A Study of Torque Vectoring and Traction Control for an All-Wheel Drive Electric Vehicle

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Abstract. Common vehicle always experience energy loss during cornering manoeuver. Thus, to ensure it did not happened especially at high speed, a study of torque vectoring and traction control need to be made since it can increase the traction control of tyres during cornering at high speed. The study of torque vectoring and traction control for an all-wheel drive electric vehicle was conducted by modelling an all-wheel drive electric vehicle (EV) in ADAMS/Car software. In addition, an optimal control algorithm will be developed for best performance to minimize energy losses using MATLAB/Simulink software. Furthermore, to prove the effectiveness of the all-wheel drive electric, the torque and traction control simulation of the all-wheel drive electric vehicle will be compared with uncontrolled electric vehicle model. According to the result, torque vectoring and traction control of in-wheel motor in all wheel drive EV can help to increase the performance of the electric vehicle during cornering manoeuver. In conclusion, this study of torque vectoring and traction control for an all-wheel drive electric vehicle will help researchers to improve the design of the future electric vehicle in term of the vehicle performance during cornering manoeuvre.

1 Introduction

Torque vectoring is a very important technology that is essential to be used in car because it related to the energy efficiency that being used in electric vehicle (EV). Torque vectoring increases the energy efficiency by transferring the torque from right wheel to left wheel, and vice versa thus it can increase the traction of the wheel to the ground during cornering. Due to the increased traction to the ground, the car equipped with this technology is much safer compared to common car on road. In this project, in- wheel motor (IWM) will be used in the all-wheel drive (AWD) electric vehicle thus, the wheel can be controlled independently and it provides far greater control than any other drive systems like front wheel drive and rear wheel drive. A vehicle dynamic model needs to be developed to characterize the torque vectoring drive system and an optimum control algorithm needs to be developed to provide the best performance and to minimize drivetrain losses. In conclusion, by introducing the torque vectoring and traction control in EV, the usage of energy especially electric energy can be reduced thus the

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efficiency of the next generation of EV will be increased and most important part is this technology gives great impact towards the sustainability of environment.

2 Torque Vectoring and the Existing Implementation

Torque vectoring (TV) is a process that translates input from the driver (brake, steering angle, acceleration pedal signals) into torque commands to the wheels of the vehicle which means with the individual torque distribution, the performance and traction control of the vehicle can be enhanced [1]. In other words, while TV system monitors steering angle, wheel speed, yaw rate, vehicle speed and other inputs, it splits engine's torque from front to back and distributed it from side to side on a given axle by using control unit deferential [2]. Figure 1 shows the diagram that defines torque vectoring concept.
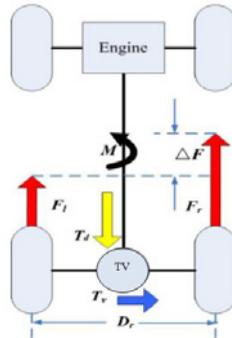
Figure 1. Definition of torque vectoring [2].

According to Li et al [2], when the vehicle is turning left with under steer, TV drive automatically transmits the input torque, T_d of the driveshaft from left rear wheel to right rear wheel with vectoring torque, T_v by engaging clutches. Thus, it results in additional driving force T_v / R acting on right rear wheel and extra braking force $-T_v$ / R acting on left rear wheel. Finally, the differential longitudinal driving force ΔF between the right and left wheel is produced, which generates yaw moment, M, helping the vehicle bend into the corner more sharply. When the vehicle is driving straight, TV behaves like an ordinary open differential with the input torque T_d equally distributed to the left and right rear wheels, which means $T_v = 0$.

Some car manufacturer has already implemented this technology to improve the performance of their cars. Quattro, xDrive, and Active Yaw Control are among the most popular torque vectoring technologies that has been implemented by Audi, BMW and Mitsubishi respectively.

3 Control Systems

Control is the process of causing a system variable to perform some desired value. While control system on the other hand, is an interconnection of components forming a system configuration that will provide a desired system respond. There are more than 95% of the control loops based on proportional-Integral-Derivative (PID) controllers are yet still be used in the industrial processes [3]. This is due to the simplicity in principle.

There are 2 types of control system which are feed-forward and feed-backward. A feed-forward controller uses information from measurable disturbances to improve the control performance; theoretically it is possible to eliminate the disturbances, but in reality, the disturbances will not perfectly eliminate. On the other hand, feed-backward control system calculation is based on measurements of the controlled output; where feed-backward control systems normally give better attenuation of low-frequency process disturbances and that they give better robustness (less sensitivity

to parameter changes) when compared to systems without feedback [3]. Among the most widely used feed-backward control mechanism in industrial control systems is a PID controller.

Another popular logic controller is fuzzy logic. It can control complex continuously-varying systems. It can approximate any continuous functions on a compact set to a given accuracy so it can be considered as a universal approximator. The advantages of using fuzzy model are the model structure is easy to understand and sometimes interpretable and various types of knowledge can be integrated in the model, including statistical objects and empirical knowledge [4]. It was found that fuzzy controller was simpler and easier to develop compare to PID controllers [5]. Fuzzy controller type will be used in this research to develop an optimal control algorithm for best performance and to minimize energy losses in MATLAB/Simulink.

3.1 Reference model

Bicycle model is the simplest method in determining lateral vehicle response which has two degree of freedom. The model combined the right and left tires at the front and rear of the car into equivalent tire which located at the centre line. The slip angles on the inside and outside wheels are approximately the same. The degree-of-freedom for constant forward speed are yaw rate, r, and lateral velocity u_y (or sideslip angle, α). In addition, this model neglects body roll and load transfer. The longitudinal speed of travel is assumed to be constant. The steer and slip angles are assumed to be equal thus, the tire forces may be assumed to vary linearly with slip angles [6]. The model which can be expressed in a state space form as follows;

$$\dot{x} = Ax + B\delta_f \tag{1}$$

$$x = \left[\beta, \gamma\right]^t \tag{2}$$

$$A = \begin{pmatrix} -2\dfrac{C_f + C_r}{mV} & -1 - 2\dfrac{l_f C_f + l_r C_r}{mV^2} \\ -2\dfrac{l_f C_f + l_r C_r}{IV^2} & -2\dfrac{l_f^2 C_f + l_r^2 C_r}{IV} \end{pmatrix} \tag{3}$$

$$B = \begin{pmatrix} \dfrac{2C_f}{mV} & \dfrac{2l_f C_f}{I} \end{pmatrix} \tag{4}$$

Where β is side slip angle, δ_f is front steer angle, γ is yaw rate, m is mass, l_f is length between center of the car and front tire, l_r length between center of the car and rear tire, I is the vehicle inertia, C_f is front cornering stiffness, and C_r is rear cornering stiffness.

4 Results and discussion

Several vehicle cornering simulation were performed which are single lane change (SLC) and steep steer (SS). The results compared the performance of EV model with controlled IWMs and EV model with uncontrolled IWMs. The results are compared based on the yaw rate characteristic which gives information on how stable the electric vehicle undergoes the manoeuvre since yaw rate is related to side slip angle.

4.1 Single lane change simulation

As stated before, SLC is to simulate vehicle that changing lane at certain given speed. Time taken for the SLC simulation is 5 second, and the SLC manoeuver will start at T= 2sec where the steering wheel

angle started to turn from 0 to 90 degree for 0.5sec and turn back from 90 to 0 degree for another 0.5sec. The vehicle speed was set constant at 90 km/h.
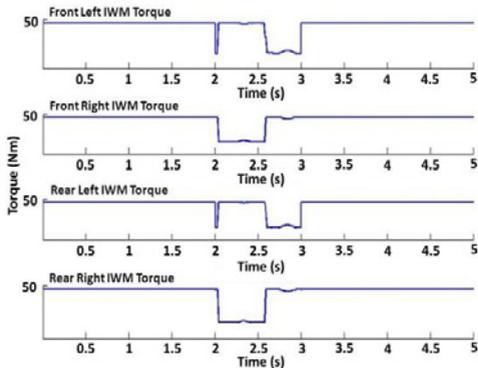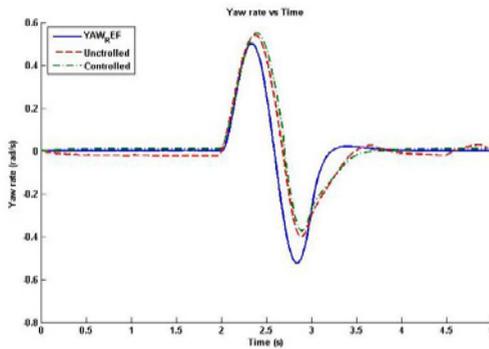

Figure 2. Torque vs. Time graph for SLC

Figure 3. Yaw rate vs. time for SLC.

Figure 2 shows the torque output at each of the wheel. The output torque at the front right and rear right wheel were lowered down by the controller at T=2s until T=2.5s. This shows that the torque vectoring system was applied thus assisting the vehicle to have a resultant moment towards the right (clockwise). At T=2.5s until T=3.0s, the torque at front left and rear left were lowered down by the controller. The torque vectoring system assisted the car to get the resultant moment toward the left. Thus, it completed the single lane change manoeuver.

Figure 3 shows the plot of yaw rate versus time for yaw reference based on two degree-of freedom (2DOF) bicycle model, uncontrolled and controlled EV model. Yaw reference plot shows that there will be slight overshoot at T=3s to T=3.5s. By controlling the IWMs of EV model, the yaw rate was found has improved the slight overshoot. On the other hand, the uncontrolled EV model still experiencing change in yaw rate after T=3.5s. Based on the plot, it can be conclude that controlling IWMs can improve the stability of the EV model during SLC manoeuver.

4.2 Single lane change simulation

SS simulation is j-turn simulation of a vehicle at a certain speed. The vehicle speed was set constant at 90 km/h. Time taken for the SS simulation is 5 seconds, and the SS manoeuver will start at T= 2sec where the steering wheel angle started to turn from 0 to 90 degree for 2 seconds and stay at 90 degree until the end of the simulation (5 seconds).
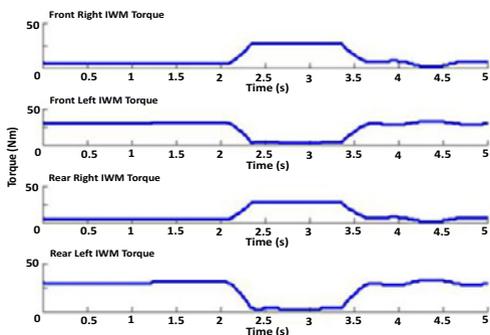

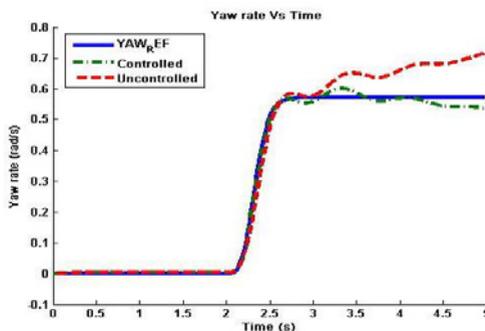**Figure 4.** Torque vs. Time graph for SS.

Figure 5. Yaw rate vs. time for SS.

Figure 4 shows the torque versus time graph. The output torque at the front right and rear right wheel were increased by the controller at T=2s until T=3.5s. This shows that the torque vectoring system assisted the vehicle to have a resultant moment towards the left (anti-clockwise) at the beginning of the j-turn. At T=3.5s until T=5.0s, the torque were lowered down and controlled by the controller at about 30Nm. At this point, the torque vectoring system tried to assist the car to balance the yaw rate according to the reference model developed before to complete the j-turn or SLC manoeuver.

Based on Figure 5, the result shows the plot of yaw rate versus time for yaw reference based on two degree-of freedom (2DOF) bicycle model, uncontrolled and controlled EV model for SS simulation. It is clearly spotted that uncontrolled EV model unable to maintain its yaw rate as the vehicle start the j-turn at T=2s. While the EV model with controlled IWMs tries to follow the reference yaw rate line as the vehicle experienced the j-turn in step steer simulation. Thus, by controlling IWMs can improve the vehicle stability in step steer simulation

5 Conclusions

In conclusion, torque vectoring and traction control of in-wheel motor in all wheel drive EV can help to increase the performance of the electric vehicle during cornering manoeuver. In addition, torque vectoring using this approach has the potential to improve response and stability where the tuning of the control model enabling vehicle behavior to meet driver's expectations.

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