



Cairo University

**ENERGY AND AVAILABILITY ANALYSIS OF THE  
STEAM POWER PLANTS  
CASE STUDY: ABU QIR POWER PLANT UNIT 5**

By

**Mohamed Sherif Ahmed Ahmed Rabie**

A Thesis Submitted to the  
Faculty of Engineering at Cairo University  
in Partial Fulfillment of the Requirements for the Degree of  
**MASTER OF SCIENCE**  
in  
**MECHANICAL POWER ENGINEERING**

FACULTY OF ENGINEERING, CAIRO UNIVERSITY  
GIZA, EGYPT  
2020

**ENERGY AND AVAILABILITY ANALYSIS OF THE  
STEAM POWER PLANTS  
CASE STUDY: ABU QIR POWER PLANT UNIT 5**

By

**Mohamed Sherif Ahmed Ahmed Rabie**

A Thesis Submitted to the  
Faculty of Engineering at Cairo University  
in Partial Fulfillment of the  
Requirements for the Degree of  
**MASTER OF SCIENCE**  
in  
**MECHANICAL POWER ENGINEERING**

Under the Supervision of

**Prof. Dr. Sayed Ahmed Kaseb**

Professor, Mechanical Power Engineering  
Department  
Faculty of Engineering, Cairo University

**Dr. Gamal Abd El Moniem El Hariry**

Associate Professor  
Mechanical Power Engineering Department  
Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY  
GIZA, EGYPT  
2020

**ENERGY AND AVAILABILITY ANALYSIS OF THE  
STEAM POWER PLANTS  
CASE STUDY: ABU QIR POWER PLANT UNIT 5**

By  
**Mohamed Sherif Ahmed Ahmed Rabie**

A Thesis Submitted to the  
Faculty of Engineering at Cairo University  
in Partial Fulfillment of the  
Requirements for the Degree of  
**MASTER OF SCIENCE**  
in  
**MECHANICAL POWER ENGINEERING**

Approved by the Examining Committee,

**Prof. Dr. Sayed Ahmed Kaseb**, Thesis Main Advisor

**Assoc. Prof. Dr. Gamal Abd El Moniem El Hariry**, Member

**Prof. Dr. Mahmoud Abdel Wahab Kassem** , Internal Examiner

**Prof. Dr. Nabil Ahmed Shawky Elminshawy**, External Examiner

FACULTY OF ENGINEERING, CAIRO UNIVERSITY  
GIZA, EGYPT  
2020

**Engineer's Name:** Mohamed Sherif Ahmed Ahmed Rabie  
**Date of Birth:** 15/09/1987  
**Nationality:** Egyptian  
**E-mail:** msaa.rabie@gmail.com  
**Phone:** +201007393277  
**Address:** 36 Ibrahim El Attar, Zizinia, Alexandria  
**Registration Date:** 01/03/2016  
**Awarding Date:** ....../....../2020  
**Degree:** Master of Science  
**Department:** Mechanical Power Engineering



**Supervisors:** Prof. Dr. Sayed Ahmed Kaseb  
Assoc. Prof. Dr. Gamal Abd El Moniem El Hariry

**Examiners:** Prof. Dr. Sayed Ahmed Kaseb (Thesis main advisor)  
Assoc. Prof. Dr. Gamal Abd El Moniem El Hariry (Member)  
Prof. Dr. Mahmoud A. Kassem (Internal examiner)  
Prof. Dr. Nabil A. S. Elminshawy (External examiner)

**Title of Thesis:** Energy and Availability Analysis Of The Steam Power Plants, Case Study: Abu Qir Power Plant Unit 5

**Key Words:** Energy; Exergy; Exergy Destruction; Irreversibility; Thermodynamic Analysis; Efficiency; Availability.

### **Summary:**

In this study, An energy and exergy analysis were made on the Abu Qir power plant unit 5 in Alexandria, Egypt to measure the performance of the unit and to identify the plant components that have the largest amounts of losses.

The analysis was made on the loads 277 MW, 260 MW, 233 MW and it is compared with the design load . The largest amount of exergy destruction was found at the load of 277 MW where the highest exergy destruction was found in the boiler which destroyed 405.6 MW. It is followed by the turbine where 66.3 MW was lost to the environment. The condenser was the third highest source of irreversibility with a value of 13 MW. The 1<sup>st</sup> and 2<sup>nd</sup> law net efficiencies in this case were 37.54% & and 35.41% respectively.

In addition, The exergy efficiency of the turbine and boiler decreased when the environment temperature raised (as in the summer) while the condenser efficiency increased. Each decrease in the intermediate turbine steam inlet temperature by 10 degrees will cause the unit load to decrease by 5 MW and the thermal efficiency by 0.73%. Also, each raise in the condenser pressure by 0.01 bar, the unit load decrease by 0.7 MW and the thermal efficiency drop by 0.8%.

## **Disclaimer**

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name:

Date:

Signature:

# **Dedication**

I dedicate this thesis to the soul of my beloved mother (may god bless her) who was the source of my persistence.

## **Acknowledgments**

In the beginning, I am grateful to God for the good health and well-being that are necessary to complete this thesis. I am also using this opportunity to express my gratitude to everyone who supported me throughout the study. I am thankful for their aspiring guidance, invaluable constructive criticism and friendly advice during the work. I am sincerely grateful to them for sharing their truthful and illuminating views on a number of issues related to this thesis.

I express my special thanks to Prof. Dr. Sayed Ahmed Kaseb and Dr. Gamal Abd El Moniem El Hariry for their support, guidance and encouragement.

From the Egyptian electricity holding company, I would like to thank the chairman of the board of directors Eng. Mohamed EL Abd, the manager of Abu Qir production sector Eng. Mohamed El Touny, the operation manager Eng. Zakaria Soffar, the operation director Eng. Mohamed khamis, my friend and colleague Eng. Ahmed Abd El Aziz, for their support and help in the extraction of the readings of unit 5.

I would also like to thank all my professors for their help throughout the years of my academic studies. I extend my gratitude to my dear colleagues and friends Tarek Said and Emad Abdel Samad for their valuable suggestions and noteworthy discussions.

Finally, special thanks to my family, my wife and my son for their patience, care and support to be able to continue this research to the end.

# Table of Contents

<b>ACKNOWLEDGMENTS .....</b>	<b>i</b>
<b>TABLE OF CONTENTS .....</b>	<b>ii</b>
<b>LIST OF TABLES.....</b>	<b>iv</b>
<b>LIST OF FIGURES.....</b>	<b>v</b>
<b>NOMENCLATURE.....</b>	<b>vii</b>
<b>ABSTRACT.....</b>	<b>viii</b>
<b>CHAPTER 1: INTRODUCTION .....</b>	<b>1</b>
1.1 Egypt energy crisis .....	1
1.2 Electricity projects and plans .....	1
1.2.1 Power plants projects .....	1
1.2.2 Pump & storage power projects .....	3
1.3 Egypt resources .....	4
1.4 Egyptian electricity holding company (EEHC) .....	4
1.5 Importance of efficiency studies .....	6
<b>CHAPTER 2: LITERATURE REVIEW.....</b>	<b>7</b>
2.1 Introduction .....	7
2.2 Detailed literature review .....	7
2.3 Research scope .....	9
<b>CHAPTER 3: THERMODYNAMIC ANALYSIS OF THE CYCLE.....</b>	<b>10</b>
3.1 Ideal rankine cycle .....	10
3.2 Actual rankine cycle .....	11
3.3 General principles for the analysis.....	12
<b>CHAPTER 4: ABU QIR POWER PLANT DESCRIPTION .....</b>	<b>14</b>
4.1 Site details.....	14
4.2 Abu Qir power plant .....	17
4.3 Unit 5 description .....	18
4.3.1 Boiler section .....	18
4.3.2 Turbine section .....	19
4.3.3 Feedwater heaters section .....	19
4.3.4 Condenser section .....	19
4.3.5 Condensate pumps .....	20
4.3.6 Feedwater pump turbine .....	20
4.4 Plant overview.....	20
4.5 Observations from the plant .....	22



<b>CHAPTER 5: THERMODYNAMIC SIMULATION OF ABU QIR PLANT COMPONENTS.....</b>	<b>27</b>
5.1 Boiler calculations.....	27
5.2 Turbine calculations.....	28
5.3 Pumps calculations.....	28
5.4 Condenser calculations.....	29
5.5 Feedwater heaters calculations.....	29
5.6 Cycle exergy destruction calculations.....	30
5.7 Cycle overall performance calculations.....	30
<b>CHAPTER 6: RESULTS AND DISSCUSSIONS .....</b>	<b>31</b>
6.1 The design load 303 MW .....	31
6.1.1 The energy analysis of the cycle gave the following results.....	34
6.1.2 The exergy analysis of the cycle gave the following results.....	36
6.2 For the load of 277 MW .....	42
6.2.1 The energy analysis of the cycle gave the following results.....	45
6.2.2 The exergy analysis of the cycle gave the following results.....	47
6.3 For the load of 260 MW.....	53
6.3.1 The energy analysis of the cycle gave the following results.....	56
6.3.2 The exergy analysis of the cycle gave the following results.....	58
6.4 For a load of 233 MW.....	64
6.4.1 The energy analysis of the cycle gave the following results.....	67
6.4.2 The exergy analysis of the cycle gave the following results.....	69
6.5 Comparison stats between the three loads.....	75
6.6 Comparison with previous work.....	80
6.7 Data Analysis.....	81
<b>CHAPTER 7: CONCLUSIONS.....</b>	<b>85</b>
7.1 Summary.....	85
7.2 Conclusions.....	87
7.2.1 At the design load of 303 MW.....	87
7.2.2 At unit load of 277 MW.....	87
7.2.3 At unit load of 260 MW.....	88
7.2.4 At unit load of 233 MW.....	89
7.2.5 Comparisons Conclusions.....	90
7.3 Recommendations for future work .....	91
<b>REFERENCES.....</b>	<b>92</b>
<b>APPENDIX A .....</b>	<b>94</b>
A.1 Introduction .....	94
A.2 ESS codes .....	94
<b>APPENDIX B .....</b>	<b>106</b>

## List of Tables

Table 4.1 : Working values of the unit at the maximum load .....	18
Table 4.2 : Observations at 303 MW .....	22
Table 4.3 : Observations at 277 MW .....	23
Table 4.4 : Observations at 260 MW .....	24
Table 4.5 : Observations at 233 MW .....	25
Table 4.6: Steam flow and Natural gas consumption .....	26
Table 4.7: Natural gas heating values .....	26
Table 6.1 : Properties at 303 MW .....	31
Table 6.2 : Plant component energy analysis result at 303 MW .....	34
Table 6.3 : Plant component exergy analysis result at 303 MW .....	36
Table 6.4 : Properties at 277 MW .....	42
Table 6.5 : Plant component energy analysis result at 277 MW .....	45
Table 6.6 : Plant component exergy analysis result at 277 MW .....	47
Table 6.7 : Properties at 260 MW .....	53
Table 6.8 : Plant component energy analysis result at 260 MW .....	56
Table 6.9 : Plant component exergy analysis result at 260 MW .....	58
Table 6.10 : Properties at 233 MW .....	64
Table 6.11 : Plant component energy analysis result at 233 MW .....	67
Table 6.12 : Plant component exergy analysis result at 233 MW .....	69
Table 6.13 : Previous work comparison .....	80
Table 6.14 : The effect of changes in environment temperature .....	81
Table 6.15 : Effect of R/H temperature change on turbine work and plant thermal efficiency.....	82
Table 6.16 : Effect of condenser pressure change on turbine work and plant thermal efficiency .....	83
Table 7.1 : 2 <sup>nd</sup> law efficiency of the plant components in the different loads .....	86
Table 7.2 : Exergy destruction quantities of the plant components in the different loads .....	87

## List of Figures

Figure 1.1 : Hamrawein power plant 3D plan .....	3
Figure 1.2 : Ataqa hydro power station 3D plan .....	4
Figure 1.3 : Egyptian unified grid in 2005 .....	5
Figure 3.1 : Rankine cycle processes.....	10
Figure 3.2 : The difference between the ideal and the actual rankine cycle.....	11
Figure 4.1: Temperature at Abu Qir in 2019 .....	14
Figure 4.2 : Wind Speed at Abu Qir in 2019 .....	15
Figure 4.3 : Atmospheric pressure at Abu Qir in 2019 .....	16
Figure 4.4 : Satellite image of the Abu Qir power station .....	17
Figure 4.5: The Unit 5 overview.....	21
Figure 6.1 : Mass flow rate balance through the different points at 303 MW.....	33
Figure 6.2 : Plant energy efficiency Shares at 303 MW .....	35
Figure 6.3 : Exergy flow diagram of the plant at 303 MW with the percent of exergy destruction share of each component .....	37
Figure 6.4 : Exergy destruction through the 3 different turbines at 303 MW .....	38
Figure 6.5: Turbine 2 <sup>nd</sup> law efficiency at 303 MW .....	39
Figure 6.6 : Exergy destruction through the different plant pumps at 303 MW .....	39
Figure 6.7 : Plant pumps 2 <sup>nd</sup> law efficiency at 303 MW .....	40
Figure 6.8 : Exergy destruction through feedwater heaters at 303 MW .....	41
Figure 6.9 : Feedwater heaters 2 <sup>nd</sup> law efficiency at 303 MW .....	41
Figure 6.10 : Mass flow rate balance through the different points at 277 MW.....	44
Figure 6.11 : Plant energy efficiency Shares at 277 MW .....	46
Figure 6.12 : Exergy flow diagram of the plant at 277 MW with the percent of exergy destruction share of each component.....	48
Figure 6.13 : Exergy destruction through the 3 different turbines at 277 MW .....	49
Figure 6.14: Turbine 2 <sup>nd</sup> law efficiency at 277 MW .....	50
Figure 6.15 : Exergy destruction through the different plant pumps at 277 MW ....	50
Figure 6.16 : Plant pumps 2 <sup>nd</sup> law efficiency at 277 MW .....	51
Figure 6.17 : Exergy destruction through feedwater heaters at 277 MW .....	52
Figure 6.18 : Feedwater heaters 2 <sup>nd</sup> law efficiency at 277 MW .....	52
Figure 6.19 : Mass flow rate balance through the different points at 260 MW.....	55
Figure 6.20 : Plant energy efficiency distribution at 260 MW .....	57
Figure 6.21 : Exergy flow diagram of the plant at 260 MW with the percent of exergy destruction share of each component.....	59
Figure 6.22 : Exergy destruction through the 3 different turbines at 260 MW .....	60
Figure 6.23: Turbine 2 <sup>nd</sup> law efficiency at 260 MW .....	61
Figure 6.24 : Exergy destruction through the different plant pumps at 260 MW ....	61
Figure 6.25 : Plant pumps 2 <sup>nd</sup> law efficiency at 260 MW .....	62
Figure 6.26 : Exergy destruction through feedwater heaters at 260 MW .....	63
Figure 6.27 : Feedwater heaters 2 <sup>nd</sup> law efficiency at 260 MW .....	63
Figure 6.28 : Mass flow rate balance through the different points at 233 MW .....	66
Figure 6.29 : Plant energy efficiency distribution at 233 MW .....	68
Figure 6.30 : Exergy flow diagram of the plant at 233 MW with the percent of exergy destruction share of each component.....	70
Figure 6.31 : Exergy destruction through the 3 different turbines at 233 MW .....	71

Figure 6.32 : Turbine 2 <sup>nd</sup> law efficiency at 233 MW .....	72
Figure 6.33 : Exergy destruction through the different plant pumps at 233 MW ....	72
Figure 6.34 : Plant pumps 2 <sup>nd</sup> law efficiency at 233 MW .....	73
Figure 6.35 : Exergy destruction through feedwater heaters at 233 MW .....	74
Figure 6.36 : Feedwater heaters 2 <sup>nd</sup> law efficiency at 233 MW .....	74
Figure 6.37 : Plant 1 <sup>st</sup> & 2 <sup>nd</sup> law efficiency.....	76
Figure 6.38 : Main plant components $\eta$ II.....	76
Figure 6.39 : The 3 main turbines $\eta$ II.....	77
Figure 6.40 : Feedwater heaters $\eta$ II.....	77
Figure 6.41 : Plant pumps $\eta$ II.....	78
Figure 6.42 : Other small destruction sources .....	78
Figure 6.43 : Plant amounts of exergy destruction.....	79
Figure 6.44 : Comparison with similar work.....	80
Figure 6.45 : The effect of changes in environment temperature.....	81
Figure 6.46 : Effect of R/H temperature change on turbine work.....	82
Figure 6.47 : Effect of R/H temperature change on Plant thermal efficiency.....	83
Figure 6.48 : Effect of condenser pressure change on turbine work.....	84
Figure 6.49 : Effect of condenser pressure change on plant thermal efficiency .....	84

## Nomenclatures

$C_p$	Cooling water specific heat (kJ/kg. $^{\circ}$ C)
$h$	Specific enthalpy (kJ/kg)
$I$	Destructed exergy (MW)
$\dot{m}$	Mass flow rate (kg/s)
$P$	Pressure (bar)
$Q$	Heat (MW)
$s$	Specific entropy (kJ/kg.K)
$T$	Temperature ( $^{\circ}$ C)
$W$	Work (MW)
$X$	Total exergy (MW)

## GREEK SYMBOLS

$\Psi$	Specific exergy (kJ/kg)
$\xi$	Ratio of chemical exergy to the LHV
$\eta_I$	Energy efficiency (%)
$\eta_{II}$	Exergy Efficiency (%)

## SUBSCRIPTS

b	boiler
c	condenser
e	exit
f	fuel
h	heater
i	inlet
j	pre-specified point
o	dead state
p	pump
t	turbine

## ABBREVIATIONS

DRT	Drain Recovery Tank
FLT	First law of thermodynamics
FWT	Feedwater Tank
HPT	High Pressure turbine
IPT	High Pressure turbine
LHV	Lower Heating Value
LPT	High Pressure turbine
SLT	Second law of thermodynamics

## **Abstract**

In this study, An energy and exergy analysis were made on the Abu-Qir power plant unit 5 in Alexandria, Egypt to measure the performance of the unit and to identify the plant components that have the largest amounts of losses.

The analysis was made on the loads 277 MW, 260 MW, 233 MW and it is compared with the design load. The largest amount of exergy destruction was found at the load of 277 MW where the highest exergy destruction was found in the boiler which destroyed 405.6 MW. It is followed by the turbine where 66.3 MW was lost to the environment. The condenser was the third highest source of irreversibility with a value of 13 MW. The 1<sup>st</sup> and 2<sup>nd</sup> law net efficiencies in this case were 37.54% & and 35.41% respectively.

In addition, The exergy efficiency of the turbine and boiler decreased when the environment temperature raised (as in the summer) while the condenser efficiency increased. As recommendations, each decrease in the intermediate turbine steam inlet temperature by 10 degrees will cause the unit load to decrease by 5 MW and the thermal efficiency by 0.73%. Also, each raise in the condenser pressure by 0.01 bar, the unit load decrease by 0.7 MW and the thermal efficiency drop by 0.8%.

# **Chapter 1 : Introduction**

## **1.1 Egypt energy crisis**

Egypt energy production sector is confronting in the present a lot of conflicting and hard challenges. This is seen in Egypt's huge efforts to make a balance between production, domestic consumption, and export revenue, while seeking to maintain internal political stability.

Despite that Egypt is the largest non-OPEC oil producer in Africa, the second largest gas producer in the continent and while the country is doing an essential role in regional and global energy markets, the country's energy production status through the last years reflects the opposite on all levels.[1]

This problem is a the result of historical 'mal-planning' as it is the consequence of the country's past years of political disturbance after the 2011 revolution. However, starting from late 2014 investment and economic growth began picking up on the back of political stability. Fixed investment was set to be the primary driver of growth as a result of greater clarity and transparency in Egypt's economic policy. Furthermore, the current government firmly displayed some extreme measures to quickly fix the energy producing sector. This is most likely disclosed under the pillars of the new energy strategy, including:

1. Security, by boosting, diversifying and improving energy efficiency.
2. Sustainability, by addressing debt build-up and phasing out of subsidies in a socially responsible manner.
3. Governance, by improving and modernizing the oil and gas sector's governance and encouraging private sector investment.

## **1.2 Electricity projects and plans**

### **1.2.1 Power plants projects [3]**

#### **1. Five year plan (2012 - 2017)**

- The amended seventh five-year plan (2012 -2017) included the addition of 27400 MW from thermal power plants to the unified grid, including the fast-track plan & Siemens projects at an estimated investment cost of USD 17 billion.
- These projects are implemented by the Electricity Sector and funded with soft loans from Arab and international financing institutions.
- Part of the Plan projects with a total capacity of 23311 MW were put to operation by the end of financial year of 2017/ 2018.
- It is scheduled to put in operation another 2790 MW during financial year 2018/2019.
- Another 1300 MW is targeted to be in operation and the whole plan projects to be completed in 2019/2020.