NUMERICAL PINCH ANALYSIS FOR PRESSURISED WATER REACTOR TOTAL SITE TRIGENERATION SYSTEM FOR CONTINUOUS AND BATCH PROCESSES

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ABSTRACT

The progressive development of industrialisation and rising of populations has led to the depletion of energy resources, global environmental pollution and climate changes. This challenges can be reduced by using trigeneration and total site systems. The trigeneration system is one of the innovations that can increase the performance of power systems by using waste energy for heating and cooling applications to meet the demand requirements. Total site system, on the other hand, is a technology that can integrate intra-processes of utility at multiple sites. However, the combination of trigeneration and total site systems has not yet been established. This work proposed a new methodology for developing an insight-based numerical pinch analysis methodology to simultaneously target the minimum cooling, heating and power requirements for continuous and batch processes of total site systems of the centralised trigeneration pressurised water reactor (PWR) system. The new proposed methodology is called trigeneration system cascade analysis (TriGenSCA). The procedure of TriGenSCA for the trigeneration PWR system in continuous processes of total site system consists of six steps which are data extraction, problem table algorithm (PTA), multiple utility problem table algorithm, total site problem table algorithm, TriGenSCA and trigeneration storage cascade table. Based on case study 1, the overall energy production, energy losses and equivalent annual cost of the optimal trigeneration PWR system are 122.6 GWh/day, 75.3 GWh/day and USD 400.0 M, respectively. As for the batch processes of total site system, additional of time slice as step 2 in case study 2 is proposed to show the batch processes of the total site system. The results found that the overall energy production, energy losses and equivalent annual cost for the optimal trigeneration PWR system are 9.0 GWh/day, 2.3 GWh/day and USD 367.5 M, respectively. This shows that energy production, energy losses and annual equivalent cost are reduced by 21.0%, 17.3% and 8.0%, respectively. Consideration of transmission energy losses while transferring the energy from the trigeneration PWR system to the demands were incorporated into the TriGenSCA methodology to improve the sizing utility in the system. The findings indicated that 1.0 MW of extra energy is required in 5.0 km of transmission lines. Additional step in a method which is called as trigeneration system sensitivity table is used to analyse the sensitivity of the centralised trigeneration PWR system if some of the industrial plants in the Total Site system are shut down. The results showed that additional 100.7 MW of hot water (HW) are needed if Plant C is shut down for continuous processes, whilst 12.6 MW of HW and 50.2 MW of cool water are required if Plant B and Plant C are shut down in batch processes.

ABSTRAK

Pembangunan perindustrian yang progresif dan peningkatan pertumbuhan penduduk telah menyebabkan pengurangan sumber tenaga, pencemaran persekitaran global dan perubahan iklim. Cabaran ini dapat dikurangi dengan menggunakan sistem trigenerasi dan keseluruhan tapak. Trigenerasi adalah salah satu inovasi yang dapat meningkatkan prestasi sistem kuasa dengan menggunakan semula tenaga buangan sebagai aplikasi pemanasan dan penyejukan bagi memenuhi keperluan permintaan. Sistem keseluruhan tapak pula merupakan satu teknologi yang membenarkan utiliti diintegrasikan secara proses luar pada pelbagai tapak. Walau bagaimanapun, gabungan antara sistem trigenerasi dan sistem keseluruhan tapak masih belum mapan. Penyelidikan ini mencadangkan metodologi baharu untuk mengembangkan metodologi berdasarkan penglihatan analisis jepit berangka untuk menganalisa serentak tenaga penyejukan, pemanasan dan kuasa untuk proses berterusan dan kelompok bagi sistem tapak keseluruhan melalui sistem pusat trigenerasi reaktor air bertekanan (PWR). Metodologi baharu yang dicadangkan ini dipanggil sebagai analisis lata sistem trigenerasi (TriGenSCA). Prosedur TriGenSCA dalam sistem trigenerasi PWR pada proses berterusan sistem tapak keseluruhan terdiri daripada enam langkah iaitu pengekstrakan data, algoritma jadual masalah (PTA), algoritma jadual masalah utiliti berganda, algoritma jadual masalah keseluruhan tapak, TriGenSCA dan jadual penyimpanan lata trigenerasi. Berdasarkan kajian kes 1, pengeluaran keseluruhan tenaga, kehilangan tenaga dan kos setara tahunan dalam sistem trigenerasi PWR yang optimum masing-masing adalah 122.6 GWh/hari, 75.3 GWh/hari dan USD 400.0 juta. Bagi proses kumpulan sistem keseluruhan tapak, penambahan potongan masa di langkah 2 dalam kajian kes 2 menunjukkan proses kumpulan sistem dalam keseluruhan tapak. Hasil kajian mendapati bahawa keseluruhan pengeluaran tenaga, kehilangan tenaga dan kos setara tahunan untuk sistem optimum trigenerasi PWR masing-masing adalah 9.0 GWh/hari, 2.3 GWh/hari dan USD 367.5 juta. Ini menunjukkan bahawa pengurangan pengeluaran tenaga, kehilangan tenaga dan kos setara tahunan masing-masing sebanyak 21.0%, 17.3% dan 8.0%. Pertimbangan kehilangan tenaga penghantaran semasa memindahkan tenaga dari sistem PWR trigenerasi ke industri dimasukkan ke dalam metodologi TriGenSCA untuk meningkatkan ukuran utiliti dalam sistem. Kaedah yang dikaji menunjukkan bahawa 1.0 MW tenaga tambahan diperlukan dalam talian penghantaran sejauh 5.0 km. Penambahan langkah dalam kaedah yang dipanggil sebagai jadual sensitiviti sistem trigenerasi digunakan untuk menganalisis kepekaan sistem PWR trigenerasi terpusat akibat beberapa kilang industri dalam sistem keseluruhan ditutup. Hasil kajian menunjukkan bahawa tambahan 100.7 MW air panas (HW) diperlukan kerana Industri C ditutup dalam proses berterusan, sementara 12.6 MW HW dan 50.2 MW air sejuk diperlukan jika Industri B dan Industri C ditutup dalam proses kelompok.

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LIST OF ABBREVIATIONS

AC	-	Alternating current
BWR	-	Boiling Water Reactor
CANDU	-	Canada Deuterium Uranium
CCs	-	Composite Curves
CHP	-	Combined Heat and Power
CHS	-	Chemical heat storage
ChW	-	Chilled Water
CPCC	-	Continuous Power Composite Curves
CW	-	Cooling Water
DC	-	Direct current
DSC	-	Differential scanning calorimeter
DTA	-	Differential thermal analysis
EAC	-	Equivalent Annual Cost
ESCA	-	Electric System Cascade Analysis
FBR	-	Fast Breeder Reactor
GCC	-	Grand Composite Curve
GFR	-	Gas-cooled Fast Reactor
HTFs	-	Heat transfer fluids
HPS	-	High-Pressure Steam
HW	-	Hot Water
HyPS	-	Hybrid Power System
ICE	-	Internal Combustion Engine
LHS	-	Latent heat storage
LMCR	-	Liquid Metal Cooled Reactor
LPS	-	Low-Pressure Steam
MFR	-	Metal Fuel Reactor
MU PTA	-	Multiple Utility Problem Table Algorithm
NPP	-	Nuclear Power Plant
PA	-	Pinch Analysis
PCC	-	Power Composite Curves

PCMs	-	Phase Change Materials
PCT	-	Power Cascade Table
PEFC	-	Polymer electrolyte fuel cells
PEMFC	-	Proton exchange membrane fuel cells
PHWR	-	Pressurised Heavy Water Reactor
PoPA	-	Power Pinch Analysis
PTA	-	Problem Table Algorithm
PWR	-	Pressurised Water Reactor
SCT	-	Storage Cascade Table
SCWR	-	Supercritical Water Reactor
SFR	-	Sodium-cooled Fast Reactor
SePTA	-	Segregated Problem Table Algorithm
SGCC	-	Site Level Grand Composite Curve
SHS	-	Sensible heat storage
SOFC	-	Solid oxide fuel cells
SSSP	-	Site source-sink profiles
STEP	-	Streams Temperature versus Enthalpy Plot
TCM	-	Thermo-chemical materials
TriGenSCA	-	Trigeneration System Cascade Analysis
TriGenSCT	-	Trigeneration Storage Cascade Table
TriGenSST	-	Trigeneration System Sensitivity Table
TSCHP	-	Total Site Cooling, Heating and Power
TS PTA	-	Total Site Problem Table Algorithm
USD	-	United State dollar
VCM	-	Vinyl-Chloride-Monomer
VHPS	-	Very High-Pressure Steam
VHTR	-	Very High-Temperature Reactor
WCR	-	Water Cooled Reactor

LIST OF SYMBOLS

$\Delta T_{\min,pp}$	-	Minimum temperature between processes
$QC_{\min}$	-	Minimum cold requirement
$QH_{\min}$	-	Minimum heat requirement
$\Delta T_{\min,up}$	-	Minimum temperature between process and utility
T’	-	Shifted temperature
T’’	-	Multiple utilities shifted temperature

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays, progressive development of industrialisation and rising of populations has led to the depletion of energy resources, global environmental pollution and climate changes. The International Energy Agency (2019) has predicted that Southeast Asia is going to experience rising of energy demands from 244 Mt of oil equivalent (Mtoe) in 2018 to 329 Mtoe in 2040. Consequently, the rising energy demands have created energy shortage gaps in some of the countries as well as increasing global carbon emissions. Currently, residential and commercial buildings consume around 40 % of the total global energy. In Malaysia, buildings consume around 48 % of the power that is generated in the country, and more than 50 % of this energy are used for occupants' comforts such as air conditioning and refrigeration (Hassan et al., 2014). Chua and Oh (2010) have revealed that in Malaysia, the total power generation and consumption are expected to drastically increase soon. The change of policy of the Malaysian government from agricultural industries to technology has led to an increase of energy consumptions in the country. The modern usage of home appliances such as air conditioning and refrigeration also contributed to the highest rate of energy consumption. Lighting, on the other hands, is the second-highest energy consumption after home appliances (Zakaria et al., 2013). Figure 1.1 summarises the rising energy consumption in Malaysia from 1990 to 2016 (Suruhanjaya Tenaga Malaysia, 2019).

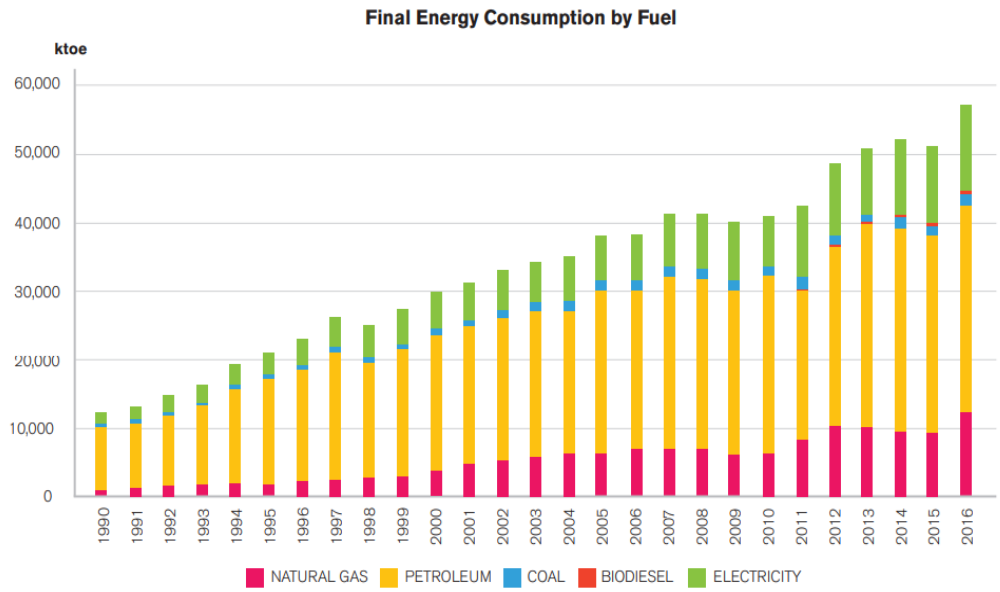

Figure 1.1 The rise of energy consumption in Malaysia from 1990 to 2016 (Suruhanjaya Tenaga Malaysia, 2019)

This has encouraged governments and private organisations to promote the development of new technologies so that the carbon emissions and energy shortage gaps can be reduced. In order to reduce carbon emissions and fuel consumption as well as to meet energy consumptions, Zhang et al. (2016) outlined strategies by proposing taxes and incentives to high efficient energy generations, as well as a mix of energy generation technologies at one site. Cogeneration is one of the technologies that can improve the thermal efficiency of the conventional power plant by enhancing useful waste heat to produce a heating application. Trigeneration is an advanced technology of cogeneration system thanks to the development of absorption chiller. The trigeneration system can be defined as a technology that is capable of generating simultaneous power, heating and cooling from a single burning of fuel. Generally, by reusing waste heat in the conventional power station to produce heating and cooling applications, the thermal efficiency can be drastically improved from 30 % - 40 % to 80 % - 90 %. Khamis et al. (2013) stated that improvement of thermal efficiency could translate into a reduction of emissions of all pollutants as well as lower operating costs. The payback period of the conventional power station can also be shortened through the use of the trigeneration system.

Nuclear energy is clean energy and zero carbon emissions that can generate numerous thermal energy for power production. Nuclear energy can be defined as the splitting of atoms to produce a large amount of heat energy to heat water to generate steam in the nuclear power plant. The production of steam in the nuclear power plant will then be supplied to the turbine for power generation. Figure 1.2 presents the formation of nuclear energy from the splitting of atoms. Currently, in certain countries, nuclear power plants have implemented a cogeneration system to meet different types of energy needs effectively. A wide range of specific temperature requirements that can be supplied to the demands is based on the utilisation of waste heat from the nuclear power plants. The waste heat with temperatures around 100°C to 300°C can be used as hot water and steam for the agriculture industry, seawater desalination and district heating. For a waste heat with temperatures more than 1,000°C, it can be supplied for process steam in oil and gas, and chemical industries. Figure 1.3 shows the range of applicability between existing nuclear power plants and heat applications based on temperatures.

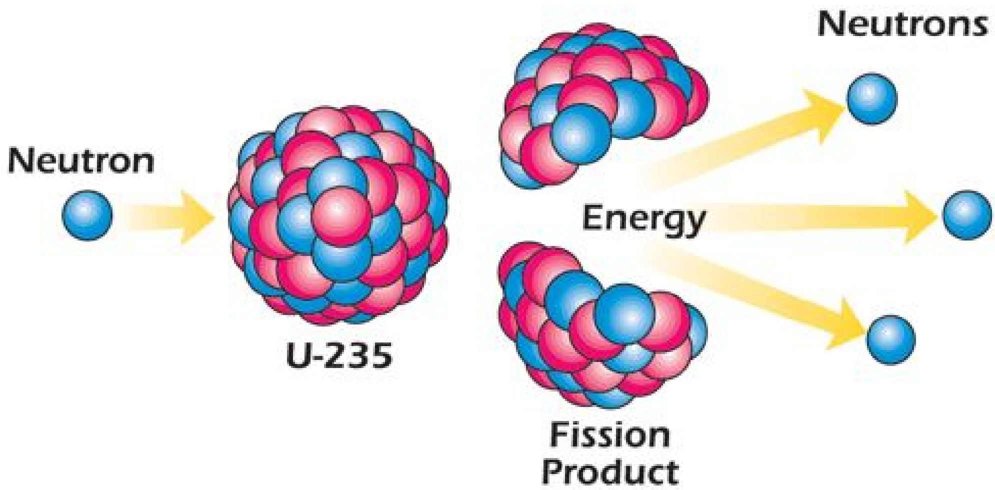

Figure 1.2 The formation of nuclear energy from the splitting of atoms (Department of Energy and Mineral Engineering, 2018)

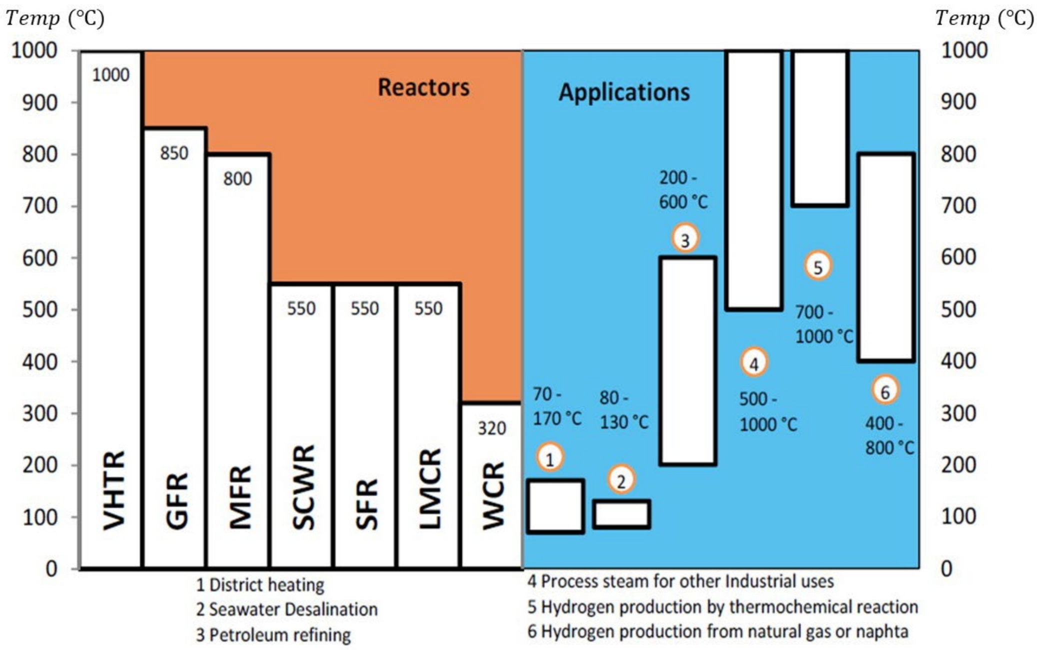

Figure 1.3 The range of applicability between existing nuclear power plants and heat applications based on temperatures (Khamis et al., 2013)

However, none of the countries has ever implemented a trigeneration system into a nuclear power plant. Implementation of the trigeneration system can generate cooling and chilling applications from the waste heat that is produced from nuclear power plants by using chillers. The chilled water can be beneficial to the food processing industries in tropical countries such as Malaysia and Thailand to refrigerate the foods for long-lasting. Along with the advantages of a trigeneration system in the nuclear power plant, several technical issues need to be considered. Firstly, the nuclear power plant needs to be placed near a ready supply of cooling water, which mostly from lakes and seawater, where the location of the population may not be necessarily near to the power plant. As consequences, the energy cost due to steam and cooling transmissions will be rising with the distance. The capacity of transmissions and inlet pressure, however, will be reduced with the rising of the distance between the power station and consumers. Reduction of inlet pressure can lead to the reduction of temperature as the energy reached to the destinations.

Particularly, the heat recovery in the Total Site system has been gained more interest since its inception in the ’90s (Klemeš et al., 1997). The Total Site system can be expressed as a system that can able to exchange utilities through the site utility system as a marketplace. The reason is that some industrial plants can generate power, heating and cooling energy due to the high cost of early purchased power. A bottoming cycle is usually applied in the industrial plants where exhaust steam from a boiler is primarily used for process heating. Available excess steam is then extracted by a turbine to produce power or through the chiller to produce chilled water. The production of excess energy from respective industrial plants can be sold to the other industrial plants which in deficit energy. The heat recovery in the Total Site system can be determined in two ways which are direct between processes and indirect through an intermediate medium. Direct heat recovery may not be the best practice in the real case study due to the distances between processes and operational issue. Indirect heat recovery, on the other hand, can give an advantage since it offers operational flexibility where the number of utility temperature levels are set as utility targets (Chew et al., 2013).

Many works on designing trigeneration and Total Site systems have been presented, but mostly in separated matters. A combination of trigeneration nuclear power plant and Total Site system, however, has not been emphasised in the past study. Process integration methodology to optimally sizing of trigeneration system in the Total Site system has also not been addressed. Recently, Sandoval-Reyes et al. (2020) developed a new methodology by combining simulation and clustering with multi-criteria decision-making to analyse the impact of load size in the trigeneration systems with a thermal storage system. The study, however, does not involve the Total Site system and has implemented complex calculations which is hard for the users to understand. Moreover, other vital decision variables are still in need to be considered, such as single and multiple periods of demands, maximum power and thermal storage systems, amount of minimum outsourced energy and excess energy source.

1.2 Problem Statement

Nuclear power plants are reliable sources of energy generation. The nuclear power plants are non-intermittent and can be classified as controlled sources which able to produce predictable power and thermal energy. However, most of the nuclear power plants only have overall thermal efficiencies of 30 % to 35 % to generate power and another 65 to 70 % of the total energy will be dissipated to the environment (Khamis et al., 2013). Three Miles Island nuclear power plant, for example, using only 33 % of total energy to generate power and the remaining is released to the environment in the form of cool water vapour through the cooling tower (Barnes, 2013). The waste heat that is dissipated to the environment shows tremendous energy losses as well as can cause increasing operational costs and payback period. A trigeneration system can be implemented in a nuclear power plant to improve total thermal efficiency. The total thermal efficiency in trigeneration system can be improved by up to 90 % by reusing waste heat for other applications (Wu and Wang, 2006).

However, the implementation of the centralised trigeneration system alone to generate energy can increase the sizing of the system since the system requires a large amount of energy to supply to the demands. The Total Site system can reduce the sizing of the centralised trigeneration system by exchanging utilities through the site utility system as a marketplace. However, implementation of the centralised trigeneration nuclear power plant in the Total Site system has not yet been emphasized. The procedure for the optimal design of the centralised trigeneration nuclear power plant in the Total Site system based on Pinch Analysis methodology has also not been established.

The previous study on designing an optimal trigeneration system involves complex mathematical formulations which makes it difficult to master. The previous methodology gives little insights into the network designs and lack of user involvements. In contrast, Trigeneration System Cascade Analysis (TriGenSCA) applied in this research is very handy to implement and allows the users to have better control over the decision making process. Effects of time variables and sensitivity analysis on the demand targets can also be explored with the insights available during various analysis and design stages. The TriGenSCA algebraic approaches are less tedious and easier to construct as the methodology provide faster in algorithmic calculations. Therefore, the concept of TriGenSCA is introduced and extended in this study to solve the problems and limitations encountered in the previous methodology.

1.3 Research Objectives

The main objective of the research is to develop a novel algebraic systematic methodology based on Pinch Analysis for optimal design and targeting minimum cooling, heating and power generation of a Pressurised Water Reactor (PWR) as a centralised nuclear power plant in the Total Site system. Sub-objectives of this research are as follows:

i. To evaluate an optimal sizing of the centralised trigeneration PWR system in single and multiple periods of Total Site system in 24 h operations.

ii. To integrate the centralised trigeneration PWR system with consideration of energy storage losses.

iii. To develop the centralised trigeneration PWR system by considering energy transmission losses.

iv. To analyse the sensitivity of the centralised trigeneration PWR system as each industry in the Total Site system shuts down.

1.4 Research Scope and Limitation

This study is focused on the design of optimal sizing of centralised trigeneration PWR in the Total Site system. The Total Site system can be implemented to diverse applications including the residential, commercial and industrial sectors.

The Pinch Analysis methodology is applied in this research through the use of Microsoft Excel as a tool. The scope of this research includes:

i. State of the art review on Pinch Analysis, types of the Pressurised Water Reactors and trigeneration system.
   Studying the development in Pinch Analysis, types of the Pressurised Water Reactors and trigeneration system, and identifying the research gaps.

ii. Development of algebraic methodology for the integration of the centralised Pressurised Water Reactor as a trigeneration system with the Total Site system.
   The developing methodology based on Pinch Analysis to determine power, heating and cooling targets as well as to design an optimal trigeneration system in the Total Site system.

iii. Development of process integration methodology for centralised Pressurised Water Reactor with energy losses consideration.
   A method with consideration of losses during conversion, transfer and storage reflects the actual power targets for the energy generation in centralised Pressurised Water Reactor.

iv. Design and sizing of centralised Pressurised Water Reactor in the Total Site system using Pinch Analysis.
   Developing a handy TriGenSCA method by using Microsoft Excel as a tool to size the centralised Pressurised Water Reactor, including the storage system for various energy demands in the Total Site system.

v. Analysis of the sensitivity of the demands in the Total Site system and centralised Pressurised Water Reactor.
   Extending the TriGenSCA methods with sensitivity analysis to determine the effect of the performance of the centralised trigeneration system to generate energy to be supplied to the demands. The backup system can be obtained through the sensitivity analysis as some industrial plants are shut down due to maintenance or production changes.

vi. Method validation

Validating the methodologies with various case studies from the literature. The results are compared with results obtained from available methodologies of different researches to prove the effectiveness and the practicality of the proposed methodologies.

The limitations of this research are also included as below:

i. The charging and discharging efficiencies of the energy storage systems, as well as utility efficiencies, are limited at constant values for each time.

ii. The proposed method does not consider variations of seasons in an annual cycle.

iii. The design of a nuclear power plant only considers PWR as a trigeneration system with six heat exchangers (Barnes, 2013 and Cholewinski and Tomkow, 2018)

iv. The trigeneration PWR system operates in continuous 24 h operations.

v. Energy consumption remains unchanged regardless of changes of the topology in the industrial plants.

vi. The energy demands fluctuation of industrial plants in the Total Site system does not consider weather changes and catastrophic events.

1.5 Research Contributions

Five main contributions have emerged from this work which is proposed as below:

i. A new systematic methodology to target and design of the centralised trigeneration PWR in the Total Site system.

   The power, heating and cooling allocations are established from TriGenSCA methodology, which can provide the designers with valuable insights for the design of optimal trigeneration Pressurised Water Reactor in the Total Site system.

ii. A new methodology with detains energy storage losses for the design of a centralised PWR in the Total Site system.

   More realistic power, heating and cooling allocations for the centralised trigeneration system that considers energy storage losses can be established to avoid an under-sized system's design.

iii. A new sizing approach for centralised trigeneration PWR in both single and multiple periods in the Total Site system.
   The best combination of the centralised trigeneration PWR with Total Site system and capacity for the centralised trigeneration PWR can be decided with the sizing method presented even the industries in the Total Site system are in continuous or batch processes.

iv. A new approach to analyse the sensitivity of the centralised trigeneration PWR in the Total Site system.
   The impact of industrial plants are shut down, or production changes on the centralised PWR and Total Site system can be determined. Through the new sensitivity analysis approach, the sizing back up system can be obtained.

v. A comprehensive methodology for optimisation of storage technologies in the Total Site system.
   The extension of the TriGenSCA methodology with the inclusion of energy losses occurring in power and thermal storage schemes can guide the designers to determine the most efficient and economical storage scheme for the given power, heating and cooling trends of the centralised trigeneration Pressurised Water Reactor.

1.6 Thesis Outlines

This thesis is divided into five chapters. Chapter 1 provides an introduction to the research, including the overview of global and Malaysia's energy outlook, problem statement, research objectives, scope and research contributions. Reviews on the development in Pinch Analysis, types of PWR and trigeneration system technologies as well as analysis on previous works are done in Chapter 2. Chapter 3 describes the stepwise methodology construction to accomplish the targeted objectives. Chapter 4 presents the results obtained from the application of the developed techniques on case studies. Finally, Chapter 5 concludes the overall research study and recommends possible future works to be explored.

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LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Jamaluddin, K.**, Wan Alwi, S. R., Hamzah, K., & Klemeš, J. J. (2020). A Numerical Pinch Analysis Methodology for Optimal Sizing of a Centralised Trigeneration System with Variable Energy Demands. *Energies*, *13*(8), 2038. https://doi.org/10.3390/en13082038. **(Q3, IF: 2.707)**
2. **Jamaluddin, K.**, Wan Alwi, S. R., Abd Manan, Z., Hamzah, K., & Klemeš, J. J. (2019). A Process Integration Method for Total Site Cooling, Heating and Power Optimisation with Trigeneration Systems. *Energies*, *12*(6), 1030. https://doi.org/10.3390/en12061030. **(Q3, IF: 2.707)**

Indexed Journal

1. **Jamaluddin, K.**, Wan Alwi, S. R., Abd Manan, Z., & Klemeš, J. J. (2018). Pinch Analysis Methodology for trigeneration with energy storage system design. *Chemical Engineering Transactions*, *70*, 1885-1890. https://doi.org/10.3303/CET1870315. **(Indexed by Scopus)**

Indexed Conference Proceedings

1. **Jamaluddin, K.,** Wan Alwi, S. R., Abd Manan, Z., Hamzah, K., & Klemeš, J. J. (2020, December). Performance of Centralised Trigeneration Plant on Sensitivity Analysis of Total Site System. In *IOP Conference Series: Materials Science and Engineering* (Vol. 991, No. 1, p. 012141). IOP Publishing. DOI:10.1088/1757-899X/991/1/012141. **(Indexed by Scopus)**
2. **Jamaluddin, K.**, Wan Alwi, S. R.., Abd Manan, Z., Hamzah, K., & Klemeš, J. J. (2020, July). Development of Numerical Trigeneration System Cascade Analysis with Transmission and Storage Energy Losses Consideration. In *IOP Conference Series: Materials Science and Engineering* (Vol. 884, No. 1, p. 012019). IOP Publishing. DOI: 10.1088/1757-899X/884/1/012019. **(Indexed by Scopus)**

3. **Jamaluddin, K.**, Alwi, S. W., Hamzah, K., Abd Manan, Z., & Klemeš, J. J. (2019, June). A new framework for optimisation of Pressurised Water Reactor design as a trigeneration system. In *IOP Conference Series: Materials Science and Engineering* (Vol. 555, No. 1, p. 012005). IOP Publishing. DOI: 10.1088/1757-899X/555/1/012005. **(Indexed by Scopus)**

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1. Sharifah Rafidah Wan Alwi, Zainuddin Abd Manan, Khaidzir Hamzah, Liew Peng Yen, **Khairulnadzmi Jamaluddin**, Trigensite – A Software to Optimise Industrial Energy Across Multiple Site, Filing number: LY2019008963. **(Status: Granted)**
2. Sharifah Rafidah Wan Alwi, Zainuddin Abd Manan, Khaidzir Hamzah, **Khairulnadzmi Jamaluddin**, Tri-generation System Integrated With Thermal Storages and Industrial Plants, Application number: PI2020000854. **(Status: Awaiting Substansive Examination)**

Awards

1. Trigensite – A Software to Optimise Industrial Energy Across Multiple Site. 21st Industrial Art and Technology Exhibition (INATEX 2019). 30 Sept – 02 Oct 2019, Dewan Sultan Iskandar UTM, Skudai, Malaysia. **(Bronze Medal)**
2. Trigensite – A Software to Optimise Industrial Energy Across Multiple Site. The 19th International Expo on Inventions and Innovations (MTE 2020). 20 – 22 Feb 2020, PWTC, Kuala Lumpur, Malaysia. **(Gold Medal, The Best Category for Electricity and International Award of Merit (Republic of Croatia))**