OPTIMAL PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLER FOR AUTOMATIC VOLTAGE REGULATOR SYSTEM USING PARTICLE SWARM OPTIMIZATION ALGORITHM

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Specially dedicated to my beloved parents, wife, daughter,
brothers and sisters who encouraged, guided and inspired me
throughout my journey of education

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ABSTRACT

Voltage control is very important in electrical power system to ensure safe operating condition for equipment. The purpose of this project is to investigate the application of Particle Swarm Optimization (PSO) algorithm in fine-tuning the Proportional, Integral and Derivative (PID) parameter of PID controller for Power System's Automatic Voltage Regulator (AVR). AVR system is employed widely in exciter control system, mainly used in areas where the supply voltage is not stable and fluctuation of load occurs. The generator excitation system maintains generator terminal voltage and controls the reactive power flow using an AVR. A practical high order and linearized Power System AVR is modelled with four main components namely Amplifier, Exciter, Generator and Sensor. The proposed PSO algorithm had superior computational efficiency, stable convergence characteristic, and easy implementation. Fast tuning of optimum PID controller parameters yields high quality solution. To estimate the performance of optimal PID controller, a fitness function that use frequency-domain and time-domain were defined. A conventional technique, Ziegler-Nichols (ZN) tuning technique was used as the comparison for proposed algorithm. Simulation result shows that PID tuned by ZN technique improved the transient response of AVR but due to high order of AVR system, it is difficult to achieve optimal PID of AVR using ZN technique which is achievable using PSO algorithm.

ABSTRAK

Kawalan voltan dalam system elektrik kuasa adalah sangat penting untuk memastikan peralatan beroperasi dalam keadaan selamat. Tujuan projek ini adalah untuk menyiasat aplikasi algoritma Pengoptimum Kumpulan Zarah (PSO) dalam penalaan parameter pengawal berkadar, kamiran dan pembeza (PID) untuk pengaturan voltan automatik (AVR) sistem kuasa. Sistem AVR digunakan secara meluas dalam sistem kawalan penguja, terutamanya digunakan dalam kawasan di mana voltan bekalan adalah tidak stabil dan turun naik beban sentiasa berlaku. Sistem pengujaan penjana mengekalkan penjanaan voltan terminal dan mengawal aliran kuasa reaktif menggunakan AVR. Satu sistem AVR yang praktikal, aturan tinggi dan lelurus untuk sistem kuasa dimodelkan dengan empat komponen utama iaitu pembesar, penguja, penjana dan pengesan. Algoritma PSO yang dicadangkan mempunyai kecekapan unggul dalam pengiraan, ciri penumpuan stabil, dan pelaksanaan yang mudah. Penalaan cepat dan optima pengawal PID menghasilkan penyelesaian yang berkualiti tinggi. Untuk menganggarkan prestasi pengawal PID yang optimum, fungsi kecergasan yang menggunakan domain frekuensi dan masa telah digunakan. Satu teknik penalaan konvensional, Ziegler- Nichols (Z-N) telah digunakan sebagai perbandingan untuk algoritma yang dicadangkan. Hasil simulasi menunjukkan bahawa PID yang ditala dengan teknik Z-N mempunyai sambutan fana AVR yang baik, tetapi disebabkan aturan sistem yang tinggi, ia adalah sukar untuk mencapai PID-AVR yang optima menggunakan teknik Z-N, yang mana dicapai menggunakan algoritma PSO.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Power equipment is design to work in designated operating system voltage and allowed certain level of power frequency overvoltage in a fraction of seconds. Power utilities provider main objective is to ensure a quality and reliable voltage and frequency profile is provided to customer. There are many devices used to ensure the objective is achieved, which is installed at Generation, Transmission, Sub-station and Distribution site. Automatic Voltage Regulator (AVR) is a device used at Generation to control generator excitation level to ensure stability of voltage generated before supplied to transmission system. In this project, in depth AVR model and methods to enhance generator's terminal voltage is discussed.

AVR system is used in power generation site to ensure voltage stability at the generator terminal hence providing acceptable voltage level to step up transformers before transmitted and distributed to end customer. AVR system without any controller will provide slow responses and may cause instability to generator excitation system. Power engineers must provide proper control of AVR system to ensure generators operated at safe and stable conditions for normal operation and fast response under any types of disturbance. This project is to study the capability of PID controller and the methods used to tune the PID parameter for AVR system.

REFERENCES

1. M. Baha Bayram., H. Ibrahim Bulbul., Celal Can., and Ramazan Bayindir (2013). MATLAB/GUI Based Basic Design Principles of PID Controller in AVR. *4th International Conference on Power Engineering, Energy and Electrical Drives*. 13-17 May 2013. Istanbul, Turkey, 1017-1022

2. Sahu, B.K., Mohanty, P.K., Panda, S., Kar, S.K., and Mishra, N (2012). Design and comparative performance analysis of PID controlled Automatic Voltage Regulator tuned by many optimizing liaisons. *2012 International Conference on Advances in Power Conversion and Energy Technologies (APCET)*. 02-04 August 2012. Andhra Pradesh, India, 1-6

3. Mohd Sazli Saad., Hishamuddin Jamaluddin., and Intan Zaurah (2012). Implementation of PID Controller Tuning Using Differential Evolution and Genetic Algorithms. *International Journal of Innovative Computing, Information and Control.* 8 (11), 7761-7779.

4. Anil Kumar., and Rajeev Gupta (2013). Compare the results of Tuning of PID controller by using PSO and GA Technique for AVR system. *International Journal of Advanced Research in Computer Engineering & Technology*. 2 (6), 2130-2138

5. A.Soundarrajan., S. Sumathi., and C. Sundar (2010). Particle Swarm Optimization Based LFC and AVR of Autonomous Power Generating System. *IAENG International Journal of Computer Science*. 37(1), IJCS_37_1_07

6. Zwe-Lee Gaing (2004). A Particle Swarm Optimization Approach for Optimum Design of PID Controller in AVR System. *IEEE Transactions on Energy Conversion.*19(2), 384-391

7. Hadi Saadat (1999). *Power System Analysis* (1st ed). New York: McGraw-Hill

8. J. Femmy Nirmal, and D. Jeraldin Auxillia (2013). Adaptive PSO based Tuning of PID Controller for an Automatic Voltage Regulator System. *International Conference on Circuits, Power and Computing Technologies*. 20-21 Mar 2013. Nagercoil, India, 661-666

9. You-bo Wang., Xin Peng., and Ben-Zheng Wei (2008). A New Particle Swarm Optimization Based Auto-tuning of PID Controller. *International Conference on Machine Learning and Cybernetics*. 12-15 July 2008. Kunming, China, 1818 – 1823

10. Mohammad Sadegh Rahimian., and Kaamran Raahemifar (2011). Optimal PID controller design for AVR system using Particle Swarm Optimization algorithm. *24th Canadian Conference on Electrical and Computer Engineering (CCECE).* 8-11 May 2011. Niagara Falls, ON, Canada, 337-340

11. James Kennedy., and Russell Eberhart (1995). Particle Swarm Optimization. *Proceeding on IEEE International Conference on Neural Networks, 1995*. 27 Nov - 1 Dec. Perth, WA, 1942 – 1948

12. Karimi-Ghartemani, M., Zamani, M., Sadati, N., and Parniani, M. (2007). An Optimal Fractional Order Controller for an AVR System Using Particle Swarm Optimization Algorithm. *2007 Large Engineering Systems Conference on Power Engineering*. 10-12 Oct 2007. 244-249

13. Manuaba, I., Abdillah, M., Soeprijanto, A, and Hery, M.P (2011). Coordination of PID based power system stabilizer and AVR using combination bacterial foraging technique – Particle Swarm Optimization. *2011 4th International Conference on Modeling, Simulation and Applied Optimization (ICMSAO).* 19-21 April 2011. UTM Kuala Lumpur, 1-7

14. Nazli Madinehi., Kiarash Shaloudegi., Mehrdad Abedi., and Hossein Askarian Abyaneh (2011). Optimum design of PID controller in AVR system using

intelligent methods. *PowerTech, 2011 IEEE Trondheim.* 19-23 June 2011. Trondheim, 1-6

15. Gao, C., and Redfern, M.A (2010). A review of voltage control techniques of networks with distributed generations using On-Load Tap Changer transformers. *Universities Power Engineering Conference (UPEC), 2010 45th International*. 31 Aug – 3 Sept 2010.

16. Naeim Farouk., and Tian Bingqi (2012). Application of self-tuning Fuzzy PID Controller on the AVR System. *Proceedings of 2012 IEEE International Conference on Mechatronics and Automation.* 5-8 August 2012. Chengdu, China, 2510-2514.

17. Sahu, B.K., Mohanty, P.K., PANDA, S., and Mishra, N (2012). Robust Analysis and Design of PID controlled AVR system using Pattern Search algorithm. *2012 IEEE International Conference on Power Electronics, Drives and Energy Systems.* 16-19 December 2012. Bengaluru, India 1-6

18. Ali Darvish Falehi., Mehrdad Rostami., and Hassan Mehrjardi (2011). Transient Stability Analysis of Power System by Coordinated PSS-AVR Design Based on PSO Technique. Scientific Research Engineering. 2011(3), 478-484

19. Mohammadi, S.M.A., Gharaveisi, A.A., Mashinchi, M., Rafiei, S.M.R (2009). New evolutionary methods for optimal design of PID controllers for AVR system. *PowerTech, 2009 IEEE Bucharest.* 28 June – 2 July 2009. Bucharest, 1-8

20. J. Duncan Glover., and Mulukutla S. Sarma. *Power System Analysis and Design.* 3rd edition. United States of America. Brooks/Cole. 2001.

1.2 Voltage Control for Power System

Generation is the first station in power system that generates power before it is transmitted and distributed to customer. In every stage of power system network, there are numerous techniques and devices used to control voltage at a specific level. In transmission network, couple of FACTS devices is available for manipulating reactive power hence controlling voltage level. At distribution stage, capacitor bank is used to generate reactive power during high load to ensure no significant voltage drop at the terminal.

At power station, the voltage level for generator's terminal output is controlled by changing excitation level of the generator. Changing excitation level will change reactive power for generator hence will improve voltage stability of generator. Detail theory for the relationship of reactive power and voltage will be discussed in Chapter 3.

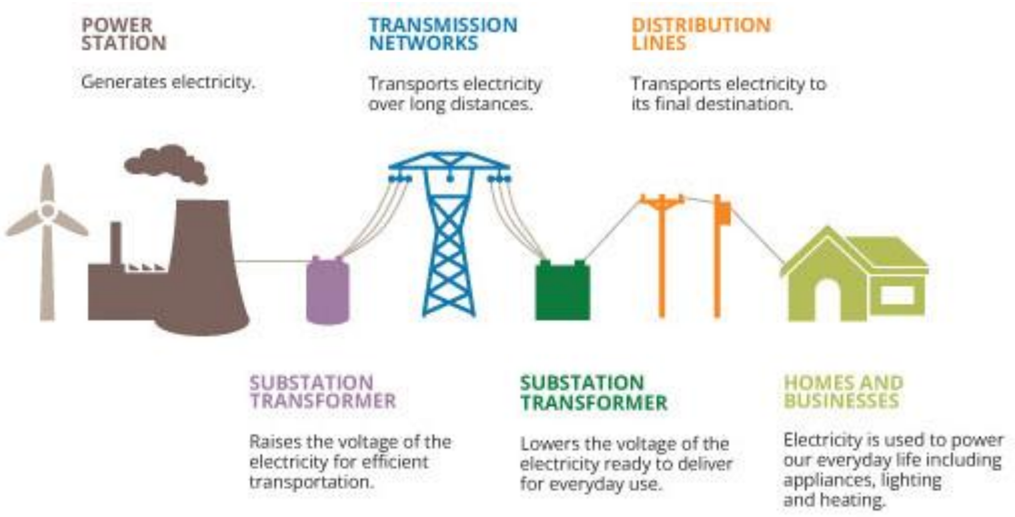

Figure 1.1: Typical Power System Network

1.2.1 Voltage Control for Generator

Figure 1.2 shows the overview of the AVR in generator system. AVR functions when there are voltage errors occurred between terminal voltage and reference voltage as a result of any disturbance in power system network. A transformer is used to reduce the voltage level from generator terminal to suite AVR voltage level. Based on the voltage error, the signal is amplified to exciter then excitation level will changes accordingly to reduce the error. The process is run continuously so that any voltage drop or increase happen AVR able to fix immediately to avoid generator system drop out from power system network.

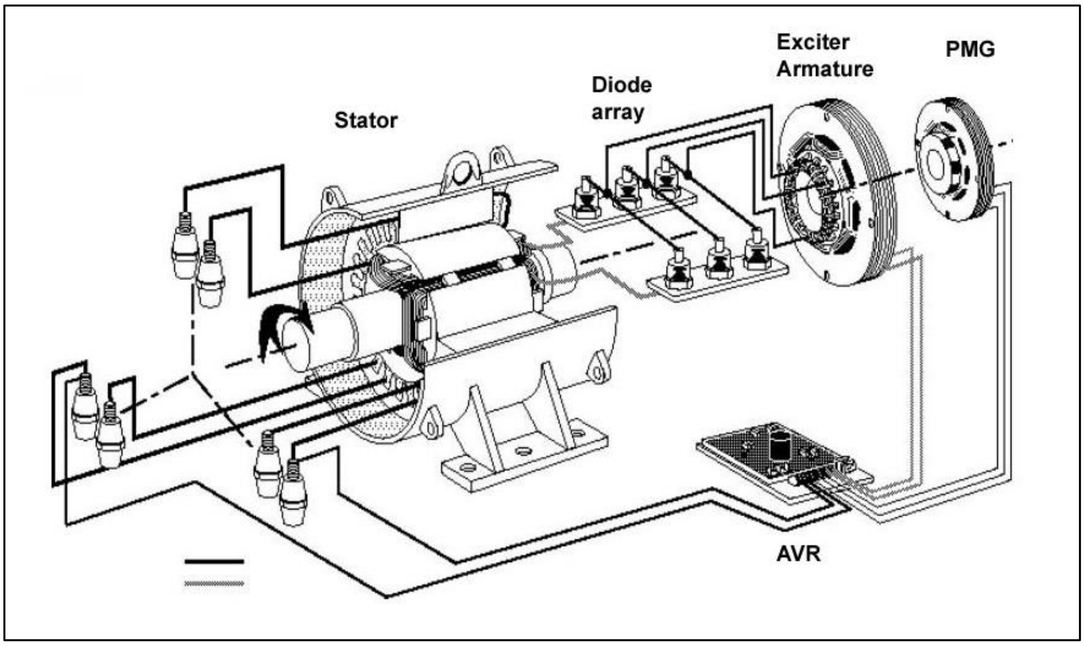

Figure 1.2: AVR system for Power Generator

1.2.2 Controller Requirement for AVR

The AVR used in generator system required a controller in order to provide response to voltage fluctuation. An AVR without optimal control may cause huge voltage error and slow responses to voltage fluctuation. A simple controller, cheap and easy implementation, PID is widely used in AVR control system. Although PID controller is simple, proper tuning of the PID parameter is critical in order to minimize voltage error as well as improving AVR response. The actual generator AVR system is deal with high order and nonlinearities thus tuning of optimal PID parameter is almost impossible using conventional method. Advance, modern algorithm is required in tuning of PID for AVR system.

Figure 1.3: Sample of AVR from ABB

1.3 Problem Statement

The generator terminal voltage is oscillating when it is subjected to disturbances, such as fault and sudden load change, thus required a robust controller to improve the stability of terminal voltage. There are many conventional PID tuning methods to improve transient response of AVR system, but the techniques that will be discussed having some demerit such as non-optimal solution due to high order system and nonlinearities.

1.4 Objectives

The main motivation in driving this project is to tune optimal PID controller using modern heuristic algorithm to control AVR system which is called Particle

Swarm Optimization (PSO) algorithm. To achieve this objective, this project is divided into five sections:

i) Modelling of an AVR system, which is adopted from literature review
ii) Review of multiple PID tuning technique including PSO algorithm, usage in MATLAB based code
iii) Write PSO algorithm and integration with MATLAB SIMULINK
iv) Apply several fitness functions formulas, and propose a suitable fitness function of AVR system for transient response performance evaluation
v) Comparing PSO based PID performance over conventional methods based on overshoot percentage, steady state error as well as the settling time.

At the end of this project, findings, limitation and key learning will be discussed for future works.

1.5 Scope

Scope of this project is to adopt practical high order, linearized AVR system model from literature review. A conventional PID tuning method, Ziegler-Nichols is used as baseline comparison of AVR response. PSO algorithm will be used to improve AVR transient response and multiple fitness function is used to suite proposed AVR system to obtain optimal PID parameter. For purpose of simulation, PSO algorithm is written in MATLAB .m file and SIMULINK will be utilized to represent AVR transfer function and visualize the AVR output responses.

1.6 Project Report Organization

This project report will be divided into six chapters. This chapter discusses the problem statement, project objectives and the scope covered. Chapter 2 discusses the literature review methods of PID controller tuning technique that was done by other researchers. Chapter 3 reviewed in detail theory of AVR system and the modelling part for control purpose. Chapter 4 presented the methodology used to achieve this project objectives and Chapter 5 is about the results obtained and discussion. In Chapter 6, conclusion and recommendation are briefly discussed.

LIFE CYCLE ASSESSMENT OF GLOBAL WARMING POTENTIAL IN PRECAST BUILDING COMPONENT

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Special for

My Beloved Parents

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ABSTRACT

Concern regarding sustainability in the construction industry has grown and many researches were conducted to improve understanding on the matter. New technologies and methodologies, including Industrialised Building System (IBS) emerge as an alternative to conventional in-situ methods of construction. Nonetheless IBS technology is not comprehensively adopted in Malaysia, which is most likely caused by lack of awareness and understanding on its beneficial impact to the environment. This study investigates the Global Warming Potential of IBS, focusing on precast concrete production of a residential building through Life Cycle Assessment (LCA). Investigation was focused on the production of wall panel or façade for a multi-storey building in a precast factory located in Pekan Nenas, Johor. Moreover, the production process and quality assurance and control for precast concrete were also identified. The boundary of this research is measuring the direct and indirect energy demand and carbon emission of precast concrete from *cradle-to-gate* where data obtained was analysed using OpenLCA software. Direct data was collected from the precast factory that comprises on the information regarding on precast concrete production process. While indirect data which includes embodied energy and carbon for raw materials production process and conversion factors for energy and carbon emission were collected from previous researches. This study found that production of mould consumed the highest energy by 55% while cement production emit highest amount CO_2 by 92%. Embodied energy and carbon for this project are 11,790,968 MJ and 19,262,915 kg respectively while posing GWP of 4.4281 kg CO_2,eq ($x10^{10}$).

ABSTRAK

Penekanan mengenai aspek kelestarian dalam industri pembinaan telah berkembang pesat dan pelbagai kajian telah dijalankan bagi meningkatkan pemahaman mengenai perkara tersebut. Teknologi dan metodologi baru, termasuk Sistem Binaan Berindustri (IBS) muncul sebagai alternatif kepada kaedah konvensional pembinaan. Namun, teknologi IBS tidak diaplikasikan dengan komprehensif di Malaysia, berkemungkinan disebabkan oleh kurangnya kesedaran dan pemahaman mengenai manfaatnya kepada alam sekitar. Kajian ini mengkaji Potensi Pemanasan Global, memfokuskan kepada pengeluaran konkrit pratuang bagi sebuah bangunan kediaman melalui Penilaian Kitaran Hayat (LCA). Kajian ini tertumpu kepada pengeluaran panel dinding atau permukaan hadapan bangunan untuk bangunan berbilang tingkat di sebuah kilang pratuang terletak di Pekan Nenas, Johor. Selain itu, proses pengeluaran dan jaminan kualiti dan kawalan untuk konkrit pratuang juga telah dikenal pasti. Sempadan kajian ini adalah mengukur permintaan tenaga dan pelepasan karbon langsung dan tidak langsung daripada konkrit pratuang dari "*cradle-to-gate*" di mana data yang diperolehi akan dianalisis dengan menggunakan perisian OpenLCA. Pertama, data dikumpulkan langsung dari kilang pratuang yang terdiri daripada maklumat yang berkaitan pada proses pengeluaran konkrit pratuang. Kedua adalah pengumpulan data tidak langsung yang merangkumi tenaga dan karbon untuk process pengeluaran bahan-bahan mentah dan penukaran faktor untuk tenaga dan karbon pelepasan dikumpulkan daripada kajian terdahulu. Kajian ini mendapati bahawa pengeluaran acuan "mould" menggunakan tenaga yang paling tinggi sebanyak 55% manakala pengeluaran simen mengeluarkan jumlah tertinggi CO_2 sebanyak 92%. Tenaga dan karbon termaktub untuk projek ini adalah 11,790,968 MJ dan 19,262,915 kg CO_2 manakala potensi GWP adalah 4,4281 kg CO_2,eqivalent ($x10^{10}$).

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INTRODUCTION

1.1 Introduction

The industrial sector is the second highest energy consumer next to transportation sector. Construction is the largest and most fragmented industrial activities which accounts for an estimated 40% of all resources consumption and produces about 40% of all waste including greenhouse gas emissions. For example, the production of a standard reinforced concrete beam was estimated to consume 109 MJ of energy and emit 79.4kg of CO_2 for every tonne of concrete produced.

Many scholars highlighted the difficulties in estimating accurate environmental impact in their studies. Generally, the most common key to estimation of environmental impact is through measuring the production of greenhouse gases (GHG) emission. GHG emission includes carbon dioxide, methane, nitrous oxides, and etc. which are commonly converted to CO_2 equivalent to measure their respective global warming potential, in comparison to carbon dioxide.

Global warming potential (GWP) is a measure of heat being trapped in the atmosphere due to greenhouse gases. There are various greenhouse gases emitted to the atmosphere and each has different potential of absorbing heat. Hence, as carbon dioxide is the most common and vastly produced greenhouse gas, the potential of heat absorption of other gases are converted to carbon dioxide equivalent ($CO_{2,}$eq) by the scholars. Greenhouse gases are the products of human activities that include the combustion of fuels for transportation, factories machineries, and electricity generation. The construction industry contributes a lot of greenhouse gases as it require high amount of energy to operate. However, comprehensive measures were taken by government bodies to retain its impact at a minimum level.

Industrialised Building System (IBS) is one of the many solutions to sustainability. Traditional construction methods will requires the materials to be cast on site where waste production is inevitable regardless of proper planning. Concrete is the most common materials for building construction due to its high strength which however requires a lot of formwork for casting. The most common formwork for concrete is wood where high demand of it will lead to serious issue of deforestation. This method is labour intensive, involving formwork fabrication, steel bending, and concreting. It requires many wet trades on-site, such as skill carpenters, plasterers, and brick workers.[1] This process can be hampered by quality issues, unfavourable site conditions, a skilled labour shortage, and bad weather conditions. On the other hand, IBS uses steel as formwork and can be reuse for a longer period of time. Although requires electricity to operate, the production of concrete using IBS is more energy efficient compared to the traditional method.

1.2 Problem Statement

Construction industry plays an important role in economic growth through contributions in the socio-economic development as well as in developing complementary industries. However, its high demand on building materials and energy poses a detrimental effect on the environment. Industrialised Building System (IBS) is one of the emerging technologies that act as a solution for a more sustainable construction development method. Other than its benefits toward faster construction, fire protection, and productivity improvement, IBS is also known to have low energy consumption and carbon emissions.

Previous research on comparison of carbon emission between two construction methods which are conventionally reinforced concrete and precast concrete panels, revealed a total emissions reduction of 26.27% through the selection of a precast wall panel system.[2] According to Omar et al. (2013), other research that highlight the benefits of prefabricated building system was conducted by Monahan and Powel (2011) whom assessed the embodied energy and emission of a construction low energy building using prefabricated panellised timber framed system. Compared with more traditional methods of construction, this system has resulted 34% reduction in embodied carbon. Similarly he also mentioned a study founding that a steel-framed prefabricated system resulted in reduced material consumption of up to 78% compared to conventional concrete construction.[3] on the other hand, previously conducted research studies to quantify the carbon emissions of precast concrete columns but failed to address the influence of indirect emissions which subsequently underestimated the results for the LCA. However none of these researches estimated the embodied energy of the system.

Carbon dioxide (CO_2) is a significant greenhouse gas and the emissions are inextricably linked to energy consumption when energy is produced through the combustion of fuels.[4] Hence, this research will study the significant influence of precast concrete in terms of both embodied energy and carbon. Moreover, there are various precast concrete systems being applied in the industry such as skeletal and load bearing system. In addition, a building construction also consist of many components; beam, column, slab, and etc. The emission of carbon and energy consumed by each system is not yet critically identified.

Research on the environmental impact of IBS system in Malaysia is considered limited which consequently causes lack of data to promote its benefits to the industry. Therefore, Life Cycle Assessment (LCA) methodology is chosen to quantitatively convey its benefits. Other than application of IBS in Malaysian construction industry, Green Building is another approach to promote sustainable development. However, the green certification system such as Green Building Index (GBI) and Leadership in Energy and Environmental Design (LEED) rating systems were criticized by researches for not including life cycle perspective to its assessment. For instance, a research argued that the LEED system "does not provide a consistent, organized structure for achievement of environmental goals" from a life-cycle perspective.[5] They recommended incorporating life-cycle assessment (LCA) for further development of the LEED system. LCA includes the entire life cycle of products; extraction of raw materials, manufacturing, transportation and distribution, operational, and demolition. This research aim is to quantify the GWP through embodied energy and carbon emission of precast concrete system using the LCA methodologies.

1.3 Objectives

The aim of this study is to estimate the Global Warming Potential of precast products which was achieved by following the objectives of the study;

i. To identify the manufacturing process involved in precast system
ii. To investigate the energy consumption and carbon emission in manufacturing process
iii. To calculate the energy and carbon life cycle inventory of precast system
iv. To estimate the embodied energy and carbon and Global Warming Potential of precast products

1.4 Scope

This study was conducted on a precast concrete factory located in Pekan Nenas, Johor. The boundary of life cycle assessment is measuring the direct energy consumption and carbon emission from extraction of raw materials to the production of precast concrete wall facade of residential building (*cradle-to-gate*). OpenLCA which is one of the many LCA-based tools will be utilised to analyse the data. Information sources for materials and energy consumption data will be obtained from the precast concrete factory, and references from previous literatures.

REFERENCES

[1] E. C. W. Lou and K. A. M. Kamar, Ph.D. (2012). Industrialized Building Systems: Strategic Outlookfor Manufactured Construction in Malaysia

[2] Wan Mohd Sabki Wan Omar, Jeung-Hwan Doh, Kriengsak Panuwatwanich, Dane MillerGriffith (2013). *Assessment of the embodied carbon in precast concrete wall panelsusing a hybrid life cycle assessment approach in Malaysia.*

[3] Wu Peng and Low Sui Pheng. (2011). *Managing the Embodied Carbon of Precast Concrete Columns.*

[4] Gillian F. Menzies (2011). *Embodied Energy Consideration for Existing Building 13.*

[5] Scheuer, C. W.; Keoleian, G. A. (2002). *Evaluation of LEED Using Life Cycle Assessment Methods.*

[6] IPCC (1996) Climate Change 1995: The Science of Climate Change. Intergovernmental Panel on Climate Change; J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, eds.; Cambridge University Press. Cambridge, U.K.

[7] Richard Haynes (2010). *Embodied Energy Calculations within Life Cycle Analysis of Residential Buildings*

[8] M.N.A. Azman, M.S.S. Ahamad and W.M.A. Wan Hussin. *Comparative Study on Prefabrication Construction Process*

[9] Zainal Abidin Hashim (2010). *House Price and Affordability in Housing in Malaysia.*Universiti Kebangsaan Malaysia, Malaysia.

[10] Mohamed Nor Azhari Azman, Mohd Sanusi S. Ahamad, and Nur Diyana Hilmi (2012). *The Perspective View of Malaysian Industrialized Building System (IBS) Under IBS Precast Manufacturing.* The 4th International Engineering Conference –Towards engineering of 21st century.

[11] Maria Isabel Acuna (2000). *Reducing Time in the Construction of High Rise Buildings.* Massachusetts Institute of Technology, U.S.

[12] CIDB. *Industrialized Building System (IBS) Roadmap 2003-2010 Construction Industry Development Board (CIDB), Kuala Lumpur, 2003*.

[13] CONQUAS 21 Enhancement Series Good Industry Practices Guide Book

[14] Leslie Struble and Jonathan Godfrey (2004). *How Sustainable is Concrete.* University of Illinois at Urbana-Champaign, USA. International Workshop on Sustainable Development and Concrete Technology.

[15] http://www.cima.com.my/cima/mainpage.php?menu=process

[16] Amanjeet Singh, George Berghorn, Satish Joshi, and Matt Syal (2011). *Review of Life-Cycle Assessment Applications in Building Construction*

[17] European Environmental Agency, Europe’s environment. The second assessment. Amsterdam, Elsevier Science, 1998.

[18] Bullard C W, Penner P S and Pilati D A (1978), Net energy analysis - handbook for combining process and input-output analysis, Resources and Energy 1, 267-313.

[19] Nisbet, M., Van Geem, M. G., Gajda, J., and Marceau, M. (2000). *Environmental life cycle inventory of portland cement concrete*. Portland Cement Association, Skokie, IL.

[20] Prof. Geoff Hammond & Craig Jones (2008). *Inventory of Carbon & Energy (ICE).* University of Bath, U.K.

[21] World Steel Association (2011). *Life Cycle Assessment Methodology Report.*

[22] https://www.ipcc.ch/pdf/special-reports/sroc/Tables/t0305.pdf

[23] United States Environmental Protection Agency (2008). *Climate Leaders Greenhouse Gas Inventory Protocol Core Module Guidance; Direct Emissions from Mobile Combustion Sources.*

[24] Professor Alan McKinnon and Dr. Maja Piecyk (2010). *Measuring and Managing CO_2 Emissions of European Chemical Transport.* Heriot-Watt University, UK.

[25] ISO 14040:2006. *Environmental management - Life cycle assessment - Principles and framework*

[26] Mark Goedkoop, Reinout Heijungs, Mark Huijbregts, An De Schryver, Jaap Struijs, and Rosalie van Zelm (2009). *ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level First edition Report I: Characterisation.*

[27] Nik Zafri Abdul Majid (2000). *The Influence of Aggregate Properties on Strength of Concrete.*

[28] Louise K. Turner and Frank G. Collins (2013). *Carbon dioxide equivalent (CO2-e) emissions: A comparison between geopolymer and OPC cement concrete*. Construction and Building Materials 43 (2013) 125–130

[29] Performance Analysis of Electric-Rubber Tired Gantries from a Green Container Terminal Perspective Yi-Chih YANG a, Wei-Min CHANG (2013)

[30] L. Romo, O. Solis, J. Matthews, D. Qin. Fuel Saving Flywheel Technology For Rubber Tired Gantry Cranes In World Ports Reducing Fuel Consumption Through Use Of Flywheel Energy Storage System (2008)

[31] Don Hofstrand. Liquid Fuel Measurements and Conversions. (2008)

[32] Norihiro Itsubo and Atsushi Inaba (2002). *Assessment of Environmental Impact of Manufacturing Steel Considering Physical Damage to Human Health.* National Institute for Advanced Industrial Science and Technology, Japan.