ELECTRIC VEHICLE YAW STABILITY USING FOUR WHEEL ACTIVE STEERING CONTROL

NAZRIN NAZIHAH BINTI ROSLI

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BACHELOR OF ELECTRICAL ENGINEERING WITH HONOURS
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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ELECTRIC VEHICLE YAW STABILITY USING FOUR WHEEL ACTIVE STEERING CONTROL

NAZRIN NAZIHAH BINTI ROSLI

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DECLARATION

I declare that this thesis entitled "ELECTRIC VEHICLE YAW STABILITY USING FOUR WHEEL ACTIVE STEERING CONTROL" 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 candidate of any other degree.

Signature	:	
Name	:	Nazrin Nazihah binti Rosli
Date	:	1/3/2021

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APPROVAL

I hereby declare that I have checked this report entitled "ELECTRIC VEHICLE YAW STABILITY USING FOUR WHEEL ACTIVE STEERING CONTROL" and in my opinion, this thesis complies the partial fulfilment for awarding the award of degree of Bachelor of Electrical Engineering with Honours.

Signature :

Supervisor Name : Dr. Muhamad Khairi bin Aripin

Date : 3/3/2021

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DEDICATION

To my beloved mother and father

Rosli bin Mohd Noor

Ruziah binti Osman

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ABSTRACT

The past few years has seen the rapid development of yaw stability control system for electric vehicle since electric vehicle is getting more attention due to its environment-friendly that can reduce harmful exhaust emissions that have been linked to global warming. Poor vehicle stability control can lead to traffic accident where the driver will react disproportionately when the vehicle loses stability hence unable to recover active control of their vehicle. Four-Wheel Active Steering control systems has been used as an effective way to improve the yaw stability of the vehicle during cornering manoeuvres, in which rear steer angles are controlled by steering controller while front steer angles are directly coupled with the driver. In this study, a Four-Wheel Active Steering control system that can control both front and rear wheel steering angle are proposed to improve the performances of the vehicle in stability and handling severe manoeuvres for the electric vehicle. Firstly, a single-track two-degree of freedom linear vehicle model as well as desired model is established. Then, a Fuzzy Logic Control algorithm is designed to control the rear steer angle of the system. Finally, the simulations are performed by using MATLAB/Simulink for steep steer manoeuvres to analyse and evaluate the effectiveness of the proposed control system under various conditions such as high and low speed on dry and wet road conditions. The results of the step steer manoeuvres demonstrate that the Fuzzy Logic Controller give better performances in tracing the desired yaw rate and improve the stability of the electric vehicle. The Four-Wheel Active Steering system can significantly improve the stability and handling under various conditions.

ABSTRAK

Beberapa tahun kebelakangan ini telah berkembang pesat sistem kawalan kestabilan yaw untuk kenderaan elektrik kerana kenderaan elektrik semakin mendapat perhatian kerana ianya mesra alam yang dapat mengurangkan pelepasan ekzos berbahaya yang telah dikaitkan dengan pemanasan global. Kawalan kestabilan kenderaan yang buruk boleh menyebabkan kemalangan lalu lintas di mana pemandu akan bertindak balas secara tidak seimbang apabila kenderaan kehilangan kestabilan sehingga tidak dapat memulihkan kawalan aktif kenderaan mereka. Sistem kawalan Steering Aktif Empat Roda telah digunakan sebagai cara yang berkesan untuk meningkatkan kestabilan yaw kenderaan semasa selekoh, di mana sudut stereng belakang dikendalikan oleh pengawal stereng sementara sudut kemudi depan langsung digabungkan dengan pemandu. Dalam kajian ini, sistem kawalan Steering Active Four-Wheel yang dapat mengawal kedua-dua sudut stereng roda depan dan roda belakang dicadangkan untuk meningkatkan prestasi kenderaan dalam keadaan stabil dan menangani manuver yang teruk untuk kenderaan elektrik. Pertama, model kenderaan linear “2-degree-of-freedom” yang dikehendaki telah dibina. Kemudian, algoritma Kawalan Logik Fuzzy dirancang untuk mengawal sudut kemudi belakang sistem. Akhirnya, simulasi dilakukan dengan menggunakan MATLAB / Simulink untuk manuver “steep steer” untuk menganalisis dan menilai keberkesanan sistem kawalan yang dicadangkan dalam beberapa keadaan seperti kelajuan tinggi dan rendah pada keadaan jalan kering dan basah. Hasil manuver “step steer” menunjukkan bahawa Fuzzy Logic Controller memberikan prestasi yang lebih baik dalam mengesan kadar menguap yang diinginkan dan meningkatkan kestabilan kenderaan elektrik. Sistem Pemacu Aktif Empat Roda dapat meningkatkan kestabilan dan pengendalian dengan ketara dalam pelbagai keadaan.

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LIST OF SYMBOLS AND ABBREVIATIONS

4WAS	-	Four Wheel Active Steering
2DOF	-	Two Degree of Freedom
7DPF	-	Seven Degree of Freedom
EV	-	Electric Vehicle
VSC	-	Vehicle Stability Control
ICV	-	Internal Combustion Vehicle
AFS	-	Active Front Steering
ARS	-	Active Rear Steering
FEM	-	Finite Element Model
DYC	-	Direct Yaw Moment Control
ESP	-	Electronic Stability Program
DOB	-	Baseline and Disturbance Observer
SMC	-	Sliding Mode Controller
FLC	-	Fuzzy Logic Controller

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Over the past century, the safety of a vehicle, especially in stability when driving at critical situations is one of the major topics in vehicle dynamics control system [1]. Vehicle stability control (VSC) is one of the most significant aspects in vehicle dynamics control, where this system is used to improve the vehicle driving condition and to keep the vehicle on the desired direction while avoiding the occurrence of an accident. The past decades has seen many vehicle control systems have been designed by researchers specifically for an electric vehicle with various types of controllers in enhancing the electric vehicle performance in handling and stability control. Electric vehicles (EV) have gained attention since they are a potential alternative to energy and environmental problems, its exhibit the outstanding advantages due to its environment-friendly and resource-saving transport as one of the solutions to today’s environmental pollution and energy shortages compared to internal combustion engine vehicles (ICV) [2].

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From the vehicle dynamics perspective, electric vehicles are developed to have various types of the driving system and the built-in motor can be mounted in each wheel in both driving and braking purposes [3]. Thus, to prevent environmental pollution, a motor is built and installed on each of the wheels of the vehicle. Electric vehicle gained more attention compared to internal combustion engine in the vehicle control field is electric vehicle has quick and very accurate torque response, where the response of the torque of electric motors is 10 to 100 times quicker than the ICV [4,5]. Therefore, the vehicle characteristics can be changed without changing the characteristics of the driver.

Four wheels active steering (4WAS) is one of the significant in chassis control technology that can enhance the vehicle manoeuvrability when travelling at low speed as well as the handling stability at high speed. By using two independent control inputs which is active front steering (AFS) and active rear steering (ARS), the lateral motion can be controlled simultaneously. The control lateral and yaw motion is possible to control by using only active front or active rear steering [5]. AFS is used to enhance the performance of the electric vehicle transient response at low speed when in cornering manoeuvres. The AFS has been developed in which the sum of the steering angle is the front steering angle controlled by the driver which is the corrective steering angle generated by the developed controller. Besides, the active rear steering (ARS) is used to improve transient response of the electric vehicle to low speed cornering manoeuvre.

Thus, the two independent control inputs which is AFS and ARS are essential in this study. This control system is based on the vehicle dynamic model, that is a single-track model and full track model that commonly has been used in the literature are established. The steady-state bicycle model is used as the reference model to evaluate the performance of the electric vehicle model. A controller in other hands is developed to improve the manoeuvrability when the vehicle travelling at low speed and the handling stability when the vehicle travelling at high speed based on yaw rate, therefore the desired vehicle performance can be achieved.

1.1 Research Motivation

As the rise of technology in the automotive industry, improving the efficiency of industrial machinery, the need to increase the safety factor is becoming a significant problem in vehicle design and handling. Electric vehicles (EV) are the solution to the crisis that the world is going to face soon. Over the past few decades, the concern over the environmental effects of the petroleum-based transport system is increasing along with the spectrum of peak oil, has contributed to renewed interest in the electrical transport infrastructure [4]. EVs have the desirable ability since electric motors and inverters are used in the drive system, they have a high advantage over internal combustion engine vehicles (ICVs) in which the torque generation of driving motors is high-speed and accurate, the torque also can be measure easily from motor current and each wheel of the electric vehicle can be controlled independently[6].

It is known that vehicle safe control plays an important role in minimizing traffic accidents from occurred [7]. The most significant priority of the study that has been carried out is to prevent the incidence of potential road crashes due to unpredictable disturbances such as intense manoeuvres in undetermined road conditions. Unintended yaw disturbances such as braking on the wet road, side wind force as well as lack of the tire pressure can lead to dangerous situation in yaw motions of a vehicle. In these cases, the driver may not respond or react immediately. Thus, it is important to design an active control system to help maintaining the yaw stability of an electric vehicle, so yaw stability control became a significant issue in vehicle stability control systems.

The vehicle becomes unstable due to oversteer or understeer, as shown in Figure 1.1 the vehicle takes a larger path that leaves the desired track under understeer case because of there is not enough yaw of the vehicle to follow, while in oversteer case, the vehicle takes smaller diameter and tends to overturn the curve road which has caused the driver to lose slightly the control of longitudinal. The vehicle stability control system can stabilize the vehicle and control the vehicle in dangerous situations.

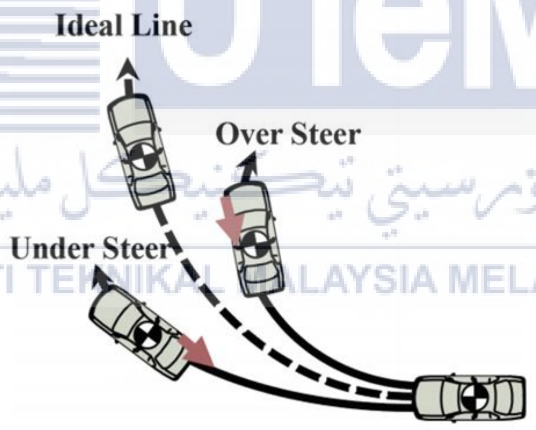

Figure 2.1 Electric vehicle schematic view in cornering [8]

In the electric vehicle system, the cornering manoeuvre is one of the important cases to enhance the yaw stability control. In vehicle control, the active steering is established to avoid the vehicle from hitting the obstacles when driving under certain conditions. Four-wheel active steering (4WAS) is one of the important chassis control technology in which the lateral dynamic response of the vehicle can be improved effectively during cornering manoeuvres [1]. The 4WAS also can enhance the manoeuvrability when the vehicle travelling at low speed and the handling and stability when the vehicle travelling at high speed. When the vehicle is travelling at low speed, the rear wheels should be turned in the counter direction of the front wheels so that the radius of the cornering will be reduced while at the medium speed, the rear wheels need to move same direction as the front wheels to enhance the lane changing manoeuvrability and stability. By developing the four-wheel active steering (4WAS) system, desired tracking or actual driving line can be followed by the driver while the vehicle stability is maintained, as shown in Figure 1.2.

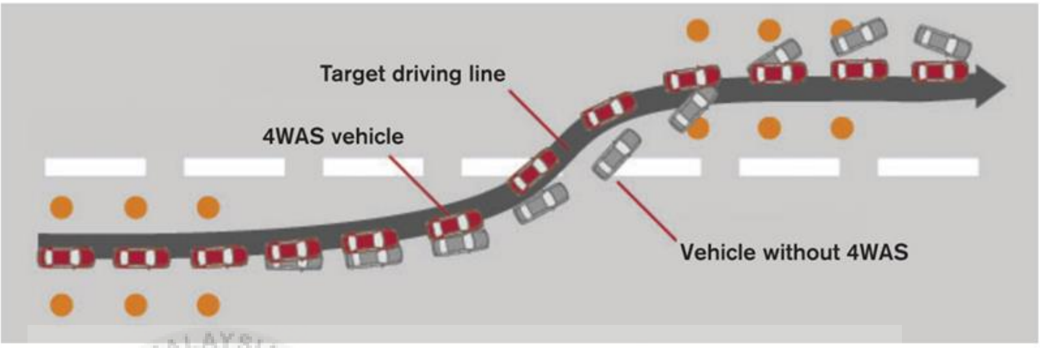

Figure 1.2 The behaviour of the electric vehicle with and without 4WAS system [9]

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1.3 Problem Statement

Car accidents can occur because of poor vehicle stability control. Vehicle stability control is extremely important in moving the electric vehicle as its the main control subject for this study, where it helps to avoid the wheels from sliding sideways during cornering or sudden steering and helps to stabilise the vehicle when turning a curve. Therefore, the mistake caused by human, especially in complicated and varied road conditions that lead to accidents can be reduced. Usually, if the performance of the vehicle loses stability, the driver tends to panic and react disproportionately while driving on unexpected road condition or driving at high speed and unable to recover active control of their vehicle. Therefore, an important parameter like yaw rate need to be analysed and evaluated to improve the stability and controllability in an electric vehicle control system, the vehicle system that controls the vehicle from drifting and spinning outside the lane is known as yaw stability control. The stability and controllability of the vehicle control system need to be improved since the current stability control system of the vehicle faced some difficulties such as uncertainties parameter or the yaw rate does not trace its desired value. Thus, applying an effective control strategy for the vehicle dynamics model is necessary to overcome this problem.

1.4 Research Objective

The main objective of this study is based on the approaches as follows:

i. To propose the dynamic modelling of linear vehicle model 2DOF for electric vehicle based on the mathematical equation.

ii. To design the Four-Wheel Active Steering controller by using Fuzzy Logic Control algorithm for yaw response.

iii. To evaluate and analyse the performances of the controlled and uncontrolled vehicle lateral dynamic response.

1.5 Research Scope

The main intention of the research is to construct a vehicle dynamics model on the single-track model (2DOF) with the desired model based on mathematical equation by using MATLAB/Simulink. The scopes of this project mainly involve the study of the yaw stability control of the electric vehicle specifically for Four-Wheel Active Steering control system with and without the injection of the designed control algorithm based on the vehicle dynamic model. In this study, the Fuzzy Logic Control algorithm is designed in the Four-Wheel Active Steering control system for the rear steer angle. The performances of the controlled and uncontrolled output behaviour of the lateral dynamic response which focus on yaw rate response are evaluated and analysed in this study. Moreover, three manipulating variables are considered in order to evaluate the performances of the vehicle with and without the injection of the designed control algorithm, which is the vehicle speed, road coefficient and the steer wheel input. The analysis is divided into two part which is low speed and high speed analysis. In this analysis, the vehicle speed is set to 10km/h for low speed and 80km/h for high speed. Lastly, the step input is used in this study to test the vehicle similar to the straight line cornering test. The input of steer wheel angle is set to 2 degrees and 15 degrees at dry road (μ =1.0) and wet road (μ =0.5) conditions only.

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1.6 Report Outline

For the next chapter, Chapter 2 will explain the literature that has been studied based on active steering control applied to an electric vehicle, vehicle dynamic model based on the number of degree of freedom as well as the studies on a controller. In Chapter 3 will be discussed on the methods that have been used in obtaining the result. The MATLAB/Simulink is used to construct the linear vehicle model 2DOF with the desired model, which is in steady-state as the ideal model. Besides, the vehicle dynamic model with the controller has been designed in this chapter, and the behaviour of the yaw rate output response for the model is analysed. In Chapter 4, the result on the performance and the behaviour yaw rate with and without a controller is presented. The desired yaw rate of the model as an ideal value is developed to analyse the vehicle dynamic model. The last chapter, which is Chapter 5, reviewed the overall conclusion and the recommendation for the future work in improving the project is also stated.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Research on the four-wheel active steering control system based on an electric vehicle is present in this chapter. In recent years, the electric vehicle has been receiving outstanding attention since it is one of the best solutions for energy conservation and environmental issues due to its Eco-friendly features without using the fuel fossil. EVs have more attractive advantages than traditional internal combustion engine in the aspect of vehicle dynamics control. The driving motor torque generation is high-speed and precise, which can increase the control performance of wheel slip control and yaw stability control [7]. Besides, all EV wheels can operate independently by using in wheels motor or can be controlled with a control system. Active front and active rear systems are designed to control the yaw rate for stabilizing vehicle's cornering motions for EVs without in-wheel motors and a torques-distribution mechanism, [8]. Because of these advantages, EVs have attracted attention among the researchers around the world to improve the performances of active steering in an electric vehicle by controlling its yaw stability. The main objective of controlling the yaw stability in an electric vehicle is to improve the stability performances and vehicle handling severe manoeuvres.

It is necessary to determine an appropriate feature of the yaw stability control system to design an effective control system. Figure 2.1 shows the yaw stability control system for an electric vehicle lateral dynamic. In this chapter, the control objective for the yaw stability, dynamic vehicle model as well as the designed controller for an electric vehicle control system will be reviewed, summarized and analysed at the end of this chapter.

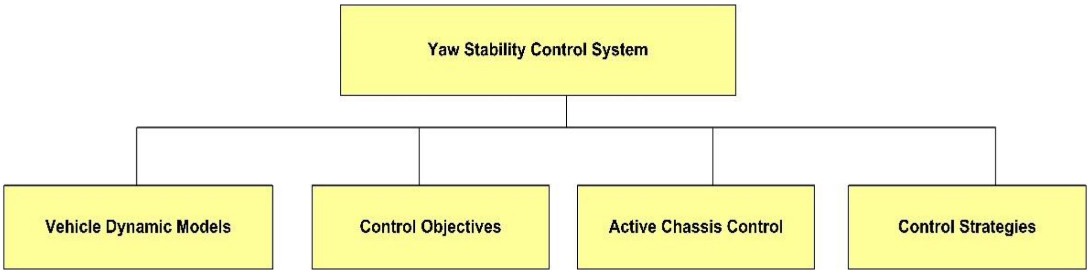

Figure 2.1 Yaw stability control system for electric vehicle lateral dynamic

2.2 Vehicle Dynamic Models

Vehicle dynamics carry a significant role in vehicle industry where the vehicle body, tire, and the suspension component are important parts of the system. Vehicle dynamic models are essential to study, evaluate and design the controller for the yaw stability control system. The modelling methods and characteristics of an electric vehicle for handling and driving dynamics have been established by many researchers. To fully express the general dynamics of the vehicle, the model must include rigid bodies, force elements and kinematic constraints. The vehicle dynamic model is started with limped parameter along with finite element model FEM, the multi body, and substructure model, then, from linear model to the nonlinear model [9]. Besides, it is designed by referring to Newton's 2nd law as the mathematical modelling dynamic motion that explains motions and forces acting on the body of the vehicle and the tires.

An electric vehicle has a complex system that consists many of subsystems and has a huge number of degrees of freedom[10]. There are several degrees of freedom associated with vehicle dynamics, for stability and handling research of an electric vehicle, the number of degree of freedoms could be two, four, seven, ten, fourteen or more. For instance, 2DOF vehicle model representing lateral and yaw motions is developed in [1,3,5,6,7,10,19,25,26,27,29,31,33,34,39,46,47], 3DOF representing longitudinal, lateral and yaw motions is developed in [15,18,24,28,37,38,41,50] while 4DOF representing lateral, yaw, longitudinal and roll motions, 7DOF which consists of the lateral, longitudinal, yaw and four- wheel rotational speed is implemented in