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Enhancement of Driveability for Integrated Motor Transmission Vehicle by the Robust Control Approach over CAN

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***Abstract*— In recent years, rapid growth in the field of electronics and computer technology which makes the life simpler and faster. This development hits the automobile sector, which makes increases the systems in vehicle like infotainment system, safety system and security system. These systems are integrated to know the status of the vehicle for each and every second, this is done by means of different networking protocols. In this paper, the network induced time varying delays because of bandwidth limitations will lead to powertrain oscillations in the vehicle which causes poor drivability. The control law adopted here is multi variable PI which in turn makes the system stable and increases the comfort.**

***Keywords*—Integrated Motor Transmission, Controller Area network, Powertrain oscillation and Multi variable PI.**

I. INTRODUCTION

The internal combustion engine vehicles and conventional powertrain systems have dominated the transportation industry. Electric vehicles (EVs), depending on their source of electric energy, have the potential to be zero emission vehicles and have potential as a future alternative to internal combustion vehicles. However, despite considerable improvements, electric vehicles still have a limited driving range due to the limitations of the current electrical storage technologies.

To address this problem, hybrid vehicles combine the advantages of two different energy sources. The hybridization of energy sources can increase energy security, improve fuel economy, lower fuel costs, and reduce emissions. Moreover, there are many different ways of implementing hybridization such as: hybrid electric vehicles, plug-in hybrid electric vehicles [1]. Environmental concern, emission norms, energy supply are the major concern in the day to day life, so the automotive companies and researchers are going for the pure electric vehicle (PEV) and hybrid electric vehicle (HEV). While HEV takes the advantage of energy management between the gasoline and electric motor. But in PEV electric motor propels the vehicle which is mainly concerned for eco-friendly purpose.

This PEV has many architectures which is mainly considered here is integrated motor transmission driveline (IMT). This IMT driveline is to improve efficiency of an electric driving system meanwhile to meet the requirements of vehicle drivability, the driving motor of the pure electric vehicle or series hybrid electric vehicle is usually provided with a decelerator or a transmission device. Conventionally, a two speed planetary gear transmission device is employed by the pure Electric vehicle or series hybrid electric vehicle. The structure of the two-speed planetary gear transmission device is relatively simple. However, a shift operation cannot be performed when the vehicle is running, which makes it difficult to optimize the drivability and the efficiency. Accordingly, based on the motor drive system characteristics and the overall requirements of the vehicle, the feasibility and optimization as well as control strategy of applying Automated Manual Transmission (AMT) without clutch to the pure Electric vehicle is difficult. Since, vehicle powertrains are characterized by fast dynamics where driveline oscillation is easy to appear. While enjoying the benefit of motor control, the controller design for the driveline oscillation damping is becoming more challenging due the absence of the clutches. Moreover the control signal and the sensor measurements are exchanged using the controller area network (CAN) which in turn plays a major role in the now a days vehicle.

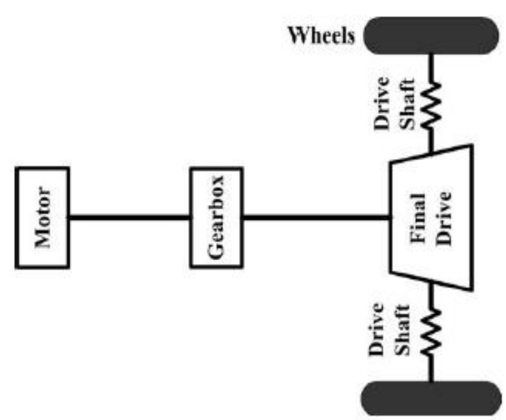

Fig 1. Integrated Motor Transmission Powertrain

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This vehicle bus standard (CAN) designed to allow electronic control units and devices to communicate with each other in applications without a host computer. As an alternative to conventional multi-wire looms, CAN Bus allows various electronic components (such as: electronic control units, microcontrollers, devices, sensors, actuators and other electronic components throughout the vehicle) to communicate on a single or dual-wire network data bus up to 1 Mb/s. The CAN Bus is a message based protocol, designed originally for multiplex electrical wiring within motor vehicles, but also can be used in many other contexts. This vehicle bus standard is also a type of a network which majorly causes the network induced time varying delays. This random time varying delays is also a major issue because of its bandwidth limitations which further lead to the powertrain oscillations can even destabilize the system. Therefore in this paper a controller is proposed to reduce the powertrain vibration and also to linearize the delays, a control law adopted here is multivariable PI. The controller adopted here is compared with the conventional controller to show the robustness as well as the effectiveness.

A. Abbreviations and Notations

AMT automated manual transmission
CAN controller area network
ECU electric control unit
HEV hybrid electric vehicle
ICE inter combustion engine
IMT integrated motor-transmission
MCU motor control unit
PEV Pure electric vehicle
TCU transmission control unit.

B. Problem Formulation.

Taking automated manual transmission (AMT) as an example, networked control structure of IMT powertrain system is shown in Fig 2. The sensors measure the output of the powertrain system and send the samples to the TCU via CAN periodically. In practical commercial vehicle control system, motor rotation speed and wheel rotation speed can be directly measured by sensors while the angles are usually estimated due to the complexity of direct measurement and also the cost. Based on the measurement signals from CAN and also the reference vehicle speed, TCU will calculates required torque each time measurement data arrived via CAN. Similarly, MCU will actuate the motor to generate the desired torque or rotation speed based on the command from CAN.

Therefore, in the control system of IMT powertrain, TCU performs just like an upper-level controller while the MCU will be lower-level controller. It can be seen that the external load torque T_{load} as well as the network-induced delays τ_k are the main uncertainties to the whole control system, which will be fully considered in the oscillation damping controller design for IMT powertrain system. In practical vehicle powertrain control system, the sensors are generally working under time-driven mode while the transmission control unit (TCU) and motor control unit (MCU) as well as motors are all in event-driven mode. The time drive sensors execute periodically with fixed sampling time. When the time-driven mode is assumed for all the nodes including the controller node and actuator node in the control system, the network-induced time-varying delays for the time driven working mode would only be integral multiple number of default sampling period.

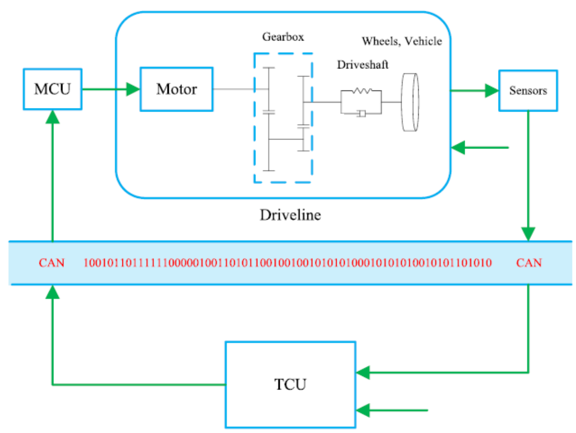

Fig 2. Control architecture via CAN

However, for the event - driven mode, the control signal will be triggered immediately at the time that measurements from the sensor node arrived at the controller or actuator node. The control signals for the MCU and motors may be coupled in each simple period due to the network-induced time-varying delays.

II. METHOD OF APPROACH

In this paper, a robust oscillation damping control is proposed for the IMT powertrain system. The main contributions of this work are in the following respects:

1) With ECUs as well as actuators working under event-driven mode, network induced time-varying delays are considered in the controller design for IMT powertrain system.

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2) Robust energy-to-peak control is applied to ensure the transient response of the IMT powertrain system so as to its oscillation damping.
3) The control law is based on multivariable PI control, which can ensure the applicability and performance of the proposed controller in powertrain control system.

III. RESULTS AND DISCUSSION

Simulations are conducted in Matlab/Simulink to evaluate the proposed controller where a conventional PI controller was adopted for comparative analysis. The parameter values of the powertrain system are referred from some existing works. The designed simulation platform is shown as Fig. 3. There are mainly powertrain module, TCU module, MCU & Motor module and network module. Based on the reference vehicle speed signal and the measurements from powertrain system, TCU will calculate the desired torque command. With the help of MCU & Motor, practical torques would be applied to the powertrain dynamic system according to these commands. The time-varying delays in the control system will be generated from the network module.

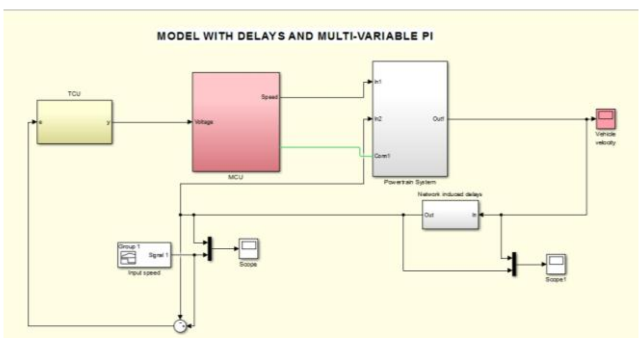

Fig 3. Simulation diagram for IMT powertrain system

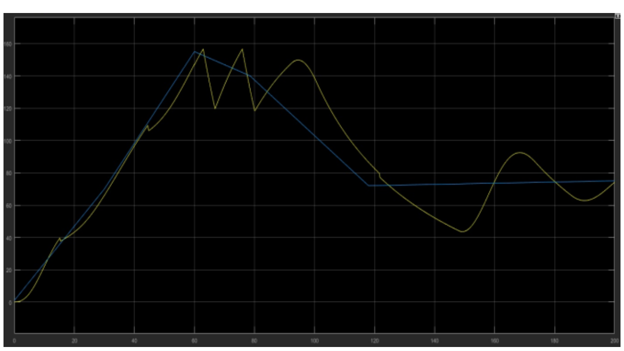

Fig 4. Conventional controller response without network

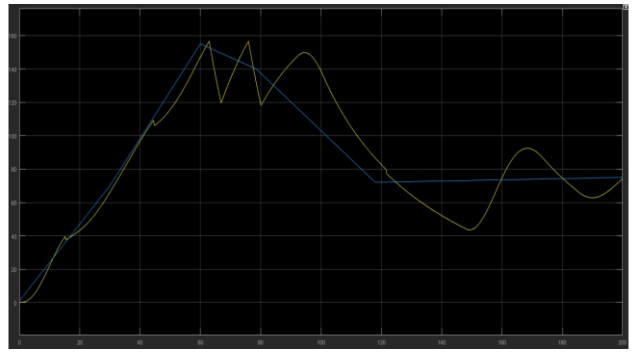

Fig 5. Conventional controller response with network

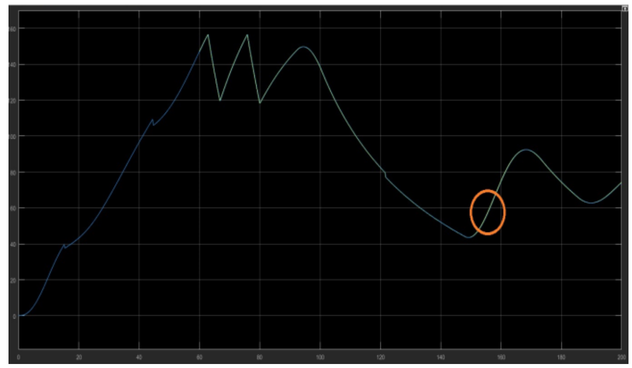

Fig 6. Network induced delays with conventional controller

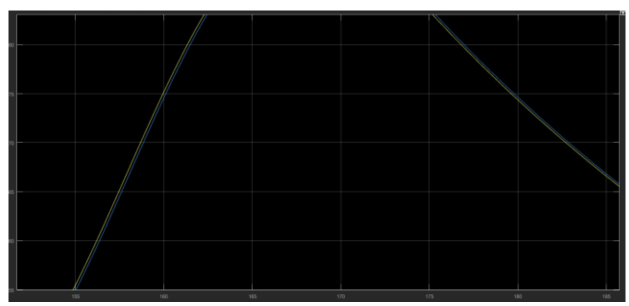

Fig 7. Maximum time varying delays with conventional controller

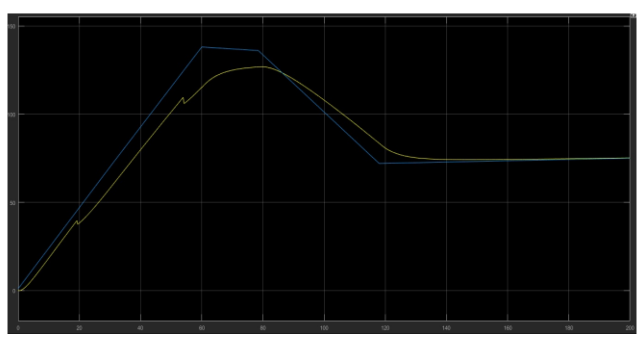

Fig 8. Proposed controller response with network

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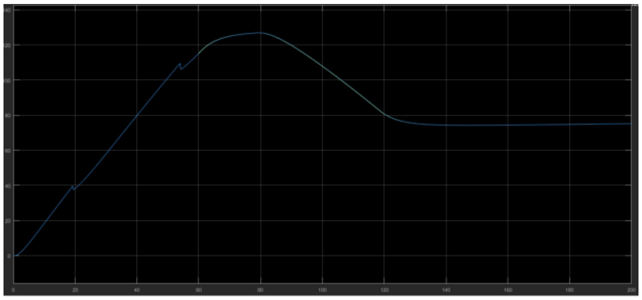

Fig 9. Network induced delays with proposed controller

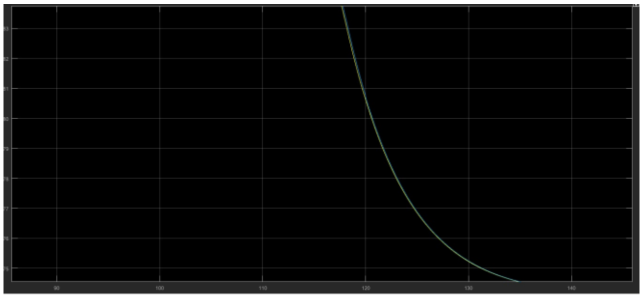

Fig 10 . Maximum time varying delays with proposed controller

Fig 4. Shows the conventional controller response i.e. the PI controller response and how the vehicle responds for the given reference speed. The vehicle response has some powertrain vibration which in turn causes the poor drivability. Fig 5. represents the PI controller response after the network induced time varying delays which has much vibrations compared to that of Fig 4. Fig 6. Shows the time varying delays present in the network with the conventional PI controller and the Fig 7. Represents the maximum delays in the network.

Fig 8. Is the representation of reduced oscillations in the vehicle powertrain with the implementation of proposed multivariable PI controller, when there is a reduction in the oscillation of the vehicle, the network induced time varying delays dynamically get reduced which is shown in Fig 9. The Fig 10. Represents the maximum delays in the network which is inevitable but it can be decreased using the proposed multivariable PI controller.

IV. CONCLUSION

In this paper, a robust energy-to-peak controller is developed to preserve the vehicle speed tracking performance as well as the oscillation damping capability for the integrated motor-transmission powertrain system in spite of network-induced time-varying delays and uncertain external load torque.

System augmentation technique is used to convert the original dynamic model into a delay-free model and the energy-to-peak performance is selected to ensure the robustness of the proposed controller. The control law adopted in the proposed controller is based on multivariable PI control. An acceleration scenario was carried out to show the effectiveness of the proposed controller. Compared with the conventional PI controller, proposed controller not only has good speed tracking performance but also the oscillation damping capability under ideal network condition. When the network-induced time-varying delays begin to appear, the conventional PI controller can result serious coalitions in the powertrain system, while the proposed controller can still maintain its good performance due to the controller's own robustness.

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