18,702	22,248	9.6	4.0	2	1.8	18.1	5.3	1.166