



Ain shams university  
Faculty of engineering

# Study the Effect of Changing the Load on the Performance of Combined Cycle

BY

**Hany Shaker Ezzat Mohammed**

Thesis submitted to the Faculty of Engineering  
Ain Shams University

In Partial Fulfillment for the degree of  
Master of Science  
In  
Mechanical power Engineering

Supervised by

**Prof. Dr. Samir M. Abdel Ghany**

**Prof. Dr. Abd El-Aziz Morgan**

**Dr. Ashraf Kotb**

Department Of Mechanical Power Engineering  
Faculty of Engineering Ain Shams University

Cairo 2016



Ain shams university  
Faculty of engineering

## **MASTER THESIS**

**Student's Name:** Hany Shaker Ezzat Mohammed

**Thesis Title:** Study the Effect of Changing the Load on the  
Performance of Combined Cycle

**Degree:** Master Degree

### **EXAMINERS COMMITTEE**

**1. Prof. Dr. Fouad Mohammed Mansour** ( )

Egyptian Electricity Holding Company  
Ministry of Electricity

**2. Prof. Dr. Kaddah Shaker Kaddah** ( )

Department of Mechanical Power Engineering  
Faculty of Engineering Ain Shams University

**3. Prof. Dr. Samir Mohammed Abdel Ghany** ( )

Department of Mechanical Power Engineering  
Faculty of Engineering Ain Shams University

**4. Prof. Dr. Abdul Aziz Morgan Abdul Aziz** ( )

Department of Mechanical Power Engineering  
Faculty of Engineering Ain Shams University

Cairo 2016

## **Statement**

This thesis is submitted to Ain Shams University in partial fulfillment for the requirements of the degree of M.SC. in Mechanical Power Engineering. The included work in this thesis has been carried out by the author at the Dept. of Mechanical Power Engineering, Ain Shams University. No part of this thesis has been submitted for a degree or a qualification at any other University or Institute.

Name: Hany Shaker Ezzat Mohammed

Signature:

Date:

## **ACKNOWLEDGEMENTS**

I thank the almighty ALLAH for his mercy and grace, which enabled me to complete this work.

I would like to express my deep appreciation to Prof. Dr. Samir Abdel Ghany for his editing corrections for the whole thesis. I thank him for his effort, concern, advices and the time he spent in helping me.

Thanks deeply to Prof. Dr. Abd El-Aziz Morgan, for treating me like his son, for his time, for the effort he had exerted for me to make this research reality, great help and efforts during developing this thesis.

My sincerest gratitude is extended to. Dr. Ashraf kotb for the help he gave, advice, patience and understanding he has shown throughout this work.

I wish to express my thanks to all friends for helping and providing me a lot of great references and especially Waleed & Mai.

Last but not least, I am grateful to my family, father, mother my brothers and especially for my wife Gehad, Omar, Reem, Seif El Din, for their help, trust and supporting me all the time.

Hany Shaker Ezzat Mohammed

2016

# **ABSTRACT**

## **Abstract**

The electricity sector in Egypt works towards the expansion in the production of electrical power to meet the electricity demand of the other national various sectors. The type of power plant to be established will be selected, either renewable energy (Wind – Solar) power plant, or thermal power plants [steam cycle power plant – simple cycle (gas turbine GT) power plant or combined cycle power plant].

Combined cycle power plant is the best in terms of technical and economical advantages such as, highest efficiency among all kinds of thermal power plants across load ranges (56%), fastest based on GT, short order to operation time, and less generation cost.

Therefore, the real understanding and knowledge of its transient behavior are thought as they may help in improving the possibility of operating it as a variable load unit as well.

The transient behavior of the steam part of the combined cycle power plants is studied under gradual and sudden changes of load. The actual transient readings of Sidi Krir combined cycle power plant are compared with the results of the mathematical model for gradual change of load. Good agreement between the field results and the mathematical model was achieved. Due to good agreement between the actual and the model results in case of gradual load

change, the study is extended to include the case of sudden change of load to show the advantages and disadvantages of each control approach. The results of the case of sudden change of load obtained from the theoretical model showed that the response is much faster than the gradual response. Fast response time does not lead to the occurrence of water hammer, however this fast change may cause thermal stresses on the metal which could lead to thermal cracks.

# **LIST OF CONTENTS**



## LIST OF CONTENTS

ACKNOWLEDGMENT	ii
ABSTRACT	iii
LIST OF CONTENTS	v
LIST OF FIGURES	ix
LIST OF SYMBOLS AND ABBREVIATIONS	xi

### CHAPTER ONE INTRODUCTION

1.1 BACKGROUND OF COMBINED CYCLE	1
1.2 OUTLINE OF THE THESIS	2
1.3 AIM OF PRESENT WORK	3

### CHAPTER TWO LITERATURE SURVEY

2.1 INTRODUCTION	4
2.2 REVIEW OF PREVIOUS WORK	4

### CHAPTER THREE COMBINED CYCLE AND TECHNICAL SPECIFICATIONS OF SIDI KRIR POWER PLANT

3.1 INTRODUCTION	10
3.2 COMBINED CYCLE MAJOR COMPONENTS	12
3.2.1 Gas turbine simple cycle	12
3.2.1.1 Air compressor	13
3.2.1.2 Combustion chamber	14

3.2.1.3	Gas turbine	14
3.2.2	Gas dampers	15
3.2.3	Steam generating unit	16
3.2.4	Steam turbine	16
3.2.5	Control system	17
3.3	COMBINED-CYCLE THERMODYNAMICS	18
3.4	TECHNICAL SPECIFICATION OF SIDI KRIR POWER PLANT	21
3.4.1	Major station parameters	21

## **CHAPTER FOUR      MATHEMATICAL MODELLING**

4.1	INTRODUCTION	23
4.2	HEAT EXCHANGERS	28
4.3	HEAT TRANSFER FROM FINS	34
4.4	STEAM & WATER DRUM AND DOWNCOMER-RISER (EVAPORATOR)	36
4.4.1	Downcomer	37
4.4.2	Riser	38
4.4.3	Steam and water drum	40
4.5	STEAM TURBINE	45
4.5.1	thermodynamics of steam turbine	45
4.5.2	Shaft speed dynamics	47
4.6	CONTROL LOOPS	49
4.6.1	PID controller	49
4.6.2	Single element control system	50
4.6.2.1	Gas damper position control loop	50
4.6.2.2	Turbine steam valve position control loop	51

4.6.2.3	Feed water valve position control loop	51
4.6.3	Two element control system	53
4.6.3.1	Gas damper position control loop	55
4.6.3.2	Turbine steam valve position control loop	55
4.6.3.3	Feed water valve position control loop	56
4.6.4	Three element control loop	56
4.6.4.1	Gas Damper Position Control Loop	57
4.6.4.2	Turbine Steam Valve Position Control Loop	57
4.6.4.3	Feed water Valve Position Control Loop	58
4.7	GAS TURBINE SIMBLE CYCLE	61
4.7.1	Air Compressor	62
4.7.2	Combustion Chamber	63
4.7.3	Gas Turbine	63

## **CHAPTER FIVE    COMPUTER SIMULATION PROGRAM**

5.1	Introduction	65
5.2	Description of Main Program and Subroutines	65
5.2.1	Main program	65
5.2.2	Initialization subroutine (INIT)	66
5.2.3	Steam table subroutine (STABLE)	66
5.2.4	Friction subroutine (FRIC)	69
5.2.5	Gas turbine subroutine (GTUBN)	69
5.2.6	Control subroutine (CONTRL)	69
5.2.7	PID controller subroutine (PID)	71
5.2.8	Steam turbine subroutine (STTURB)	71
5.2.9	Updating variables subroutine (CHANG)	71

5.2.10	Downcomer-riser subroutine (DCRS)	73
5.2.11	Drum subroutine (DRUM)	74
5.2.12	Parallel cross flow heat exchanger subroutine (HECROS)	74
5.2.13	Properties subroutine (PROP)	74

## **CHAPTER SIX                      RESULTS, DISCUSSIONS**

### **CONCLUSIONS & FUTURE WORK**

6.1	INTRODUCTION	75
6.2	LOAD DECREASE GRADUALLY	75
6.3	SUDDEN DECREASE OF LOAD	80
6.4	CONCLUSION	87
	<b>REFERENCES</b>	89
	<b>APPENDICES</b>	94

## LIST OF FIGURES

### CHAPTER THREE COMBINED CYCLE AND TECHNICAL SPECIFICATIONS OF SIDI KRIR POWER PLANT

Figure 3.1	Schematic diagram of combined cycle	11
Figure 3.2	Gas turbine simple cycle	12
Figure 3.3	Joule–Brayton reversible cycle	19
Figure 3.4	Steam turbine efficiency $\eta_{st}$ vs. gas turbine efficiency $\eta_{gt}$ for combined-cycle efficiencies $\eta_{cc}$ 0.4–0.7	21

### CHAPTER FOUR MATHEMATICAL MODELLING

Figure 4.1	schematic diagram for the combined cycle modules	24
Figure 4.2	Schematic diagram showing the meshes for parallel cross flow heat exchangers (economizer and superheater)	29
Figure 4.3	3 Schematic diagram showing the mesh for cross flow heatexchanger (evaporator)	29
Figure 4.4	A finite element with the volume (dx,dy,dz) in a convective cross flow heat exchanger	30
Figure 4.5	Efficiencies of circumferential fins of rectangular profile.	34
Figure 4.6	Schematic of the drum, downcomer-riser loop	36
Figure 4.7	Longitudinal and circular cross section of the cylindrical drum	43
Figure 4.8	(T-S) diagram of the ideal Rankine cycle.	46
Figure 4.9	A schematic for the steam cycle of a simple combined	47

	cycle	
Figure 4.10	The single element control loop	52
Figure 4.11	The two element control loop.	54
Figure 4.12	The three element control loop	60
Figure 4.13	A schematic for the gas turbine simple open cycle	61
Figure 4.14	(T-S) diagram of the gas turbine simple cycle	62

## **CHAPTER FIVE      COMPUTER SIMULATION PROGRAM**

Figure 5.1	Main program flow chart	68
Figure 5.2	Control subroutine flow chart	70
Figure 5.3	downcomer-riser subroutine flow chart	72
Figure 5.4	Drum subroutine flow chart	73

## **CHAPTER SIX      RESULTS, DISCUSSIONS CONCLUSIONS &FUTURE WORK**

Figure 6.1	Comparison of the actual results of Sidi Krir power plant combined cycle during gradual change of load with the corresponding model results.	77
Figure 6.2	The computer model results in case of sudden load decrease.	87

# **LIST OF SYMBOLS AND ABBREVIATIONS**