A STRATEGY FOR POWER PLANTS PLACEMENT OPTIMIZATION FOR BETTER EFFICIENCY: KUWAIT AS A CASE STUDY

BY

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ABSTRACT

Electricity is a fundamental requirement for human daily life. A power plant is one of the main sources to generate electricity. The main systems of such powerplants are the gas turbine cycle, steam turbine cycle, and combined cycle. A Combined cycle power plant (CCPP) is a combination between Gas turbine (Brayton cycle) and a steam turbine (Rankine cycle) to increase overall plant efficiency. This thesis is based on simulations analysis using MATLAB/Simulink. The first part of this work performed optimization and performance analysis of Sabiyah Combined Thermal Power Plant using real operating data and comparing it with actual output data from the software. The model was developed using MATLAB software. The exhaust of the Gas turbine reached up to 600^{o}C. The main factors in the top and bottom cycles of the combined cycle are investigated and discussed. The net-power output based on the performance model using MATLAB (Simulink) is greater than the current real output in the station by 20.5% and the overall thermal efficiency of the power plant is raised also from 50.5% to 55.2%. The second part investigated performance enhancement for gas turbines using MATLAB Simulink. Intercooler-reheat gas turbine configuration system (IRGT) has been proposed to be implemented in Sabiyah Thermal Power Plant instead of the simple cycle to raise the output power and efficiency with the same fuel burnt. The results of the modeling and analysis indicated that the efficiency is higher in IRGT with 45.20% compared with simple cycle (35.5%). The power output also increases to 210MW in comparison with the current output in the station which is around 160MW only.

خلاصة البحث

الكهرباء مطلب أساسي لحياة الإنسان اليومية، وتعتبر محطة توليد الكهرباء من المصادر الرئيسية لتوليد الكهرباء. تعتبر التوربينات الغازية والبخارية والدورة المركبة هي الأنظمة الرئيسية لمحطات توليد الطاقة. محطة توليد الطاقة ذات الدورة المركبة (CCPP) هي مزيج بين التوربينات الغازية والتوربينات البخارية لزيادة الكفاءة الكلية للمحطة. تعتمد هذه الأطروحة على تحليل المحاكاة باستخدام MATLAB / Simulink. الجزء الأول من هذا العمل يهدف لتحسين وتحليل الأداء لوحدة واحدة من الوحدات المركبة في محطة الصبية لتوليد الطاقة بالكويت، هذه الدراسة تعتمد على بيانات تشغيل حقيقية من محطة الصبية. تمت مقارنتها مع المخرجات الفعلية من برنامج MATLAB، حيث ان النموذج تم تطويره باستخدام برنامج MATLAB بنظام المحاكاة. وصلت درجة حرارة عادم التوربينات الغازية إلى 600 درجة مئوية. تم فحص ومناقشة أنواع مختلفة من العوامل الرئيسية في الدورة العلوية والسفلية للوحدة المركبة. ناتج الطاقة الصافي على أساس نموذج الأداء باستخدام MATLAB (Simulink) يعتبر أكبر من النتائج الحقيقة الحالية في المحطة الصبية بنسبة 20.5٪ حيث تم رفع الكفاءة الحرارية الكلية لمحطة الطاقة من 50.5٪ إلى 55.2٪. تطرقت الرسالة في الجزء الثاني الى تحسين أداء التوربينات الغازية باستخدام MATLAB Simulink. وتم اقتراح نظام تكوين توربينات الغاز (IRGT) ليتم تنفيذه في محطة الصبية بدلاً من الدورة البسيطة لهدف زيادة الانتاجية ورفع مستوى الكفاءة مع حرق الوقود نفسه الذي يتم في التوربينات الغازية الفردية. أشارت نتائج النمذجة والتحليل إلى أن الكفاءة أعلى في IRGT بنسبة 45.2٪ مقارنة بالدورة البسيطة بنسبة 35.5٪. يزداد إنتاج الطاقة أيضًا إلى 210 ميجاوات مقارنةً بالناتج الحالي في المحطة والذي يبلغ حوالي 160 ميجاوات.

APPROVAL PAGE

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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Signature .... Date: 13/02/2022

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LIST OF SYMBOLS

Low-pressure compressor	LPC
High-pressure compressor	HPC
Combustion chamber	CC
High-pressure turbine	HPT
Low-pressure turbine	LPT
Boiler heat exchanger effectiveness	BHEX
Gas turbine cycle	GTC
Turbine Inlet Temperature	TIT
Gas turbine	GT
Combined Cycle Power Plant	CCPP
Steam Turbine	ST
Intercooler-Reheated Gas Turbine	IRGT
Heat Recovery Steam Generator	HRSG

CHAPTER ONE

INTRODUCTION

1.1 GENERAL BACKGROUND

Electrical energy is a basic need for the maintenance and development of modern society. Fossil fuel plants such as coal, natural gas, and uranium have entered much of the generation today. The continued growth in the world's population, with the seemingly growing demand for electricity, has clearly shown the need to increase the power generation capacity. According to global statistics (IEA 2007), there was a steady increase in the energy supply during the past years. However, it is still commonly held that the power generation plants available are not sufficient to produce the required. Thus requiring further investment in the construction of new power, energy supply has shown a steady increase in recent years (Okeniyi, Anwan et al. 2012, Okeniyi, Atayero et al. 2018).

Since it would be inexpensive to increase the number of generating stations and trigger installation-related problems later method must increase generation. Plants that use fossil fuels as their energy source have poor efficiency, as the calorific value of the fuel cannot be fully exploited (Rai, Hasan et al. 2013). However, since the early 80s, the terms energy and environment have been associated. Because of the Carbon footprint issue. A term that refers to increasing Earth's temperature, as well as pollution that also causes climate change. Although renewable energy is becoming mainstream, fossil fuel use is still around 80%. This number is unchanged since 2015.

Therefore, improving power plant performance is no longer an option. The power plant company should improve efficiency. One approach is to increase gas turbine system efficiency by optimizing all associated input and output parameters.

Due to the demanding diversification of generating capabilities, thermal power plants became one of the main sources of power generation. To operate these power plants, natural gas is the suitable fuel used due to its availability. However, the operation of thermal power plants is more complicated than the operation of hydroelectric plants this is because of the usage of working fluids with high temperature and pressure and due to the related challenging operating conditions of metal tubes, headings, combustion chamber turbines, heating surfaces, casing, etc. Furthermore, the need for complex automatic control systems and the effort required to maintain high performance and reliability (Ibrahim, Rahman et al. 2010, Basha, Shaahid et al. 2012).

The main aim of this research is to study the performance modeling and analysis and optimizations of single and combined cycled in Sabiyah Thermal Power Plant which is located in Kuwait as shown in Figure 1.1. Sabiyah Thermal Power Plant was established in 1998 and is known as one of the important power plants in Kuwait. After several development stages, now it is considered one of the biggest power plants in the Middle East. Figure 1.1 shows a side view of the power plant.

In 2000, the first stage of Kuwait's Subiya oil-fired power plant was completed. At the $2.2 billion Subiya I facility, eight 300MW boilers and turbines produce 2,400MW and up to 12MGD of drinking water. The gas-fired 2,000MW Subiya II plant would increase the drinking water supply to 96MGD. In 1989, Kuwait's Ministry of Electricity and Water (MEW) began construction on the 2,400MW Subiya project in the country's northwestern region. The station was designed to assist existing power plants in the event of an emergency and to provide sufficient coverage of future power demand. Subiya I has a total full-load cooling water demand of 100m3 per second, which has been raised by Subiya II to 148m3 per second**.**

Kuwait's largest power station is the Sabiyah West gas-fired combined-cycle power plant. The 2GW gas-fired power station, which is owned and controlled by Kuwait's Ministry of Electricity and Water (MEW), is made up of three combined-cycle power blocks. As part of the New Kuwait Vision 2035 to boost the efficiency of the country's power and water infrastructure, the Sabiyah West power station is undergoing an upgrade that will increase its total production by more than 7%. By 2019, the facility's initial power block had been upgraded. The Sabiyah West combined-cycle power project, worth £1.59 billion ($2.65 billion), began construction in September 2009, and the plant began simple-cycle service with approximately 1,400MW installed capacity in June 2011. In phase two, which was completed in July 2012, the plant was converted to a combined-cycle service with a total generating capacity of 2GW.

Figure 1. 1: Kuwait’s Power plants

Figure 1. 2: Sabiyah Thermal Power Plant (CCGT Power Plant)

1.2 PROBLEM STATEMENT

The State of Kuwait faces an ever-increasing demand for electricity and water corresponding to the rapid population growth. To get better products, better analysis tools are needed to optimize them and to get closer to the limit of what the material can withstand. Meanwhile, air pollution needs to be taken into consideration. It is required to improve the performance of the cycle and reduce both the natural gas used for driving the cycle and the CO_2 emissions (Kadhim, Jabbar et al. 2018).

1.3 RESEARCH PHILOSOPHY

The research focused on improving power plant efficiency through gas turbine optimization. Improvement will be conducted through several stages: (1) Identification of the gas turbine-based power plant in Kuwait. (2) Acquiring the power plant schematic of a gas turbine-based power plant system. (3) Converting the schematic system into the gas turbine power plant (Brayton cycle). (4) Modelling the Brayton cycle in a MATLAB Simulink environment. (5) Assessing the current performance of the initial model of the Brayton cycle. (6) Developing the new improved model of the turbine power plant and (7) Assessing the new improved optimized model of the Brayton cycle and comparing it to the initial one and (8) Proposing the new procedure of the processing configuration in a gas turbine-based power plant.

1.4 RESEARCH SCOPE

(1) Acquiring data: The data consist of a map of the gas turbine power plant facility in Kuwait, data of the gas turbine specification, data of the specification of other apparatus as part of the gas power plant, and data of the current performance or efficiency of the gas turbine power plant.

(2) Acquiring industrial standardizations related to gas turbine power plants such as ANSI standard for power generation, EPA Power plant Standard.

(3) Tools to perform modelling: Gas turbine modelling and optimization using MATLAB Simulink and extract the result to Microsoft Excel.

(4) Some of the existing numerical analysis methods for optimizing the gas turbine power plant such as Monte Carlo, Artificial Neural Network, and Fuzzy logic.

1.5 RESEARCH OBJECTIVES

1) To study all thermodynamic cycles and the working principle of every cycle.

2) To analyze the mathematical formulation for all types of configurations

3) To analyze and simulate the behavior of the Combined cycle using MATLAB/Simulink.

4) To analyze and simulate the behavior of the Single Gas turbine cycle using MATLAB/Simulink.

5) To propose the new procedure of the processing configuration in a gas turbine-based power plant.

1.6 THESIS FLOW CHART

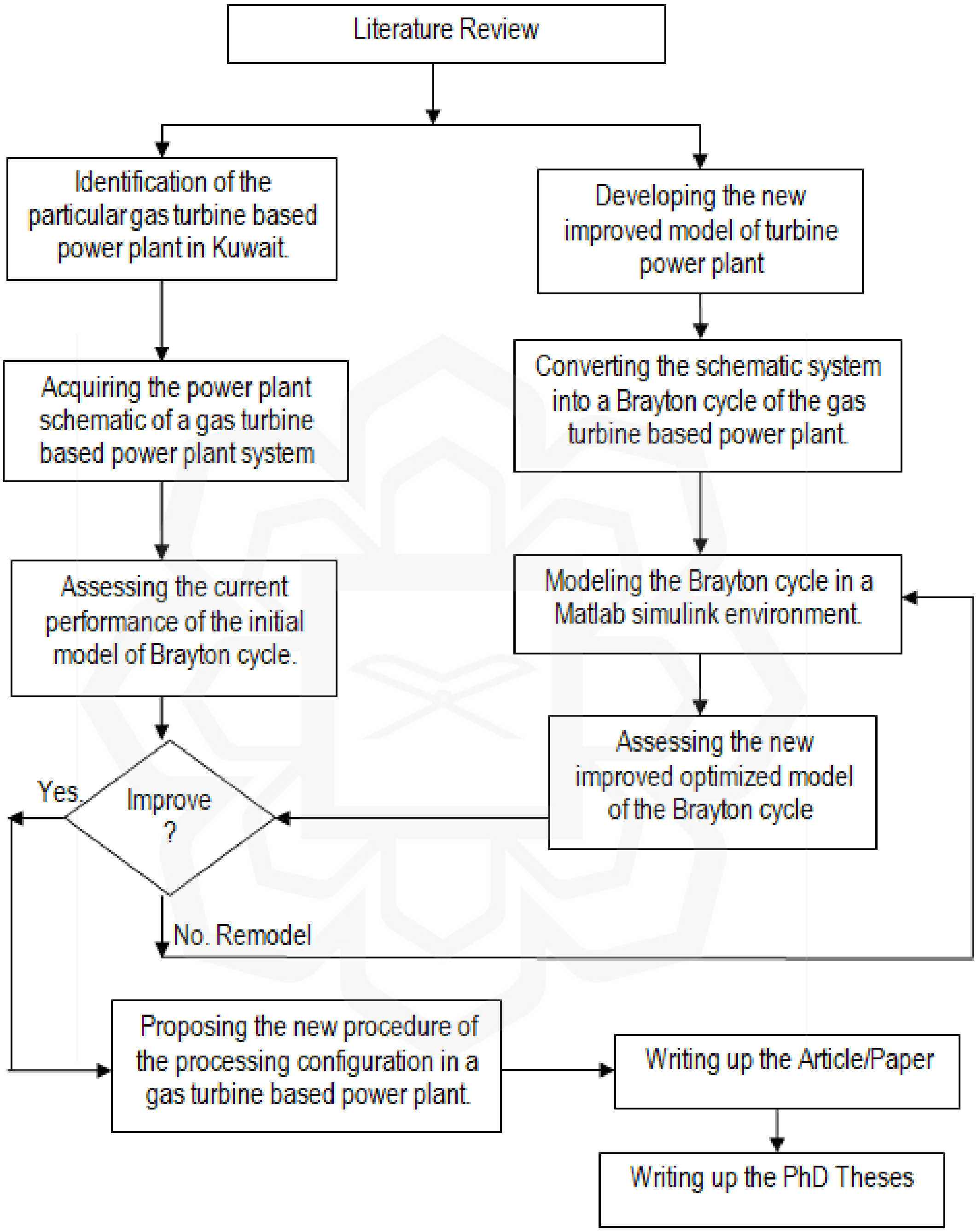

Figure 1. 3: Thesis flow chart of the thesis

CHAPTER TWO

LITERATURE REVIEW

2.1 GENERAL OVERVIEW

Satisfaction with human egalitarian lives, accommodations, and inventions is the main goal behind many advances in human history. Facilities such as transport, air conditioning, and many other modern necessities of life are then developed. These have been planned to be powered by the energy emitted from the various energy sources. The methods used to generate such energy are primarily fossil fuels, nuclear reactions, and renewables. In each case, the energy has its form, requirements, and the unique method by which the individual facility normally releases and uses it.

In general, energy became a fundamental requirement for human existence. The energy demand has gradually increased due to rapid population growth and lifestyle growth. However, the ongoing wasteful use of part of the energy resources such as fossil fuels (oil/gas, coal) in the past IEA (2013) has had significant catastrophic effects (pollution, change in weather patterns, global warming, etc.). Thus, the understanding of the aim of increasing access to commercial electricity is crucial for every society's future and sustainable growth. (Mohamed 2007, Rao and Parulekar 2012).

Due to the rapidly increasing population in the world, the difficulties to enhance lifestyles, and global economic growth, the energy demand is increasing sharply. Recently, it became very dangerous to accommodate the expected rise of energy demand in some countries, since it is now commonly recognized that the wide activities of the human without caution, such as the burning of fossil fuels involved in energy systems, are the primary causes of acid rain and greenhouse gases that are the major contributors to emissions (Goswami and Kreith 2007). In his thesis, Yadav (2009) noted that one of the most important challenges facing humanity in the 21st century is to provide everyone on the planet access to healthy, secure, and sustainable energy supplies.

One of the most important aspects of the country's economy is the production of electricity. Due to the rapidly increasing economy and population, the energy demand is growing. Both industry and households should be supported by electricity. Particularly in the last decades in which operations are conducted 24 hours a day and seven days a week, the need for energy supply is irregularly increased (Lisin, Strielkowski et al. 2015). On the other side of production, the energy supplier's growth is not as quick as the demand side. Thus, the challenge is how to resolve both sides' unbalanced growth. The problem facing the power plant business is the energy regulatory requirement (Mohamed and Koivo 2010). As reported in the study conducted by the European Climate Foundation (ECF), energy players must increase their efficiency, as fossil fuels still contribute significantly to climate change (Roadmap 2010).

The energy player has an opportunity to motivate them to enhance their efficiency in terms of an effective output of energy. Improvisation by applying optimization techniques (Li and Nilkitsaranont 2009). The benefits of optimizing the power plant will contribute to the country's long-term stability and sustainability not just for the energy player, nor for a short period of economic growth (Xu, Niu et al. 2016). Continuously monitoring the implementation of the optimization process and introducing a so-called smart monitoring system that can predict energy demand irregularity and fluctuation. It will contribute significantly to saving fuel and reducing the carbon footprint (Diesendorf and Saddler 2003).

In the next few decades, global energy demands are expected to rise, with the domination of fossil fuels as the energy source. Therefore, CO_2 emissions are expected to rise dramatically. World Energy Outlook (WEO) forecasts between 2011 to 2035 indicate a sharp increase in energy demands (overtake 66%). This would lead to rising CO_2 emissions by 20% and the temperature increases by around 3.6°C (IEA, Agency et al. 2013).

Essentially, various methods are typically used to satisfy correlative demands. Using such techniques will ensure improved energy efficiency with appropriate environmental impact standards. The first approach is to use various sources of renewable energy to fuel these facilities such as nuclear reaction and renewables. The technologies that use these energy sources are either fully established with low outputs or feature unstable operating availability. However, the high construction and maintenance costs added to the use of these technologies. The second approach to solutions targeted modern and more efficient thermal power plants. The approach also enhances the operating station performance by increasing its thermal efficiency combined with a substantial decrease in its harmful discharges.

Recently research has concentrated on power-generation installations. Fossil fuel-fired power plants, with their associated environmental effects, are responsible for producing much of the present worldwide electricity. These power generation plants use 32% of fossil fuel resources and 41% of CO_2-related energy releases (Taylor, d'Ortigue et al. 2008). In 2010, 67.4 % of total world electricity was generated from coal, oil, and gas, as reported by IEA (2013) with 60%, 33%, and 7 %, respectively.

Thermal power plants generated over 90% of the electricity produced. The average thermal efficiency of electricity generation from a standalone fossil-fuel mechanism does not normally exceed 36%.

From the 1880s, fossil fuels were used in power plants to produce industry electricity. The first generating station in 1882 is established by Thomas Edison. Then various power plants were built worldwide. Several technologies are implemented to improve power plant operations such as power plant automation and enhancements to boost power plant performance and minimize hazardous emissions (Flynn 2003).

Optimizing energy sources regarding the environmental condition and general energy supply is required. Units that provide control become more complex. Power plant owners call for guaranteed high-performance power plants. The increasing price of fuel and environmental effects highlight energy issues considerably (Dincer and Al-Muslim 2001).

The optimization of the thermal power plant is a very complex operation. It is known as maximizing thermal efficiency, minimizing the cost of power generation, minimum emissions, or minimum downtime. Power plants owners aim to be more efficient and actively explore strategies to minimize costs, minimize time, schedule time and use computer-aided (CAD) approaches to prevent delays and errors (Perz 1991).

Currently, natural resources are used to generate electricity which is absorbed rapidly as a world energy resource. Simulation Devices are parts of optimizing power plant processes. Most engineered systems run at loads below the designed value. Operating at lower thermal efficiencies than expected (Egelioğlu 2002).