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تحليل محطات الدورة المركبة باستخدام كود حاسب آلى

تعتبر محطات الدورة المركبة أحد الأنظمة الواعدة في مجال استغلال الطاقة و استخدامتها واقتصادياتها. حيث يصل إجمالي الطاقة المولدة من محطات الدورة المركبة بنهاية عام ٢٠٠٠ إلي حوالي ٤٥٠٠٠ ميجاوات. كما تتميز محطات الدورة المركبة بأنها عالية الكفاءة عند جميع الأحمال وقليلة التكلفة في الإنشاء وسهل الحصول علي مستلزماتها، كما انه من السهل تحويل المحطات الغازية إلى محطات دورة مركبة مما يتيح استغلال الطاقة المفقودة فى غازات العادم للوحدات الغازية.

في هذا البحث تم عمل برنامج حاسب آلي يمكن من التحليل الثرموديناميكى لمحطات الدورة المركبة المستخدمة في العالم والتي تشتمل علي اى عدد من المكونات التالية (ضاغط، غرف احتراق، توربين غازي، مولد بخار وتوربين بخاري بأنواعهما المختلفة، مكثف، مضخة). يقوم هذا البرنامج بإجراء تحليل ثرموديناميكى كامل للدورة المركبة عند الحمل الكامل والأحمال الجزئية المختلفة باستخدام القانون الأول و الثاني للديناميكا الحرارية. فمن البيانات المتاحة في المحطات يمكن تغذية البرنامج والحصول علي (الكفاءة الحرارية، كفاءة القانون الثاني، والطاقة المفقودة القابلة للتحويل) وذلك للمحطة الكاملة لجميع أجزاء المحطة. كما يمكن استخدام البرنامج في التصميم الثرموديناميكي للمحطات المركبة باستخدام معاملات التصميم المختلفة. كما يعطي البرنامج إمكانية استنتاج عوامل التشغيل المثالية لكل جزء من أجزاء المحطة لإعطاء أقصي قيمة للكفاءة و القدرة الناتجة، كما يعطي البرنامج امكانية إضافة أي نوع جديد من المحطات.

والبرنامج مكتوب بلغة FORTRAN و يتكون من برنامج رئيسي وعدد ٢٨ برنامج فرعي علي ٣ مستويات، وفي حوار مع البرنامج يقوم المستخدم بتحديد مكونات المحطة المراد تحليلها أو تصميمها أو استنتاج عوامل التشغيل المثالية لها، ثم يقوم المستخدم باعطاء بيانات التشغيل المتاحة ونوع ونسب مكونات الوقود المراد استخدامه.كما يعطي البرنامج النتائج في صورة جداول.

لإثبات صحة نتائج البرنامج، تم إجراء تحليل ثرموديناميكى لمحطة دمياط المركبة ذات قدرة ١٢٠٠ ميجاوات ومقارنة النتائج الخاصة بالبرنامج بالنتائج المنشورة عن هذه المحطة. أثبت التقارب فى النتائج المقارنة الدقة العالية لهذا البرنامج.

كما تم إجراء تجربة عملية لمحطة طلخا ذات الدورة المركبة ذات قدرة ٣٠٠ ميجاوات للحصول علي بيانات التشغيل عند الحمل الكامل والاحمال الجزئية المختلفة، وبادخال هذه البيانات إلى برنامج الحاسب الآلي تم الحصول علي تحليل ثرموديناميكي كامل لكل من المحطة وأجزائها المختلفة.

أشارت نتائج الدورة الغازية إلى أن الضاغط يستهلك ٥٠%، ٦٦% من قدرة التوربين الغازي عند الحمل الكامل وعند ٥٠ % من الحمل الكامل علي التوالي. كما تحدث أقصي قيمة للطاقة المفقودة القابلة للتحويل في غرف الاحتراق و تصل إلي حوالي ٣٨.٥%. بينما تحدث أقل قيمة للطاقة المفقودة القابلة للتحويل في الضاغط و التوربين الغازى وتكون تقريبا ٤% و٤,٢% على التوالى، كما يتوجه الباقي من الطاقة القابلة للتحويل مع غازات العادم الي مولد البخار. تصل كفاءة القانون الثاني للتوربين الغازى إلي حوالي ٩٥% وهي تعتبر أقصي قيمة لكفاءة القانون الثاني للأجزاء المكونة للدورة وتعتبر كفاءة القانون الثاني لغرف الاحتراق أقل كفاءة حيث تزداد من ٥٤,٦٧ % الى٦١,٧٩% عند تغير الحمل من ٥٠% إلي ١٠٠%. بينما تظل كفاءة القانون الثاني للضاغط تقريبا ثابتة بحوالي ٨٩%.

أفادت نتائج الدورة البخارية بأن أقصي قيمة للطاقة القابلة للتحويل المفقودة تحدث في مولد البخار بينما تحدث أقل قيمة للطاقة القابلة للتحويل المفقودة في المكثف. وتزداد قيمة الطاقة القابلة للتحويل المفقودة للتوربين البخاري من ٥,٤٣ إلي ٩,١٨ ميجاوات مع تغير الحمل من ٢٥ إلي ١٠٠%. كما تحدث أقصي قيمة لكفاءة القانون الثاني فى مولد البخار وتصل إلي ٨٩% و أقل قيمة لكفاءة القانون الثاني في المكثف و تزداد من ٤٧,٢ إلي ٥٧,٨% بزيادة الحمل من ٢٥ إلي ١٠٠%. كما أفادت النتائج أن الكفاءة الكلية للقانون الثاني تزداد بنسبة ١٤% والكفاءة الحرارية تزداد بنسبة ١٣% وذلك بعد تحويل المحطة الغازية الى الدورة المركبة.

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ANALYSIS OF COMBINED CYCLE POWER PLANTS USING A COMPUTER CODE

Thesis
Submitted in Partial Fulfilment of Requirements for
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BY

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ABSTRACT

In the present work, a computer program code is constructed for the thermodynamic analysis of the most used combined cycle power plants in the world and can be extended for any new type of combined power plant. It can be used also to optimize the operating conditions of any component of the combined cycle power plant. In addition the program can be used in the thermodynamic design of any new combined cycle power plant. The program gives a complete analysis for the combined power plant at the base load and part loads. From the common available running measured data of the combined plant and for any kind of fuel, a complete thermodynamic analysis for the first and second law efficiency, exergy expanded and losses, air to fuel ratio, excess air for the whole plant, can be obtained. As well as the first and second law efficiency, exergy losses for each component of the gas and steam cycle systems. To show the validity of the computer program code a comparison for the results of the computer program for the Dammietta combined cycle power plant is carried out with the results of Shalaby et al (1999). An experimental test is made for Talkha combined cycle power plant, and a complete thermodynamic analysis using the program code is presented.

The results for gas turbine cycle show that, the compressor consumes about 66 to 50% of gas turbine power at 50 to 100% load. With the increase of the load, the heat added increases nearly linearly, the airflow rate increases, while the percentage excess air and air to fuel ratio decrease, and high exhausts gases exit temperatures from the combustion chamber occur. The maximum exergy loss occurs in the combustion chamber. It is about 38.5% from the exergy expanded of the cycle at base load. While the minimum occurs in the compressor and gas turbine, It is nearly 4% and

4.2% respectively. The rest of the expanded exergy is the gas turbine power and the exergy flow with the exhaust gases. The 2nd law efficiency of the gas turbine is the highest of the cycle components. It is about 95%, while the 2nd law efficiency of combustion chamber is the lowest. It is changed from 54.67 to 61.79% with the increase of the load, from 50 to 100%. The compressor 2nd law efficiency remains nearly constant with 89%.

The results for steam turbine cycle components of the combined cycle show that, the maximum exergy loss occurs in the HRSG, and the minimum occurs in the condenser. The exergy loss of the steam turbine increases from 5.43 to 9.18MW with the variation of load from 25 to 100% respectively. The highest 2nd law efficiency occurs in the HRSG, it is about 89%. The lowest 2nd law efficiency occurs in the condenser, it increases from 47.2 to 57.8% with the increase of load from 25 to 100%.

The results of both plant cycles show that, the overall 2nd law efficiency and the overall thermal efficiency for the plant after integrating the steam cycle to the gas turbine cycle are increased by nearly 14%, and 13% respectively.

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NOMENCLATURE

a	Molar fraction of O_2 in reactants
AD.C.C.	Additional combustion chamber
b	Molar fraction of N_2 in reactants
C.C	Combustion chamber
Comp	Compressor
CP	Circulating pump
CV	Calorific value, kJ/kg
d	Molar fraction of CO_2 in products
DP	Double pressure
E	Exergy flow, kJ/kg
e	Molar fraction of H_2O in products
EC	Economizer
f	Molar fraction of N_2 in products
FC	Forced circulation
FWP	Feed water pump
G	Gibbs function, kJ/k mole
g	Acceleration of gravity, m/s^2
G.T	Gas turbine
h	Specific enthalpy, kJ/kg
H	Enthalpy, kW
HCP	High pressure circulating pump
HD	High pressure drum
HEC	High pressure economizer
HEV	High pressure evaporator
HP	High pressure
HSU	High pressure superheater
I	Irreversibility, kJ
LCP	Low pressure circulating pump
LD	Low pressure drum
LEC	Low pressure economizer
LEV	Low pressure evaporator
LP	Low pressure
LSU	Low pressure superheater
m	Mass, kg

NC	Natural circulation
NSF	No supplementary firing
p	Gage pressure, kPa
PRE	Preheater
Q	Heat flow , kJ
Q_k	Heat transfer through the boundary, kJ
RH	Reheater
s	Specific entropy, kJ/kg.K
S	Entropy, kW/K
SU	Superheater
T	Temperature, K
T_k	Temperature of the heat transfer surface, K
TP	Tipple pressure
U	Internal energy, kJ
V	Volume, m^3
V	Velocity, m/s
W	Work, kJ
WSF	With supplementary firing
x_n	Volumetric fraction of fuel
Z	Height from datum, m
η	Efficiency, %
ψ	Flow availability for an open system, kJ/kg
ϕ	Non flow availability for a closed system, kJ

Subscripts

a	Air, actual, mole number of carbon in fuel
b	Mole number of hydrogen in fuel
ch	Chemical
Comp	Compressor
cv	Control volume
e	Exit
f	Fuel
g	Gasses
gen	Generated
i	Inlet
I	1st law of thermodynamics
II	2nd law of thermodynamics
is	Isentropic

l	Loss
mech	Mechanical
n	Number
o	Reference condition
p	Products
r	Reactants
rev	Reversible
turb	Turbine

Superscripts

•	*Rate*

Chapter 1

Introduction

INTRODUCTION

1.1. General

The combined cycle power plant is a promising mode of energy recovery and conservation and is an economically interesting proposition. Conversion of simple-cycle gas turbine facilities into combined-cycle plants offers clear-cut benefits whenever rising power demands must be met. These benefits include dramatic improvements in efficiency at all loads, and improved operating reliability with relatively low-cost addition to existing power facilities. By the year 2000, the total capacity of combined cycles used by utilities is expected to reach about 45000 MW, Najjar (1999).

1.2. Early History

The history of the combined power plant goes back to the early part of the 20th century. Emmet (1925) described substantial development work on a mercury-steam plant. He called the system "the Emmet mercury-vapor process" but referred back to an earlier presentation to the American Institute of Electrical Engineers in 1913, linking the name of Charles Pradley to the basic principle of the combined cycle. Emmet initially considered superheating of the lower steam cycle and ideal regenerative heating within that cycle, but the results show his second more conventional proposal, with similar pressure and temperature levels, a Rankine steam cycle with no feed heating, and consequently a slightly lower overall efficiency (yet still 54%).

The early development of the gas/steam turbine plant came somewhat later and was described by Seippel and Bereuter (1960). They showed seven possible combinations of gas turbine and steam turbine plant. The first has developed as the major from combined cycle power plant, although not now with supplementary heating of the gas turbine exhaust. The second shows the original concept of the pressurized boiler in which the gas turbine compressor charges the steam boiler (the Velox system developed by Brown Boveri in the 1930s). Other proposal by Seippel and Bereuter were not developed, but a useful more modern classification has been given by Wunsch (1978).

By the 1970s the so-called “recuperative” plant [a higher level gas turbine, exhausting to a heat recovery steam generator (HRSG), which supplies steam to the lower (steam turbine) cycle, with no supplementary heating of the exhaust] had become well established, primarily by General Electric and Westinghouse in the United State and by Brown Boveri in Europe. Wood (1971) was able to give a list of some 40 such plants (mostly small, in the range 15-20 MW) installed in the United States, mainly with unfired exhausts and with single pressure steam cycles. But one of the biggest, a combined heat and power plant of Dow Chemical in Texas, produced 63 MW (43 MW from the gas turbines and 20 MW from the steam turbines) was an exception in that it used supplementary firing of the gas turbine exhaust to provide steam at 1200 psia, 950 °F, exhausting to process at 185 psia; Wood quotes it nominal efficiency as 41%. In Europe the original Brown Boveri Korneuberg a plant in Austria was the biggest in service about the time (75 MW at nearly 33% overall efficiency) and this was also an example of a plant with supplementary firing of the HRSG.

The fully fired system, primarily replacing a conventional steam boiler with a main boiler in which the gas turbine exhaust was “supplementary fired” less well advanced at this time, but major development followed in the mid-70s, for peak and base load operation.

In this work, chapter one gives an introduction to the combined cycle power plant. The literature review of the previous researches is presented in chapter two. Principles of first and second law of thermodynamics are summarized in chapter three. The computer program code is described in chapter four. As an application of this code, complete thermodynamic analysis for both Talkha and Dammietta combined cycles are illustrated in chapter five.

Chapter 2

Literature Review

LITERATURE REVIEW

2.1 Combined Cycle

Sourour (1995) presented a lecture review for the state of the art on the combined cycles power plants. The types of the combined cycles and the application of each type are outlined. The first type is combined cycle of gas and steam turbine with single and double pressure Heat Recovery Steam Generator (HRSG). The second type is combined cycle of gas and steam turbine with HRSG and supplementary firing. The third type is combined cycle of steam and gas turbine topping. The properties of the combined cycles are compared with other plants. The advantage of combined cycle technology is also revealed.

Twelve research investigations, carried by Najjar and his associates are reviewed by Najjar (1999). The reviews covered twelve gas turbine systems, which would contribute towards efficient use of energy.

2.2 Computer Program Codes

Some software computer program codes have been developed for the analysis of steam power system all based upon Rankine cycle with various additional components such as feed water heaters and reheat stages.

Somerton (1987) presented a software package for analysis of steam power systems using the first and second law principles. This software considered twenty-eight configurations. The package is demonstrated by two examples. In the first, the optimum operating conditions for a simple reheat cycle are determined by using the program. The second example involves calculating the exergetic efficiency of actual steam power plants. The package allows also for inefficiencies in the pump and the turbines and accounts for pressure losses and heat losses in the piping. Results are provided in terms of the thermodynamic state properties before and after each device, the work of the pump and turbines, heat added to and rejected from the cycle, and the overall thermal efficiency of the cycle. Along with these results, drawing of the cycle and the temperature-entropy diagram are also provided as an output. The software package has been shown to be useful in the steam power plant design for classroom demonstration.

Perz (1991) using the first law analysis presented flexible computer package for the thermodynamics steam power cycle calculations. By this package the user can analyze any model and cycle scheme by selecting components from a library and connecting them in an appropriate way. By this way the package can be used to study any conventional and advanced power cycles. The package was not intended to use program for the analysis of the part-load behavior. The omission of this feature allows use of the very simple mathematical models for component analysis (e.g., the performance of the turbine is determined by constant efficiency).

Akiba et. al. (1993) created three computer programs to calculate the thermodynamic properties of the working fluids and to evaluate the performance of the Brayton-Rankine cycles. Also many parameters can be varied to study the effect of their variation on the performance of the combined Brayton-Rankine cycle power plants. The computational results for existing power plant were compared with the actual data of those power plants, appropriate assumptions have been made such as the efficiency of compressor, inlet pressure of air, outlet pressure of gases from gas turbine …etc. The first program has been made in order to calculate the Brayton cycle. The second program has been created to calculate the heat recovery boiler side. The third program has been designed to calculate the Rankine cycle. The thermodynamic properties of air, gases and steam were calculated by using empirical formulas.

Caracasi and Facchini (1996) described a highly flexible computerized method of calculating operating data in combined power cycle. The flexibility of the computerized method is not restricted by any defined cycle scheme. Each power plant component is represented by its typical equation relating to fundamental mechanical and thermodynamics laws. So, a power plant system is represented by algebraic equations, which are the typical equations of components, continuity equation, and data concerning plant condition. This equations system was not linear. They reduced it to a linear equation system by using variable coefficients. The solution is simultaneous for each component and is determined by an iterative process.

Akiba and Thani (1996) studied the performance of a new combination of supercharged boiler gas turbine cycle, which is expected to reduce the cooling air in the combustor and heat recovery cycle. From the thermodynamic point of view, two designs of this cycle were adopted and the influences of various operating parameters, such as compressor pressure ratio, ambient temperature, inlet gas temperature of gas turbine, percentage of excess air, and number of feed water heaters were studied. The computer program was used to evaluate the analysis of heat recovery boiler. The calculation of the program was expressed in 12 subroutines. The results of this program are inlet and outlet temperature of each part, mass and heat transferred energy at high-pressure and low-pressure sides. A performance comparison between the adopted cycle and a conventional heat recovery cycle was made. The results show that there is an improvement in the overall cycle efficiency.

Agazzani and Massardo (1997) presented a simulator tool for the thermoeconomic analysis of thermal energy systems. The approach looks at a generic process and analyzed it, not as a whole system, but as an assembly of several elemental components interconnected in various ways. This allows the user to simulate any plant configuration with out adapting the core of the code. The approach employed is based on the Thermoeconomic Functional Analysis (T.F.A), which through definition of the "Functional productive diagram" and establishment of the capital cost function of each component, allows the marginal costs and the unit product costs, i.e., the internal economy of the functional exergy flows to be obtained in correspondence to the optimum point. The optimum design of the system is obtained utilizing a traditional optimization technique. They presented a code called TEMP (ThermoEconomic Modular Program). Each component considered as a black box, and scans in turn the appropriate set of thermodynamics and Thermoeconomic equations that are known to apply to that component. The tool presented aimed the following target:

1. Thermodynamic and exergy analysis.
2. Thermoeconomic analysis.
3. Optimization.

2.3 Exergy Analysis of Power Plant

Auracher (1984) discussed some aspects of the theory and application of exergy. First he summarized the most important fundamentals. Then some problems of the heat transfer process are presented as an example for the application of exergy to one of the most important elementary processes in energy transformation. He also discussed some problems as exergy losses due to pressure losses and due to heat transfer and application of non-isentropic mixture in compression heat pump. He wanted to simulate a wider use of exergy concept in energy economics.

El-masri (1987) presented quantitative analytical tools based on the second law of thermodynamics to provide insight into the complex optimization incountered in the design of a combined cycle. These tools are especially valuable when considering approaches beyond existing body of experience, whether in cycle configuration or in gas turbine-cooling technology. A framework for such analysis was provided using simplified constant property models. He applied the second law method to calculate and to provide a detailed breakdown of the sources of inefficiency of a combined cycle. The calculation of stage-by-stage turbine cooling flow and loss analysis is performed using GASCAN program.

Chin and El-masri (1987) presented an exergy analysis and optimization of combined cycles with two-pressure steam bottoming cycles. Selecting the optimum parameters of dual pressure bottoming cycle as a function of the gas turbine exhaust temperature are presented. Exergy analysis is applied to quantify all loss sources in each cycle. They compared the single pressure at typical gas temperatures to the optimized dual-pressure configuration. They found that the dual-pressure increased steam cycle work output on the order of 3%, principally through the reduction of the heat transfer irreversibility from about 15 to 8% of the exhaust gas energy. They measure the further rdeuction of the heat transfer irreversibility such as three pressure systems or use of multi component mixtures can therefore only in modest additional gains. The results for the efficiency of optimized dual-pressure bottoming cycles are correlated against turbine exit temperature by simple polynomial fits.

Toole et. al. (1990) outlined the main concepts of exergy analysis with special emphasis on the fact that exergy can be transferred and transported and on the distinction between work and useful work. They described the exergy transferred associated with work and with heat. They explained the relationship between the flow exergy and non-flow exergy. They presented three conceptual devices, which can be inserted at an analysis boundary. They achieved mechanical separation between the system on either sides of the boundary so that an exergy transfer equivalent to the net exergy transferred and transported across the boundary can be visualized and evaluated. The first conceptual device can be used where heat transfer occurs at a boundary, the second where a steady flow fluid stream enters and leaves a system, and the third where air and fuel streams enter and flue gases leave a combustion system.

Habib (1994) presented an analysis of steam turbine cogeneration system. He compared the performance of the plant to a conventional plant with separate production of process heat and power. The analysis first and second law based and, therefore quantifies the irreversibilities of the different components of each plant. In the cogeneration plant, the heat required in the boiler can be obtained either from fuel firing or from exhaust gases of a simple gas turbine. He presented the influence of the heat to power ratio and the process pressure on thermal efficiency, utilization factor, and irreversibilities of the different components of each plant. His results show that the total irreversibility of the cogeneration plant is lower by 38% compared the conventional plant. This reduction in irreversibility is accompanied by an increase in thermal efficiency and utilization factor by 25 and 24%, respectively. His results show that most irreversible losses are due to boiler.

Ishida et. al. (1996) have been analyzed to operating advanced power plants a super critical steam plant and a gas-steam combined cycle using a methodology of graphical exergy analysis (EUD_s). In contrast, the EUD methodology (Ishida et. al. 1982) may provide more specific information based on graphical exergy analysis instead of exergy values between the output and the input. In EUD methodology, one first decomposes each process into pairs of energy donor and energy acceptor, and then focuses on the variation of energy levels, which is defined by:

M.A. Shalaby et. al. (1999) presented a second law analysis of Damietta combined cycle power plant at part-load (50% , 75% , 100% load). The analysis was used to determine the proportion of exergy losses among the plant components. The analysis shows that, at full load operation, 35% of the fuel chemical exergy is destroyed in the combustion chamber, 17.5% destroyed in the other plant components, 1.3% is lost in the stack exhaust gases, 32% is gained as a useful power from the gas turbine and 10% is gained also as a useful power from the steam turbines. They show also that the efficiency defects of the plant components are increased with decreasing load and the highest defects occurs in the combustion chamber. With decreasing load from 100% to 50%, the exergetic efficiency of the gas turbine, steam turbine and combined cycles is decreased by 20.4%, 2.5% and 11.9% respectively. Also, with increasing ambient temperature, the rate of exergy destroyed and the efficiency defect of the gas turbine, high pressure steam turbine and pumps are increased, while those of the compressor, combustion chamber, HRSG, gas stack, low pressure steam turbine, dearator and condenser is decreased.

El-Agouz et. al. (1999) presented an exergy analysis of steam power plant for constant and sliding pressure modes. They studied the location and magnitude of the exergy destruction of the individual component of the power plant. The effect of the load on the thermal efficiency, exergetic efficiency, efficiency defect and exergy coefficient of different component of the power plant is presented for constant and sliding pressure modes. They presented also a computer program to obtain the performance of different components and of the overall plant. The analysis shows that, the largest source of the efficiency defect occurs first in the boiler (47-53%) and second in the turbines (4-7%) while, this defect is smaller in condenser, heaters and pumps.

In the present work, a computer program code is developed for analysis of any available configurations of the most used combined cycle power plants in the world. The computer program code can be extended for any new type of combined power plant with the standard components mentioned in this work. It can be used to optimize the operating conditions of any components of the combined cycle power plant. Also the program can be used in the design of any new combined cycle power plant with the standard components. The program gives a complete analysis for the combined power plant at the base load and any part load. From the common available running measured data of the combined plant, a complete analysis for the first and second law efficiency, exergy expanded and losses, air to fuel ratio, excess air for the whole plant, can be obtained. As well as the first and second law efficiency, exergy losses for each component of the gas and steam cycle systems. A comparison for the results of the computer program for the Dammietta combined cycle power plant is done with the results of Shalaby et al (1999) and proved the validity of the program. Also, An experimental live test is made for Talkha combined cycle power plant, and a complete analysis using the program code is presented.

Chapter 3

Principles of the First and Second Law of Thermodynamics

جامعة المنصورة
كلية الهندسة
قسم هندسة القوي الميكانيكية

تحليل الدورات المركبة باستخدام كود حاسب آلي

كأحد المتطلبات

للحصول علي درجة الماجستير في هندسة القوى الميكانيكية

مقدمة من

مهندس/ وليد فكـــــري فهـــــمي

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Mansoura University
Faculty of Engineering
Mech. Power Engineering Dept.

ANALYSIS OF COMBINED CYCLE POWER PLANTS USING A COMPUTER CODE

Thesis
Submitted in Partial Fulfilment of Requirements for
The Degree of Master
in
Mechanical Power Engineering

BY

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