FREQUENCY TRANSIENT CONTROL BY USING STATE FEEDBACK H-INFINITY FILTER FOR POWER SYSTEM WITH SINGLE GENERATOR

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in partial fulfilment of the requirements for the degree of
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2021

DECLARATION

I declare that this thesis entitled "FREQUENCY TRANSIENT CONTROL BY USING STATE FEEDBACK H-INFINITY FILTER FOR POWER SYSTEM WITH SINGLE GENERATOR is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 22/6/2021

APPROVAL

I hereby declare that I have checked this report entitled “Frequency Transient Control by using State Feedback H-Infinity Filter for Power System with Single Generator” and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : MOHD SAIFUZAM BIN JAMRI

Date : 22/6/2021

DEDICATIONS

This report is specially dedicated to myself, mom and dad as well as the lecturers who will be evaluating.

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In the name of Allah, The Beneficent, The Merciful. First and the foremost praise is to Allah, The Almighty, on whom ultimately we depend on for guidance. Secondly, I am grateful to all my family members especially my parents, Abd Manaf bin Jusoh and Normala binti Ab Aziz who have been the backbone of my journey through out this project and also my study in UTeM. My sincere appreciation goes to Mr. Mohd Saifuzam bin Jamri as the project supervisor, for his unending support and guidance through out this project. This project would not have been the same as the one presented here without his continuous encouragement and involvement.

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ABSTRACT

The control strategy and design for a power system is highly crucial in order to produce a stable output. Unstable output frequency can have major effect on the frequency grid and may lead to equipment and infrastructure damage. Tenaga Nasional Berhad (TNB), as the only utility company that handle the electrical power grid and obeys the regulation of The Grid Code [1] in Peninsular Malaysia have set the frequency of power system grid shall be nominally 50 Hz and be controlled within the limits of 49.5 Hz or the tolerance of 1%. This report will present how the frequency transient is controlled by using H-infinity method. In this study, the dynamical frequency quality of the generator will be analysed and controlled by the proposed algorithm and the simulation will be performed by using MATLAB/Simulink. A robust estimation method is employed in order to control the influence of outliers and other disturbance. The experimental results will show how the H-infinity controller differs and has multiple advantages as the secondary controller compared to primary controller.

ABSTRAK

Strategi dan reka bentuk kawalan untuk sistem kuasa sangat penting untuk menghasilkan output yang stabil. Frekuensi output yang tidak stabil boleh memberi kesan besar pada frekuensi grid dan boleh mengakibatkan kerosakan peralatan dan infrastruktur. Tenaga Nasional Berhad (TNB), sebagai satu-satunya syarikat utiliti yang mengendalikan grid kuasa elektrik dan mematuhi peraturan The Grid Code [1] di Semenanjung Malaysia telah menetapkan frekuensi grid sistem kuasa mesti kekal dalam 50 Hz dan dikawal dalam lingkungan 49.5 Hz atau dengan toleransi 1% . Laporan ini akan membentangkan bagaimana frekuensi sementara dikendalikan oleh kaedah H-infinity. Dalam kajian ini, kualiti dinamik frekuensi penjana kuasa akan dianalisis dan dikendalikan oleh algoritma yang dicadangkan dan simulasi akan dilakukan dengan menggunakan MATLAB / Simulink. Kaedah anggaran yang kuat digunakan untuk mengawal pengaruh outlier dan gangguan lain. Hasil eksperimen akan menunjukkan bagaimana pengawal H-infinity berbeza dan mempunyai banyak kelebihan sebagai pengawalan kedua berbanding penwalan pertama.

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1. CHAPTER 1

INTRODUCTION

1.1 Overview

Chapter 1 summarise the work of this Final Year Project entitled "Frequency Transient Control by using State Feedback H Infinty Filter for Power System with Single Generator". It is a mandatory requirement for final year students of Faculty of Electrical Engineering (FKE), Universiti Teknikal Malaysia Melaka (UTeM) to submit their final year project progress report. Each student is appointed with a supervisor that will guide them throughout the process of completing the project.

1.2 Introduction

The world nowadays has been focusing and investing mostly on electrical power generation as the main source of energy. Almost all appliances and machines whether at home or in industry use electricity as their main source of power to operate. One of the most important parameters in electrical power generation is the operating frequency which need to be controlled and monitored.

Basically, frequency control is a process to maintain the stability in a power system. In power systems, the frequency in the system can become lower when the load is higher than the power supply. In the same manner, the frequency in the device would increase when the load is lower than the power supply. Load disruption is a common issue, and as the load demand is dependent on customer use, this cannot be managed. Therefore, in order to operate the system in a stable state, the frequency at the generating stations must be constantly monitored and controlled.

If the frequency is not maintained within the appropriate range (±2.5Hz), the turbines will be affected instantly and the power grid failure will result in damage to the safety and control equipment in the system. By operating the speed governor properly, the frequency can be controlled. As the variation in load demands is adjusted, this speed governor is needed to adapt. Here, the H-infinity method will be proposed as the approach to control the frequency.

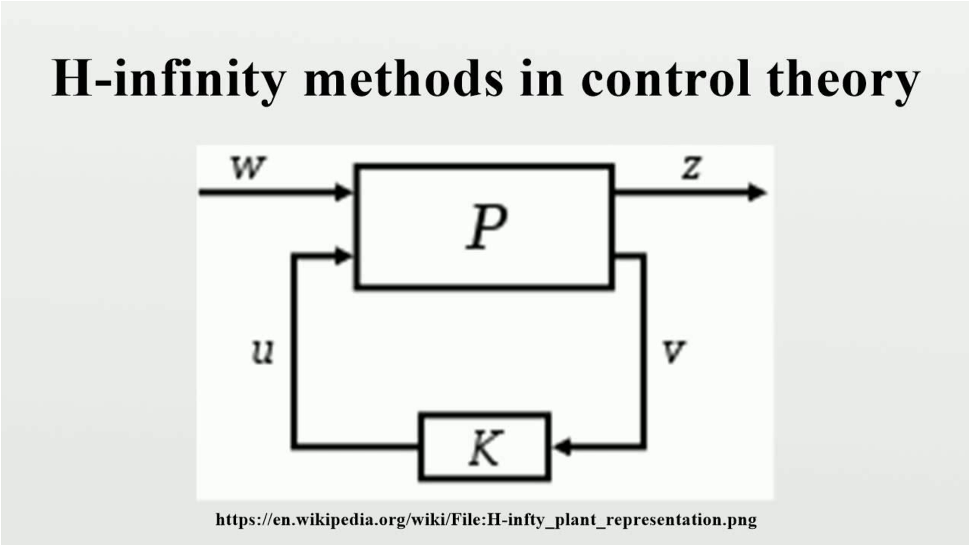

Figure 1-1: Block diagram of control theory

1.3 Motivation

The study of this project mainly motivated by the advantages and importance of load frequency control in an isolated power system. As the load on the generator is increased, an increase in current flow causes the voltage to drop. The control system need to be able to sense and adjust to the changes in order to return the voltage to the desired level. In order to maintain the dynamical frequency quality so that the range of frequency regulation set by TNB would not differ with minor changes in the power generation or load changes in a power system and also to make sure that with the presence of large disturbance, the grid system of the power system with single generator will able to maintain its frequency. Furthermore, with load frequency control maintaining the frequency and voltage stability, the reliability of electric power supply can be ensured.

1.4 Problem Statement

With the development of power system generation, it is vital to stabilize and maintain the quality of frequency output following a relatively large disturbance and load changes arising from the loss of transmission elements or generation facilities. The capability of a power system controller to sustain the frequency despite the major changes will be focused here. So, a controller based on H-infinity method will be designed and simulated by using MATLAB/Simulink.

1.5 Objectives

1. To develop a mathematical model of isolated power system network, consist of one local generator.
2. To design and build up a model of H Infinity controller by using the MATLAB Simulink software.
3. To analyse the impact of frequency variation of the power system and the differences between a system with H-infinity control and without H-infinity control.

1.6 Scope

This report focuses on the following scope:

- Analysing the isolated power system with single generator.
- Create a mathematical model from the system above.
- Design a feedback controller by using H-infinity synthesis approach.
- Identify the capabilities of the controller to counter measure the error and disturbance in the control area of the power system.
- Use MATLAB/Simulink to verify the H-infinity controller

2. CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, some topics related to H-infinity controller designing which are state space, state feedback, and load frequency control will be discussed. Here, the topics will be enlightened on how they affect the system controlling design.

2.2 State space of a system

State space representation can be defined as a set of input, output and state variables in form of mathematical model for a certain system related by first-order differential equations. It also can be refers to a group of probabilistic graphical model that shows the probabilistic dependence among a measurement that is observed and also latent state variable. The term 'state space' was created during the time of control engineering in 1960s. It also can be describe with other terms which are hidden Markov models (HHMs) and latent process models (Rabiner, 1989). State space model is said to be able to provide a conceptual structure for analyzing theoritical and deterministic dynamical system that are deliberated and detected through a stochastic process. The conceptual structure of state space also has been proven successful to solve a wide range of dynamical system problems in engineering, computer science, economics and also statistic. Among the state space models, the most well studied is the Kalman filter which can specify an excellent algorithm for inferring linear Gaussian systems (Zhe Chen, Emery N. Brown, 2013).

In state space models, the main objective is to figure out the best estimation and measurement of the hidden state with the observed data given. This data may be derived as a repetitive form of Bayes's rule (Brown, 1998). X(t) is the state variables of the system and they can be varies and can be reformed depends on the measured input-output data, but are not recorded during the experiment is conducted. According to Bunpei, Junichi and Ryo (2007) in their article, state space in considered a key concept of system theory. If a suitable state space is selected to represent a system, it will be easier to manipulate and understand the property of a system. The variables in this model will be expressed as vectors in order to indefinite the value of inputs, outputs and states. Algebraic equations and differential equations can be written in matrix form if the dynamical system is considered time-invariant, linear and finite-dimensional (Katalin M. Hangos, R. Lakner & M. Gerzson, 2001). The state space method also can be defined by expressing algebra of general system theory, which allow this method to use Kronecker vector-matrix structures. The application of these structures is able to greatly enhance the research systems with modulation or without modulation due to its capacity (Vasilyev A.S, Ushakov A.V, 2015).

The entire state of a system can be represented by the internal state variables which are the smallest possible subset of a system variables (Nise, Norman S., 2010). Usually, the minimum number of state variables, n needed to represent a certain system and the order of the system's defining differential equation is the same, but not necessarily. Vlas Ignatenko, Anton Yudintsev and Danil Lyapunov (2019) in their research paper entitled "Application of State-Space Method for Control System Analysis" stated that mathematical modelling using state space method is an effective way to analyze the converter's dynamics. This method able to investigate the essential properties of the developed system by taking into account the expressed system by the normal differential equation of the n-th order in the time domain by using a set of state variables. In computational neuroscience, state space model can provides a strong and consolidated paradigm to analyze and build the signals in a dynamic fashion in both space and time no matter what the specific modality and applications.

2.3 State feedback of a system

State feedback also can be called pole placement is one of the methods applied in control engineering. This method engaged in the feedback control system theory in order to place a closed-loop poles of a system in one suggested locations in the s-plane. In a controllable system, placing poles is highly important since it corresponds directly to the eigenvalues of the system. According to M. Sami and Antonio Visiolli (2013) in their article, control system theory use state feedack method to place the closed-loop poles of a system in pre-determined locations in the s-plane. This method require the use of state vector in order to figure out the control action for specified system dynamics.

D. Inman stated in an encyclopedia that state feedback can be refered to compelling the feedback control law to be a linear combination consist of state variables only which are position and velocity. It also can be used to achieve the desired pole locations of the closed-loop functions T(S). There are several other possible control laws after the state feedback is chosen to be control force form. One of them is to use pole placement where the desired modal damping ratios and natural frequencies will be determined. Another method is called eigenstructure assignment which can be considered more radical compared to the previous. This method refers to a control law that targeting to create a closed-loop system with both eigenvalues (poles or natural frequencies and damping ratios) and eigenvectors (mode shapes) wanted.

Designing a controller that utilize state feedback, three main component need to be considered which are controllability, observability, and also the steps in considering the best control system. In order to determine the state variable feedback gain matrix, Ackerman's formula is one of the method that can be used. This method place the system poles at the desired locations. When the feedback does not have the full state, an observer need to be utilized. The design process of the observer is described and establishing the applicability of Ackermann's formula.

2.4 Load frequency control

Control techniques and protection are very important for a power system in order to operate with stability and load frequency control is one of them. Load frequency control is the most time-consuming control mechanism due to its mechanical parts. Eventhough load frequency control may ensure the the stabilization of power system, since the control algoritms of frequency stabilization send control signals in a split of seconds, load frequency control cannot bear those complicated data validation algorithms and this will make it more exposed to cyber attacks and outlier disturbances. Due to this circumstance, this field need more advanced research in order to protect them from the development of attack resilient frequency stabilization techniques (Athira, Nader,.2012).

The main goals for load frequency control applications are to stabilize the exact frequency and the desired power output. In a case of an interconnected power system, a small changes of load in any of the areas may resulting in the fluctuation of the frequencies at every area even the power in tie line. Load frequency control assimilates a suitable control system for an isolated power system with the purpose to bring back the frequencies of every area and the tie line powers back to original point as rated. (Niranjan, 2013). According to Rahul and Sanjeev (2012), the load frequency control is one of the function in Automatic Generation Control (AGC) and always been at the top topics in control problems research. Frequency deviation and nominal value of frequency deviation may affect the stability and reliability of a power system entirely. Two of the main problems in load frequency control and should always being monitered and investigated are frequency and tie-line power exchange.

Stabilizing the power interchanges and frequency with the neighbouring areas at the rated value are two main goals of the load frequency control in a power system. To ensure these goals are acheived, a control error signal called the Area Control Error (ACE) is measured. This signal represents the unbalanced in real power between the power generation and load. This signal also a linear combination of frequency deviations and net interchange.

2.5 Principle of H infinity controller

H-infinity filter is a controller that used a method by expressing the control problem as a mathematical optimization problem and then finds the controller that solves this optimization. This method is used to manufacture controllers to achieve stabilization with guaranteed performance [7] According to a recent research by Randeep Kaur and Jyoti Ohri, H-infinity filter is guaranteed for its excellent and robustness performance in controlling the pneumatic servo system [8]. They also stated that the outcome of a robust H-infinty control is a flawless control to linear systems to maintain in adverse operating conditions such as parameter shift, high disturbance environment, actuator saturation and model instability.

Due to these features, Ximena Celia M ´endez Cubillos and Luiz Carlos Gadelha de Souza in their research paper has proposed to use H-infinity method in attitude control system of rigid-flexible satellite [9]. As for a power system, a research paper by Arlene Davidson R and Dr. S. Ushakumari showed that H-Infinity method indeed a useful and successful method to be used for controlling load frequency of Automatic Generation Control of power system. To achieve decentralization, the relations between each control area and the rest of the system as well as the contracts existing in a deregulated system are viewed as input disruption signals. Dynamic responses for three contract cases of operation in a deregulated system using the H-infinity controller will be obtained [10].

3. CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter discussed the flow of project timeline, project work and also the methods that will be used along the process of the project.

3.2 Project flowchart

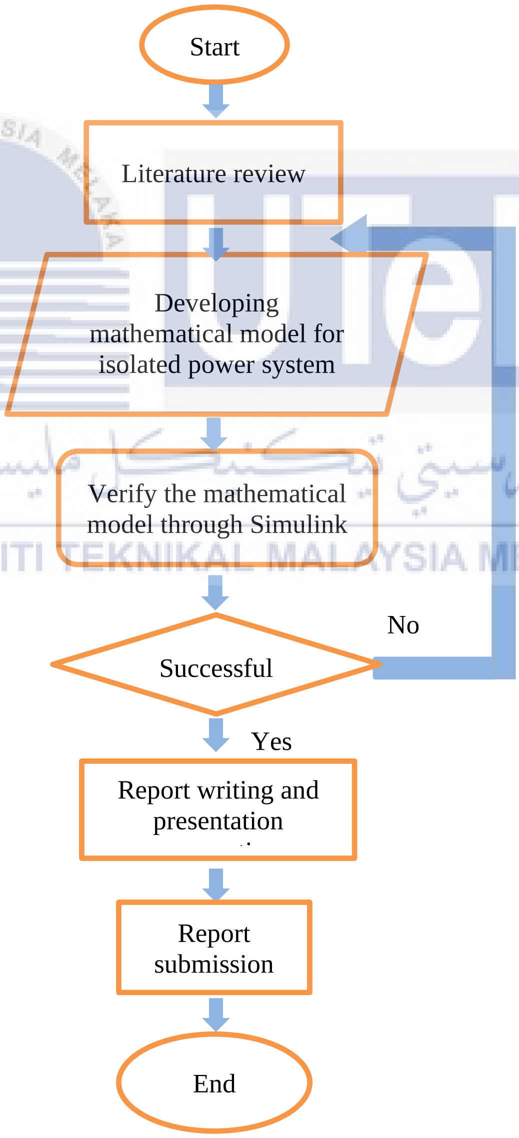

Figure 3-1: Project flowchart

1. Start :

Planning and drafting of the project started. The process to understand the overall purposes and objectives of the project as well as the outcome.

2. Literature review :

In this stage, the priorities and important areas on the topic will be gathered in order to provide necessary knowledge on the project based on previous article and work related to this field.

3. Developing mathematical model for isolated power system network :

The system block diagram will be analyzed and develop the mathematical model for each and every component in the system.

4. Verify the mathematical model through Simulink :

The mathematical model that have been developed will be verified by simulation in MATLAB/Simulink to come out with the result either the model is successful of not. If the result is not a success, then the mathematical model need to be reconstructed.

5. Report writing and presentation preparation :

Report on the project can be written based on the results and gain from the project. Then, presentation preparation including slide and presentation video can be prepared.

6. Report submission :

Submit report to supervisor and panels to be evaluated.

7. End :

Project ended.

3.3 Project Timeline

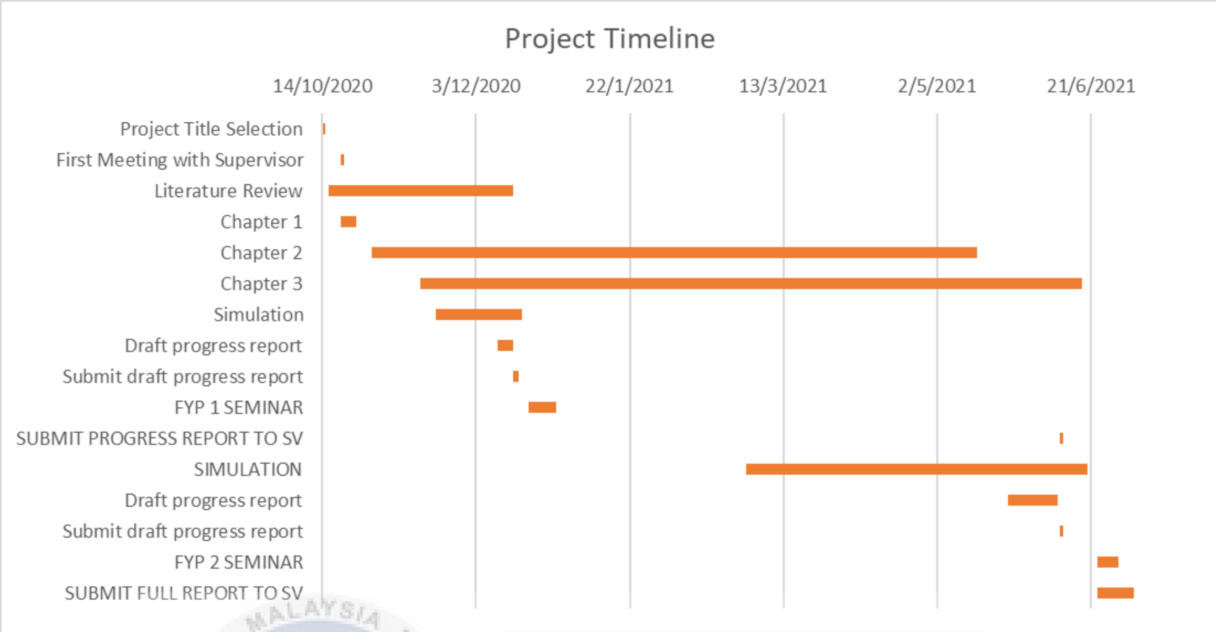

Figure 3-2: Project timeline

Figure 3-2 above is the timeline of this project.

1. 14th October 2020, this project entitled 'Frequency Transient Control by using State Feedback H-Infinity Filter for Power System with Single Generator' has been selected.
2. 20th October 2020, the first meeting with supervisor, Mr. Mohd Saifuzam bin Jamri was held at his office.
3. 16th October 2020, begun reviewing literature for this project to have insight on this tittle, previous study and scope of work.
4. 21st October 2020, chapter 1 started and wrote the introduction on this project. Reviewing again this chapter on Final Year Project 2 after some changes have been made on the objective and scope of work.
5. 30th October 2020, begun writing chapter 2 which is the literature review that has been conducted earlier. On Final Year Project 2, this chapter is updated again with new literature and information on this project.
6. 15th November 2020, project methodology started where project flowchart and methods is figured out. The methods is updated again during Final Year Project 2.
7. 20th November 2020, mathematical modelling was simulated and adjusted until the desired result is obtained.

8. 10th December 2020, drafting progress report for the current result and progress such as successful mathematical model and expected results for Final Year Project 2.
9. 15th December 2020, submit the draft progress report to supervisor to be checked on.
10. 20th December 2020, Final Year Project 1 seminar was held. The project progress along Final Year Project 1 was presented to panels.
11. 11th November 2020, progress report for Final Year Project 1 is submitted to supervisor and panels to be evaluated.
12. 1st March 2021, begun simulation on H-infinity controller designing by simulation for Final Year Project 2.
13. 25th May 2021, drafting progress report for the final result of the project.
14. 11th June 2021, submit the report draft to supervisor to be checked on.
15. 23rd June 2021, Final Year Project 2 seminar was held. The final results and outcome for the project was presented to panels to be evaluated.
16. 5th July 2021, submission of Final Year Project thesis to supervisor and panels to be evaluated.

3.4 Project Method

For this ongoing studies, two methods are to be used to achieve the desired result.

1. Mathematical modeling from the power system to get the state-space model for load frequency control. H-infinity controller will be designed based on the mathematical model.

2. Simulation by MATLAB/Simulink software.

3.4.1 Mathematical modelling for isolated power system network

In this method, two of the most common approach have been chosen which are transfer function method and states space representation. The transfer function is obtained from the states or components in the system while state space representation is constructed from the transfer function by using MATLAB simulation. In order to use this method, the system must be linearized first. Some variables need to be assumed and approximate properly to linearize the mathematical equations describing the system. The transfer functions are obtained from the following commponents.

3.4.1.1 Generator Model

Considering the problem of controlling the power output in a power system based on the scheduled frequency of the generator. The generator need to speed up or slow down depending on the changes of the load or other disturbance which may lead to changes in frequency. So the transfer function for the generator is obtained as followed.

By applying the swing equation of a synchronous machine,

$$\frac{2H}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e$$

where H is the inertia constant of the generator-turbine unit to describe the ratio of kinetic energy stored at the synchronous speed to the generator. It also can be defined as the Mega Joules of stored energy of the machine at the synchronous speed per MVA of the machine.

With speed expressed in per unit, without explicit per unit notation,

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e)$$

Taking Laplace transform into the equation,

$$\Delta\Omega(s) = \frac{1}{2\mathrm{Hs}}[\Delta P_m(s) - \Delta P_e(s)]$$