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Mitigating Instability in Electric Drive Vehicles Due to Time Varying Delays with Optimised Controller

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Abstract**--***The instability in the Electric vehicle would reduce the performance and even severely damage the system. This instability is mainly due to the random time-varying delays occurring in CAN network and the improper efficiency of controllers. This uncertainty and error occurrence makes it difficult to design the electric vehicles considering the advantages of Electric Vehicles being, the future to reduce harmful emissions due to fossil fuels, the instability can be mitigated by using optimized H∞ controller. The results of Simulations through MATLAB demonstrate the Effectiveness of the improved controller by comparing with the normal PI controller. The results of comparison illustrate the strength of explicitly.*

Keywords: CAN-Control Area Network, H∞ Controller, LQR Controller (Linear Quadratic Regulator), MATLAB-Matrix Laboratory, Optimization.

I. INTRODUCTION

Owing to the emerging vehicular pollution to the environment and the deterioration of fossil fuels that increase the effect of global warming, the development of alternate energy source vehicles has been in fast pace. Nowadays there is great demand for vehicle driving safety, manoeuvrability, and driving comfort. Meanwhile the electric vehicle is at rapidly growing phase due to its simpler transmission, electronic initiative chassis and regenerative braking system of each wheel.

Rapid improvement in electric motor, battery, and control technologies makes the four-wheel-independent drive electric vehicle (4WID-EV) as an emerging configuration of EV. Quick dynamics of vehicle control, faster energy propulsions, good energy optimisation and structural flexibility makes the electric vehicles with in-wheel motors more preferable. There have been researches and works going in a way to develop a integrated control system to control the uncontrolled motion of steering and yaw rate.

Vehicle's lateral stability mainly depends on the steering controls and yaw moment controls.

Yu and Moskwa designed a four-wheel steering and independent wheel torque control system to enhance vehicle maneuverability and safety [1].

Bedner *et al.* proposed a supervisory control approach to manage both braking and four-wheel steering systems for vehicle stability control [2]. A coordinated and reconfigurable vehicle dynamics control system that can coordinate the steering and braking actions of each wheel individually was designed in [3]. There are also some works focusing on combining active front-wheel steering (AFS) and DYC systems. An integrated front-wheel steering and individual wheel torque controller was proposed to govern the vehicle lateral position using frequency weighted coordination [4]. Nagai also proposed an integrated control system of AFS and DYC to control the vehicle yaw rate and the sideslip angle using a model-matching controller [5]. A vehicle yaw stability control approach coordinating steering and individual wheel braking actuations was developed in [6]. A coordinated controller of AFS and DYC based on an optimal guaranteed cost method was designed in [7]. Mokhiamar and Abe compared different combinations of DYC with AFS, active rear-wheel steering (ARS), and AFS + ARS in simulation in [8].

Heinzl *et al.* also compared three different control strategies, namely, AFS, AFS plus unilateral braking, and ARS plus unilateral braking for vehicle dynamics control in a severe cornering and braking maneuver situation in simulation [9].

Among all the solutions coordinating the steering-based system and the DYC control system, the combination of AFS and DYC shows the best compromise between control performance and system complexity. With in-wheel motors, each wheel of the 4WID-EV can generate not only individual braking torque but individual driving torque as well, are able to yield greater direct yaw-moment than the conventional vehicles. In addition, the 4WID-EV dynamics control capability can be further enhanced by the integration of an AFS. Li *et al.* proposed an integrated model predictive control algorithm of AFS and DYC to improve the control performance of 4WID-EVs with in-wheel motors [10]. However, all of these aforementioned control methods for combined AFS and DYC assumed that the controllers, sensors, and actuators were directly connected by wires. In other words, the 4WID-EV was considered as a centralized control system. Rather, with the development and appearance of in-vehicle networks and x-by-wire technologies, the control signals from the controllers and the measurements from some sensors are exchanged using a communication network in modern vehicles [11], i.e., Controller Area Network (CAN). Thus, a 4WID-EV is a networked control system rather than a centralized control system, which imposes the effects of network-induced delays into the control loop. The unknown and time-varying delays of the network communication between different controllers could degrade the control performance of the entire system or even make the system unstable. For example, according to the research of Caruntu *et al.*, time varying delays of the CAN can lead to driveline oscillations in the control of a vehicle drive train [11].

However, the instability in electric vehicle makes it difficult to be designed and used in normal road conditions. The instability is due to three main reasons

1. Driver action
2. Road disturbances
3. Network induced delays

1.1 Driver action:

The electric vehicle usually follows Drive-by-wire mechanism and even a small error can cause severe damage to the entire network and controller. For instance, if a driver had to make a right turn at 50kmph, in normal vehicles differential will take of this by rotating the outer wheel in a faster rate than the inner wheel. In case of electric vehicles with in-wheel motor, the controller will take the responsibility of the differential and it should code in such way, it should avoid under steer or over steer.

1.2 Road Disturbances:

The road obstacles also play a crucial role in designing the electric vehicles, cause a small bump in the road can a deviation in the yaw rate and it may lead to yawing moment of vehicles. It also includes the wind disturbances that will cause the vehicle to be unstable. Hence the road disturbances will also be the reason for electric vehicle instability.

1.3 Network induced delays:

Generally in most of the vehicles, both mechanical and electric vehicles have the usage of CAN bus network in order to reduce the use of wires which may add extra weight to the vehicle. The CAN Bus interconnects each system and provides a common platform for information to be transferred. In CAN bus network, there are three types of delays

- Process delay
- Transmission delay
- Packet-queue delay

1.3.1 Process delay:

In network, process delay is the time it takes routers to process the packet header. Processing delay is a key component in network delay. In the past, the processing delay has been ignored as insignificant compared to the other forms of network delay. However, in some systems, the processing delay can be quite large especially where routers are performing complex encryption algorithms or modifying packet content.

1.3.2 Transmission delay:

In a network, transmission delay is the amount of time required to push all the packet’s bits into the wire. In other words, this is the delay caused by data-rate of the link.

1.3.3 Packet-queue delay:

In network, the queuing delay is the time a job waits in a queue until it can be executed. It is the key component of network delay and it contributes maximum out of these three delays.

For vehicle lateral stability control, steering-based systems and direct yaw-moment control (DYC), systems are most effective, and there have been various research studies on the combination of two systems. With in-wheel motors, each wheel of the 4WID-EV can generate not only individual braking torque but also individual driving torque, and can able achieve better yaw moment control than other systems.

However, all these aforementioned control methods for Combined AFS and DYC were assumed that the controllers, sensors and actuators were directly connected by wires. In other words the 4WID-EV was considered to be a centralized control system.

With the development of in-vehicle network, the control signals from the controllers and the sensors are exchanged through a communication network, i.e., Controller Area Network(CAN).Thus a 4WID-EV is a networked control system rather than centralized control system, which imposes the effects of network-induced delays into the control loop. The unknown and time-varying delays of the network communication between different controllers can degrade the control performance of the entire system or even make the EV unstable a time-varying CAN lead

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to driveline oscillations in the control of a vehicle drive train.

II. METHODOLOGY

In an AFS system, the front-wheel steering angle is determined as a sum of two contributions. One is directly determined by the driver from her/his steering wheel angle input, and the other is decided by the steer-by-wire controller. One input is from the steering wheel of the driver, whereas the other is from the servo motor controlled by the electronic controller of the AFS system, which is connected to the in-vehicle network via the CAN bus.

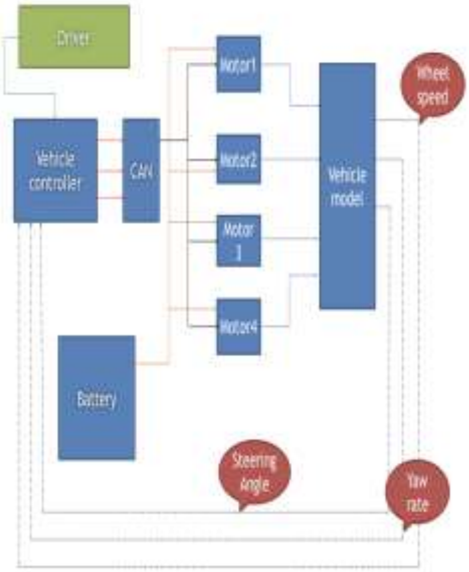


Fig.1: Schematic of the Project

The upper-level controller decides the steering angle to be superposed to the front wheels and the direct yaw moment to be imposed to the vehicle, whereas the lower-level controller distributes the total direct yaw-moment to the torque commands of the four in-wheel motors. This paper only studies the upper-level controller, which has the direct responsibility on the system robustness against time-varying network delays. In most vehicle motion control systems, the yaw rate sensor and the longitudinal/lateral acceleration sensor are usually directly connected with the vehicle controller, from which the vehicle yaw rate and the sideslip angle can be measured or estimated by the upper-level controller directly without going through the in-vehicle network.

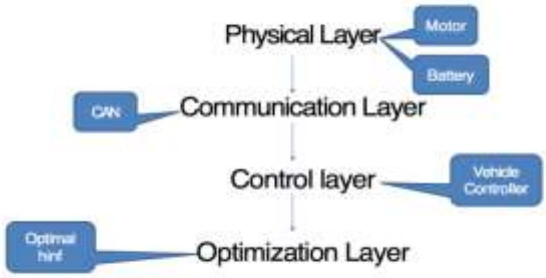


Fig.2: Layers of project

There are four layers in the project

2.1 Physical Layer:

It consists of motor, and its components and battery. It's the layer that we can feel and touch in the model.

2.2 Communication layer:

It consists of the CAN bus network.

2.3 Control layer:

It has the controller system used in the electric vehicles. The controller used here is PI controller as the basic controller and errors are rectified using the LQR controller, further enhanced by the combination of both.

2.4 Optimization layer:

The future work will be the optimization of the model done through LQR method, which is done by Hinf method.

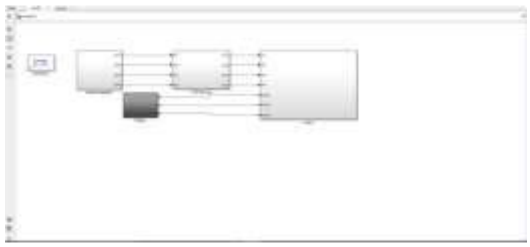
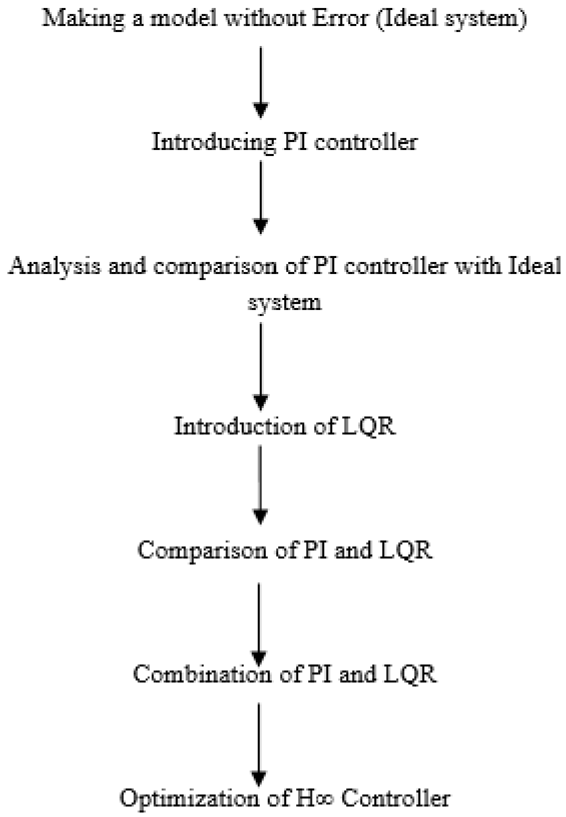


Fig.3: Model Outline

III. WORKING METHOD



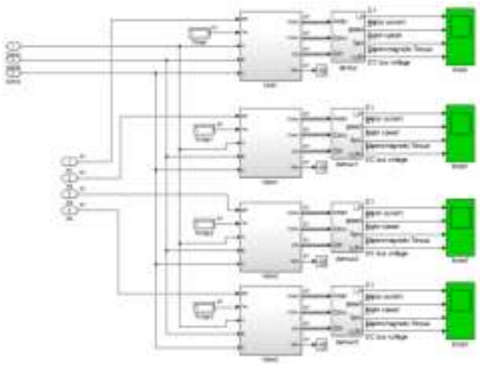


Fig.4: Complete model without delay

The above model Fig.4 has been done as a reference model to compare the results with the output from this. This system is said to be ideal since it has no error, all the input is converted into output.

The model with errors Fig.5 has the same PI Controller used in the ideal system, both uses the same controller, the only difference is, here the instability due the road disturbance, driver action and controller delay will be considered.

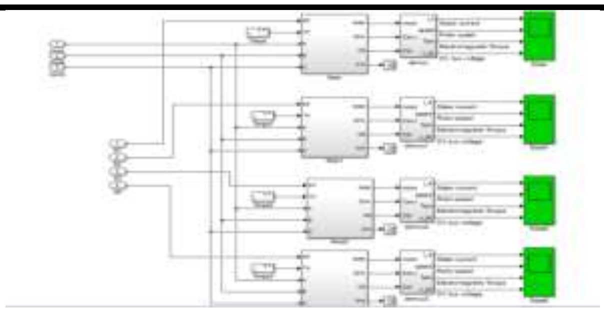


Fig.5: Complete model with delays

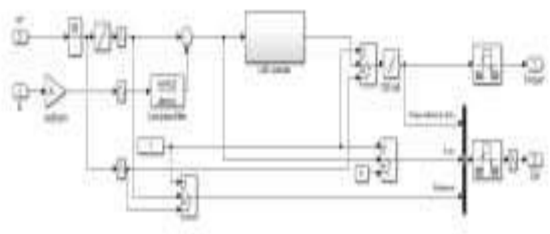


Fig.6: LQR Controller

The third model Fig.6 has the LQR controller that will reduce and minimize the instabilities caused by various disturbances.Comparison the results of controllers has been discussed below.

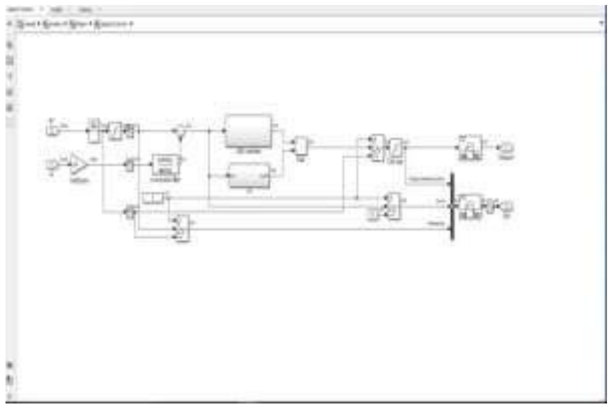


Fig.7: Combination of PI and LQR Controller

PI and LQR Controllers are combined to see the combined efficiency of both the models. The combination is actually over shades the disadvantages of the PI Controller. The LQR Controller takes full responsibility and it makes the system a little advantageous than the normal PI Controller.

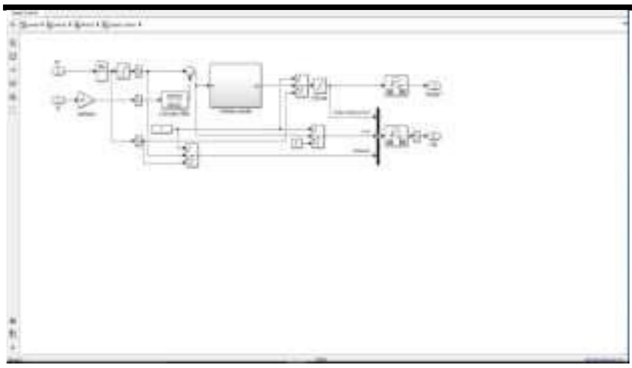


Fig.8: H∞ Controller

Finally after analyzing the PI, LQR and Combined PI and LQR Controllers, the next step is optimizing the H∞ Controller so as to get the output that over shadows all the above used controllers.

IV. RESULTS AND DISCUSSION

The models are performed using SIMULINK. The LQRD controller is designed and simulations are conducted in SIMULINK. The parameter values are given for the in-wheel motor. First the PI controller with no delays called as ideal system is simulated and results are taken. Then the PI controller with delays is been simulated in SIMULINK and the results are taken. After comparing these two models, a LQRD controller is introduced in order to reduce the delays further. The CAN-induced delays are assumed to be time varying delays and uniformly distributed in interval of [0, 1.7Ts], where Ts=10ms is considered to be the sampling period of closed loop system. The Matrix used in the conventional LQR are

$$Q_C = \begin{bmatrix} 2000 & 0 \\ 0 & 100000 \end{bmatrix}$$

$$R_C = \begin{bmatrix} 8000 & 0 \\ 0 & 0.00001 \end{bmatrix}$$

$$J = \sum_{i=0}^{\infty} (e_i^T \, Q e_i + u_i^T R \, u_i)$$

Then use the lqrd command in MATLAB, and hence the control gain matrix of LQRD is

$$K_C = \begin{bmatrix} 0.099 & 0.945 \\ 1716.6 & 44485 \end{bmatrix}$$

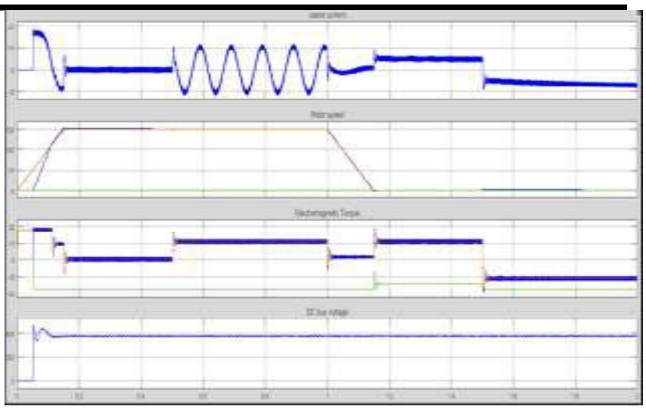


Fig.9: PI controller without delays

Fig.6 shows a PI controller without delays .This is an ideal system where there are no errors. All the input is converted into output.

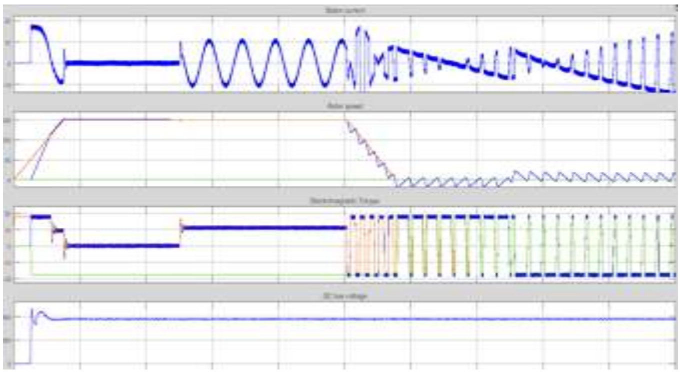


Fig.10: PI controller with delays

Fig.7 shows the PI controller with delays. Here the speed, current, torque and voltage varies with time which causes instability of electric vehicles. The blue color represents reference value and other color represents actual value. The wriggles are more here.

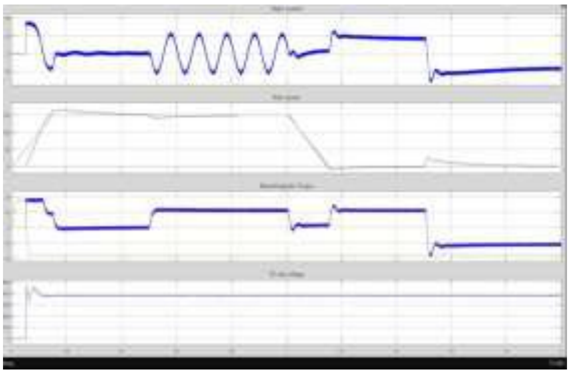


Fig.11: LQRD Controller

Fig.11 represents LQRD controller where the delays are reduced by optimizing it. Comparing with PI controller the delays are very much reduced in LQRD controller. The wriggles are reduced here. There is no big variation in output.

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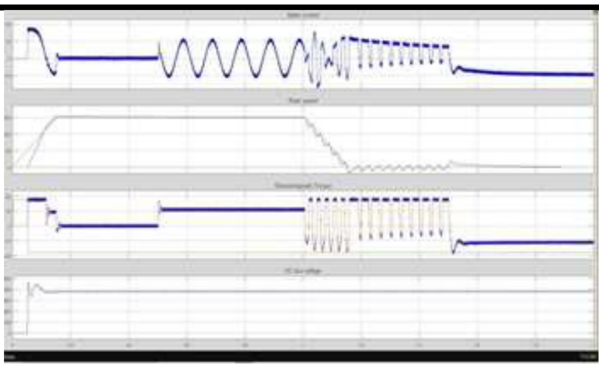


- *Fig.12:.Output obtained as a result of combining LQR and PI Controller*

- The output obtained by the combination of LQR and PI controllers has an efficiency less than that of LQR Alone and greater than the PI controller.
- Hence it wont be good to have the combination of PI and LQR to have a great working condition.
- LQR controller alone will suffice according the output, for this kind of environmental condition.
- Further Hinf controller may have a better output when compared with the others.

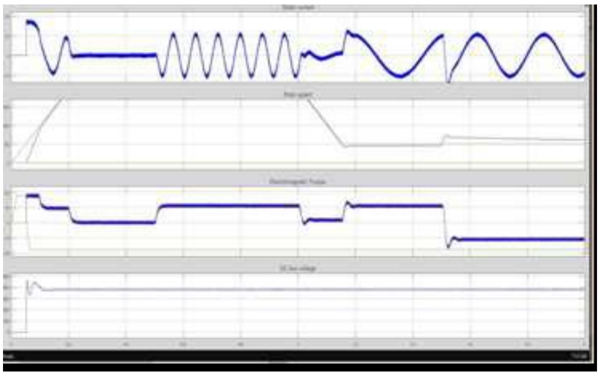
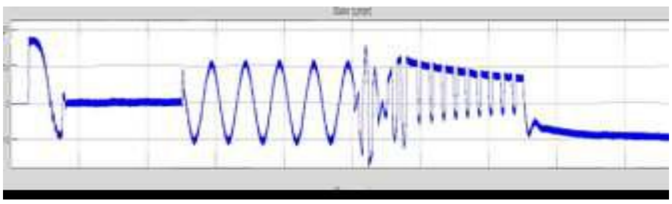


Fig.13:.Output of H ∞ Controller

The output obtained from the H∞ Controller has a much better rotor speed characteristics and torque characteristics when compared with the other controllers.It has a unbelievable efficiency of 3.45% in comparison with the rotor speed.

V. COMPARISON OF COMBINED PI AND LQR WITH H∞ CONTROLLER



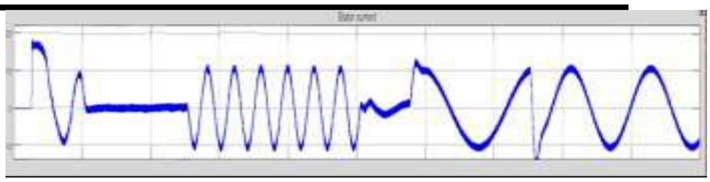


Fig.14: Comparison of Stator current between Combined LQR and PI with H∞

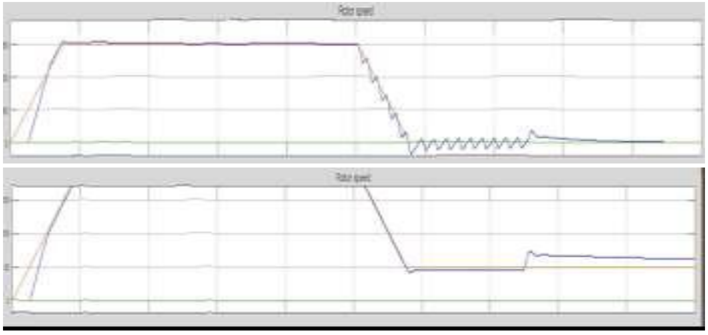


Fig.15: Comparison of Rotor speed between Combined LQR and PI with H∞

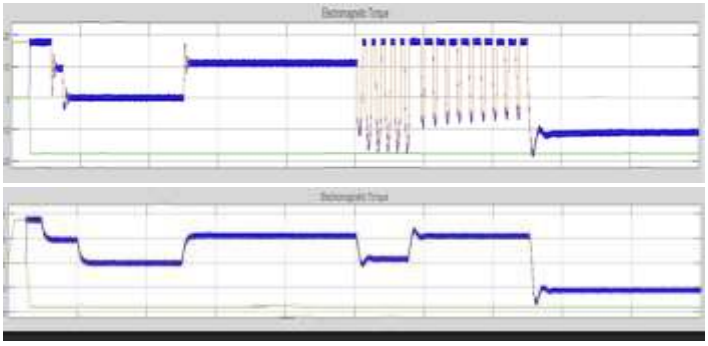


Fig.16: Comparison of Electromagnetic Torque between Combined LQR and PI with H∞

VI. COMPARISON OF LQR AND H∞ CONTROLLER

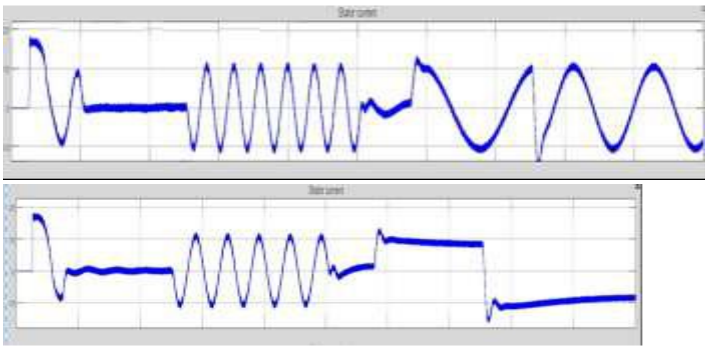


Fig .17: .Comparison of Stator current between LQR and H∞

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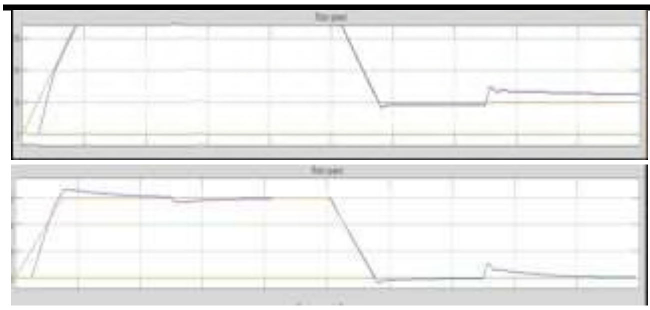

Fig.18: Comparison of Rotor speed between LQR and H∞

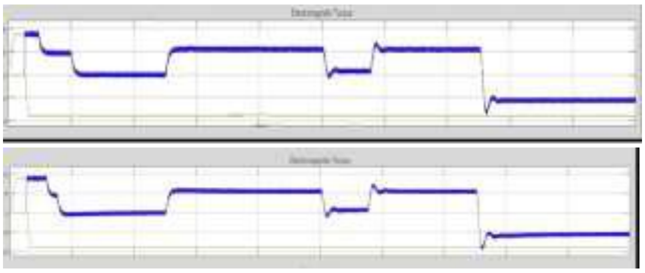

Fig.19: Comparison of Torque between LQR and H∞

VII. CONCLUSION

In this paper we have reduced the time varying delays in the CAN network by using a LQRD controller. This is been incorporated for lateral motion and stability control of 4-Wheel Independent Drive EVs. The PI controller with delays produces ripples and fluctuations in the electromagnetic torque. So LQRD is used to reduce the time varying delays and fluctuations in electromagnetic torque. The comparison between the results ensures the robustness and performance of the vehicle due to reduce in the time varying delays in the closed loop system. This paper indicates the time varying delays in networked control systems would cause the system performance. So with this LQRD controller the robustness of the system is increased.

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