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Design and mathematical modeling of new electric vehicles

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Abstract

This paper presents the modeling and optimization of automatic control in electric vehicles (EVs). The performance and overall cost reduction of electric vehicles could be enhanced in multi-speed transmission with some challenges, such as avoiding jerk gearshift that will sometimes demonstrate to be incredible in the event of motor and clutch saturations. This work introduces explicit definitions to understand the jerk gearshift resulting from actuators or motor saturations. The gear shift includes transferring transmission torques from one friction clutch to another. The study of the influence of planetary gear sets on the gear shift dynamics trajectory with impact on the non-jerking. To improve the electric vehicle's performance, the number of gears in automatic transmission is being minimized, as the trucks which continuously increased. The structure of a multi-speed transmission could be optimized by double transitions shift with less difficulty. The simulations result illustrates that the non-overlapping of clutches' inertias phase in the dual transitions shifting could efficiently reduce the shift jerks. The torque phase overlap with the inertia phase of other clutches could be controlling the power loss at law level because of using less shift times. Additionally, this proposal offers tools to compare the transmission architecture through the conceptual designs for new electric vehicles.

Keywords: Mathematical modeling, New electric vehicles

1. Introduction

The continuous gear shift of electric vehicles is a required feature [1, 2]. Nevertheless, not all multi-rate transmissions are proficient in this technique [3, 4]. This capability could be provided by vehicle design engineers who should choose the transmission characteristics architecture to enhance the motor torque in continuous transfer from one transmission to another through gear shift [5, 6]. In current clutch saturation [7, 8] and motors [9], such uniform transmissions could nosedive to offer continuous gear shift [10, 11]. Recognized design methodology attributes a reputation to the theoretical enterprise stage, as its result has a big impact on the respite of the proposal scheme [12], and eventually, the quality of the final product [13, 14]. The derived train concept has the potential to meet a specific client's requirements [15, 16]. Possibly, the simplest design is by using a single motor with a fixed reduction ratio between the wheel and the motor [17, 18]. This concept offers excellent drivability but presents significant drawbacks for vehicle design, particularly in meeting performance specifications and operating the engine within its optimal efficiency range [19, 20]. This will especially become problematic in heavy vehicles. The natural development of the single-motor fixed-ratio idea is the introduction of multi-rate transmission [21, 22]. The simplest idea is the manual transmission, which consists of increasing gears on a bearing and a selected barreling of different gears to the transmission's shift to provide diverse transmission ratios [23, 24]. Since electric motors do not require to idle, the possibility exists to use physical transmissions without clutches between the transmission and the motors [25, 26]. To shift the gear, the motor's rotation is first abridged to zero, and then the initial gears are detached [27]. The motor's rate is coordinated with additional gear and betrothed, and finally reapplied the torque of the motor drive. In addition, the synchronization might help the shaft and gear engagements [28, 29]. In case of a proper performance, the gear shift has to be disengaged and engaged when no torque is predictable. Hence, to minimize this torque gap, the transmission architecture could be introduced typically as a clutch placed between the transmission output and the motors by using a gear shift. In electric vehicles, the use of an alternative to manual transmission is by automatic and dual-clutch transmission. The electric train could involve a mechanical continuous variable transmission to provide drivability.

Many approaches have been introduced in this field, but still some limitations in the different transmission parameters that will be improved in this paper as described in subsequent sections. The module that we address in this work is the transmission, which has been widely investigated for applications within traditional vehicles. Generally, an electric vehicle (EV) could offer necessary torques over a larger speed range than an internal combustion engine; therefore, electric vehicles do not require a multi-speed transmission, due to one-speed transmissions suffice. This structure is the most common obtainable on the present markets. Though given that torque and speed are limited, designers must arrive at a compromise between acceleration and grade aptitude on one hand, and top speeds on the other. For these reasons, higher-performance vehicles have been prepared with multi-speed transmissions. Selecting the appropriate transmission for a specific vehicle requires an approach that can quickly and accurately create models and evaluate various transmission types within the context of a complete electric vehicle. This paper relates to different research streams, such as [30]. The authors deal with EV controlling and designing optimizations from a system viewpoint. This is also known as EV co-design, and it is characteristically solved with curved optimizations or a derivative-free solver. To confirm computational docility, this method either adopts a fixed transmission effectiveness or disregards losses completely. The second relates to the transmission design and control optimizations at the component levels [31]. Though the optimization problem typically has component-specific objectives, like minimizing the noise and volumes or maximizing the strengths of the gear teeth, it leveraged a computationally expensive finite-elements model. The objective and the methodology do not connect well to the holistic, system-level perspective that is required in EV designing optimization.

2. Materials and methods

The SIMULINK environments are used to design and model the drive train under state flow that enhances the model by representing transmission control logic techniques. The MATLAB programs provide an efficient block set for designing and simulating the dynamic system and associated processing. In overall systems, the guide function, such as mode change or appealing new gains schedule, should respond to the event that might occur and conditions that develop over time. The resulting environment needs a capable language to manage these conditions and modes. In this work, the state flow validates the strength of these capacities through the execution of the functions of gear selection in automatic transmissions. These functions are combined with drive train dynamics in nature and instinctive manners by incorporating a state flow block in MATLAB/ SIMULINK. Figure 1 illustrates the flow of power in a typical automotive drive train, which is normally ordinary differential equations – the vehicles, engines, and four-speed automotive transmissions. The decisions and logic are complete in the transmission control and do not advance to formulate an equation. The unit of transmission control is better suited for state flow representations, which monitor the events resembling significant relations within the systems and take suitable actions as they happen.

The engine inputs are the throttle, and the engine is linked to the impellers of the rotation converters that couple with the transmissions. The torque converter input/output could be expressed as a function of the turbine and engine's rate, and the power flow direction is assumed to be from the impellers to the turbines. In addition, the model of transmission is implemented through a static gear ratio, assuming a very small shifting time. The throttle openings are one of the inputs to the engines. The engines are connected to the impellers of the torque converters, which couple them to the transmission as shown in the equation below:

$$I_{ei}N_e = T_e T_i \qquad (1)$$

Where Ne is the engine speed, Iei is the moment of inertia for the impeller and engine, and Te and Ti are the torque of the impeller and engine.

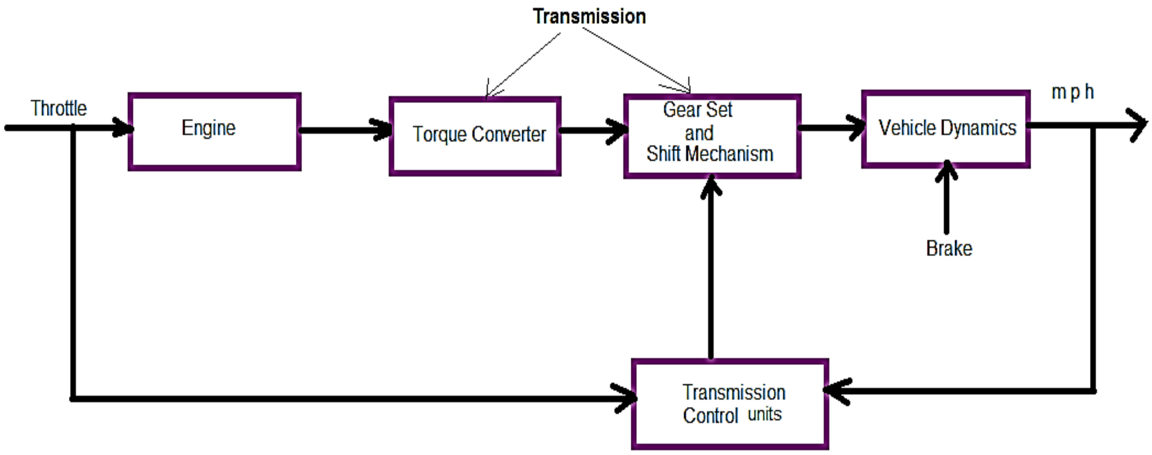

Figure 1. General drive train systems diagrams

The input/output characteristics of the torque converters could be expressed as a function of the engine's speeds and the turbine's speeds. In this model, the power flow direction is always supposed to be from the impellers to the turbines as:

$$T_i = \frac{{N_e}^2}{K^2} \qquad (2)$$

And

$$K = f_2 \frac{N_{in}}{N_e} = K - Factor\ capacities$$

$$N_{in} = turbine\ speed = transmission\ input\ speed\ (RPM)$$

$$R_{TQ} = f_3 \frac{N_{in}}{N_e} = torque\ ratio$$

The transmission models are implemented through static gear ratios, supposing a smaller shift time as follows?

$$R_{TQ} = f_4\ (gear) = transmission\ ratios \qquad (3)$$

$$R_{out} = R_{TR} T_{in}$$

$$N_{in} = R_{TR} N_{out}$$

$$T_{in}, T_{out} = torque\ of\ transmission$$

$$N_{out}, N_{in} = speed\ of\ transmission\ (RPM)$$

The last drives, inertia, and dynamic variable loads constituted the vehicle's dynamics as follows:

$$I_v N_w = R_{fd}\ (T_{out} - T_{load}) \qquad (4)$$

Where I_v is the vehicle inertia, N_w is the wheel speeds, R_{fd} is the ratio of final drive, $T_{load} = f_5\ (N_w) = the\ torque\ of\ the\ load$

The load torques include road loads and braking torques. The road loads are the sum of friction and aerodynamic loss as expressed below:

$$T_{load} = sgn(mph)(R_{loado} + R_{load2}mph^2 + T_{brake}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

$$T_{load}, T_{brake} = torque\ of\ brake\ and\ load$$

$$R_{load0} + R_{load} = frictions\ and\ aerodynamics\ drag\ coefficient$$

$$mph = linear\ velocity\ of\ vehicle$$

The models program the shift point for the transmission rendering to the schedule shown in Figure 2. For the assumed throttles in an assumed gear, there is a unique vehicle speed at which upshifts take place.

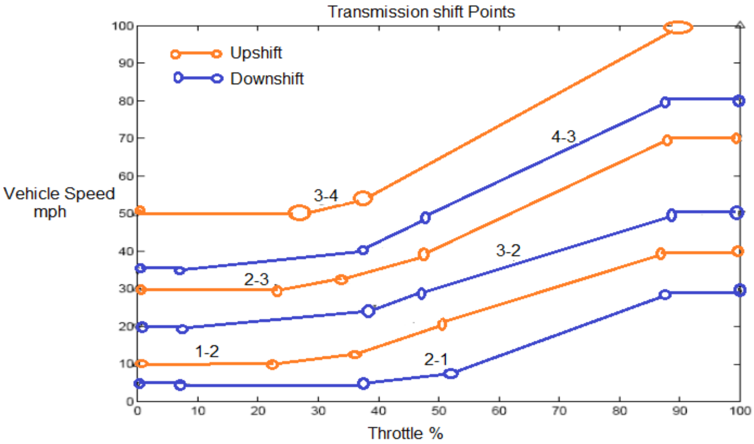

Figure 2. Shifting schedules

The suggested model illustrated in Figure 3 represents the top-level modeling in MATLAB/SIMULINK environments. This model comprises the modules, including engine, vehicle, shift logics, and transmission. The shift logic is used to control the ratio of transmission. The model inputs are in the form of torque and throttle. The subsystem of the engine consists of a two-dimensional table that interpolates the torque of the engine against the throttle and the speed of the engine. The whole subsystem inside this model is illustrated in Figures 5, 6, 7, 8, and 9.

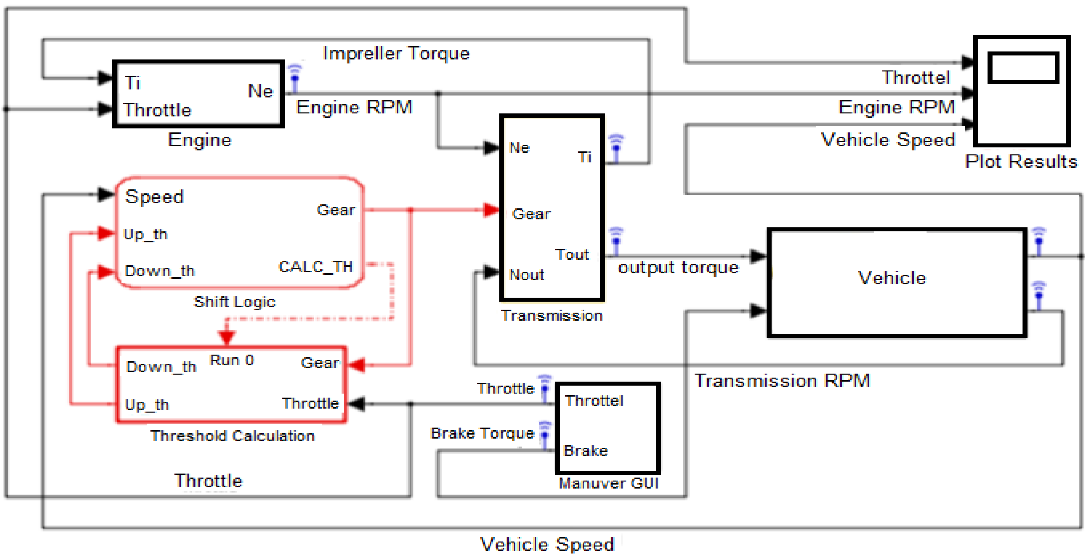

Figure 3. Modeling and simulation model

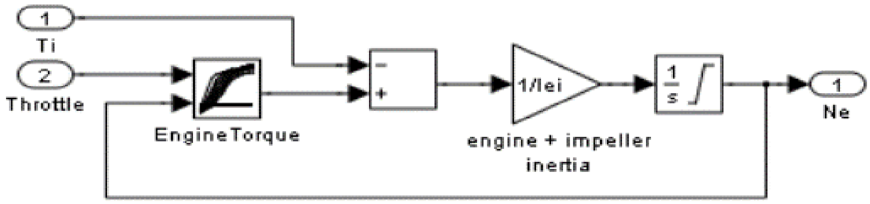

Figure 5. Subsystem of the engine

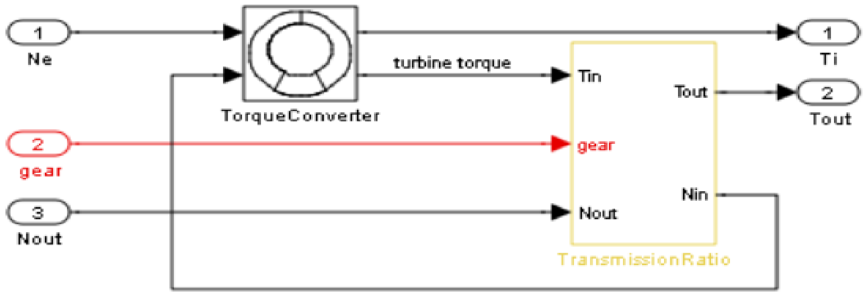

Figure 6. Subsystem of transmission

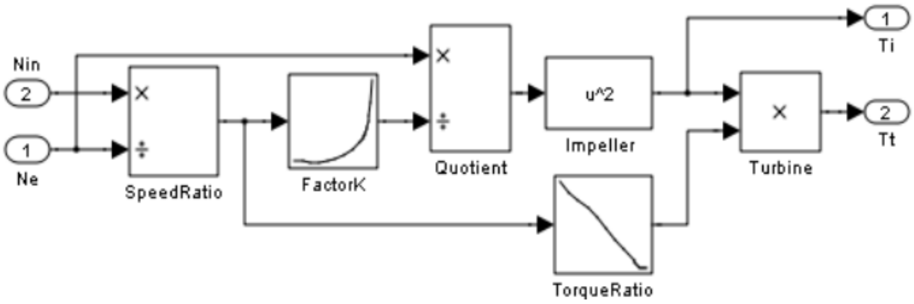

Figure 7. Subsystem of torque converters

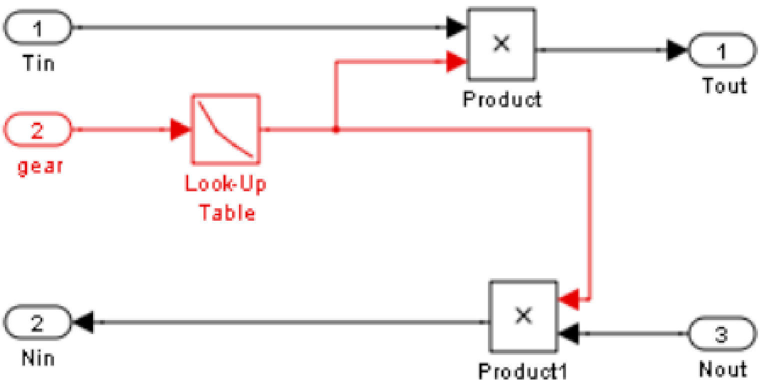

Figure 8. Subsystem of transmission gear ratio

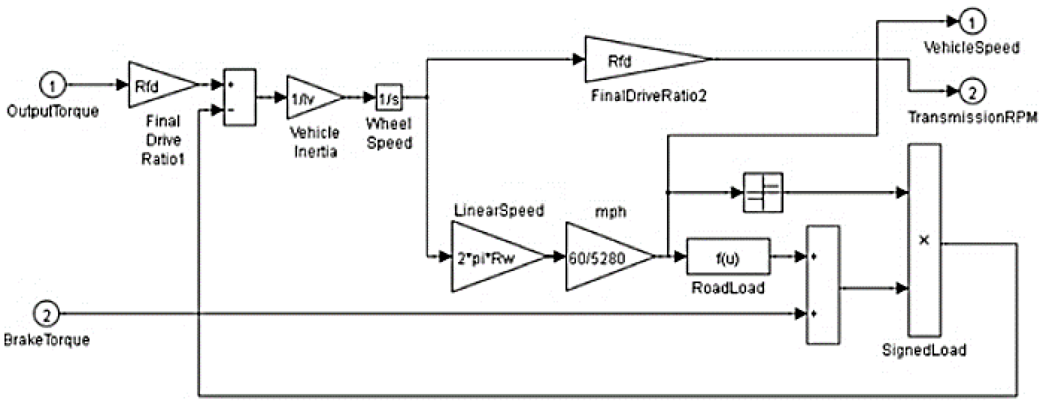

Figure 9. Subsystem of the vehicle section

The state flow is utilized to define the input as vehicle speed, throttle, and desired gear output numbers. All chart is executed as discrete-time systems, which are sampled every 40 ms. Figure 10 shows the state flow functionality in the blocks for shift logic transmission.

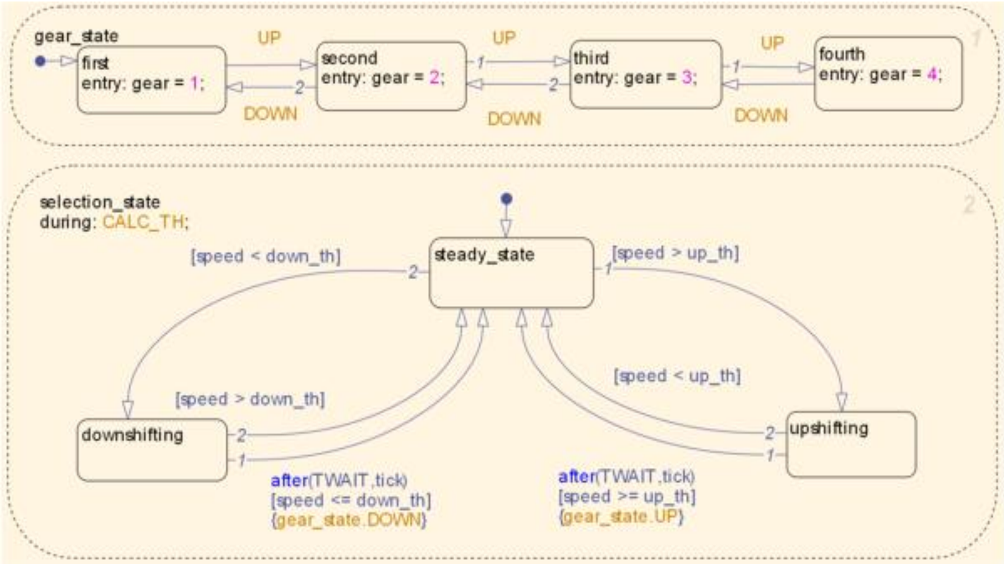

Figure 10. Transmissions shift logics, state flows

In case the speed of vehicles no longer satisfies the shift conditions, the confirming states modelling ignores the shifts and the transmission returns to stable states because of noisy conditions. In addition, when the shift conditions remain effective for the period of the model's transition, via low junctions depend on the current gear. Then, the model activates the steady state again after transition via the central junction.

3. Results and discussion

After the model was running, the results could be displayed in the time scope as shown in Figure 11.

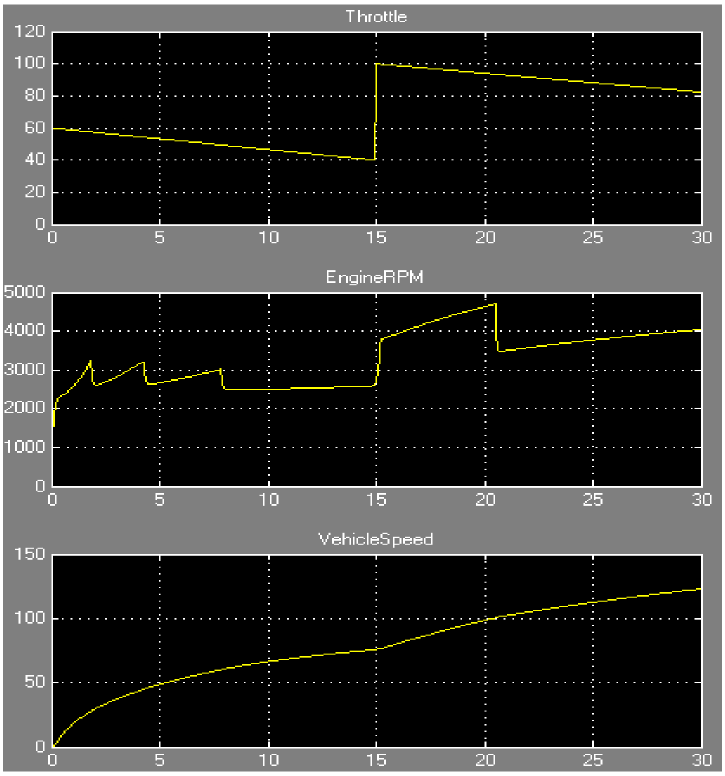

Figure 11. The results of the suggested model

The torque converters and engine torque characteristics resulting from the model simulation are illustrated in Figures 12 and 13. The engine speed starts at 1000 RPM, and the vehicle speeds start at zero.

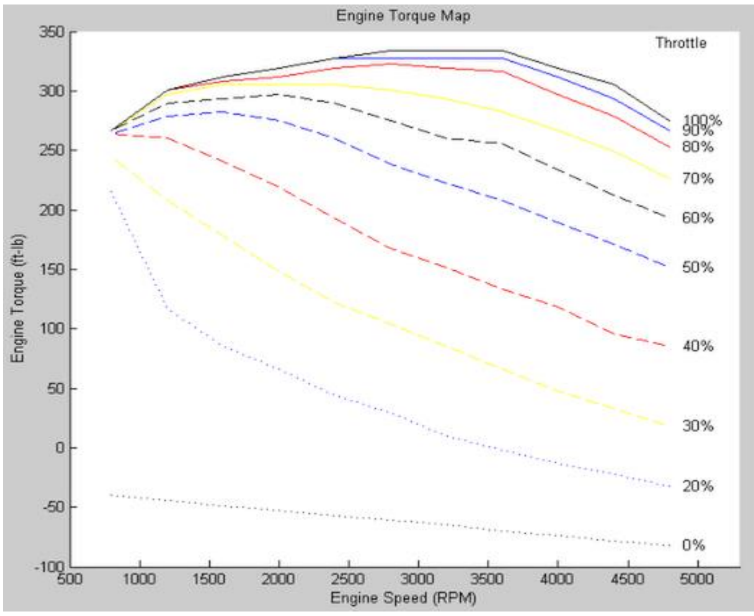

Figure 12. The maps of engine torque

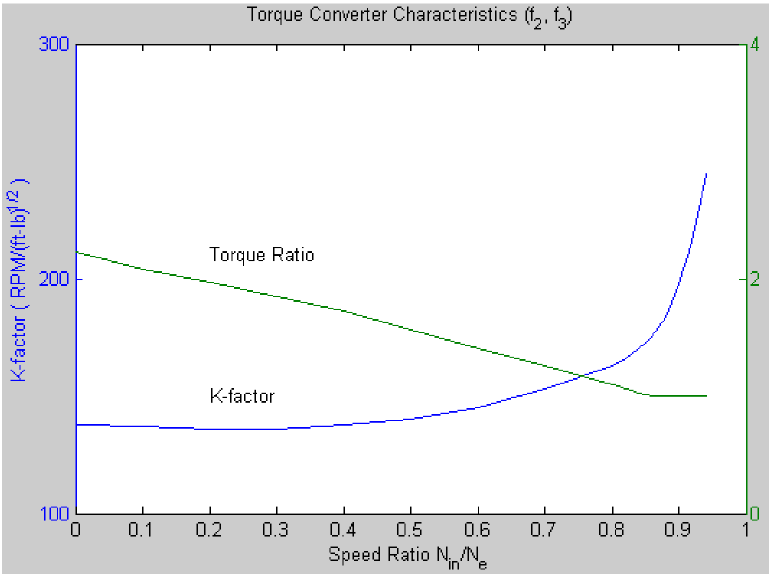

Figure 13. The characteristics of the torque converter

The baseline result plot illustrated in Figure 14 under default parameters as drive step to 70% and throttle at t = 0, and the engines are directly responding through extra rates. This will bring a low rate ratio transversely the torque converters; therefore, a large torque ratio is required. Quickly, the vehicle accelerated and the engines and the gain rate of the vehicle till the time reaches 2 seconds, at which the time upshift occurs. The speed of the engine dropped abruptly and resumed the acceleration, and the vehicle speed remains much smoother because of the huge inertia.

At t = 15 seconds, the throttle and drive step at 100% may be a typical pass maneuver, and the transmission downshifts to third gears while the engine jumps from 2600 to 3700 RPM with engine torque increasing. The vehicles accelerate to 100 mph and then shift to overdrive during 21 seconds. In fourth gear, the vehicle cruises for a reminder of the simulation conditions. This study can be incorporated with techniques of low-pass filter [31], bandpass filters [32, 33], and other filtering techniques and power dividers in [34, 35].

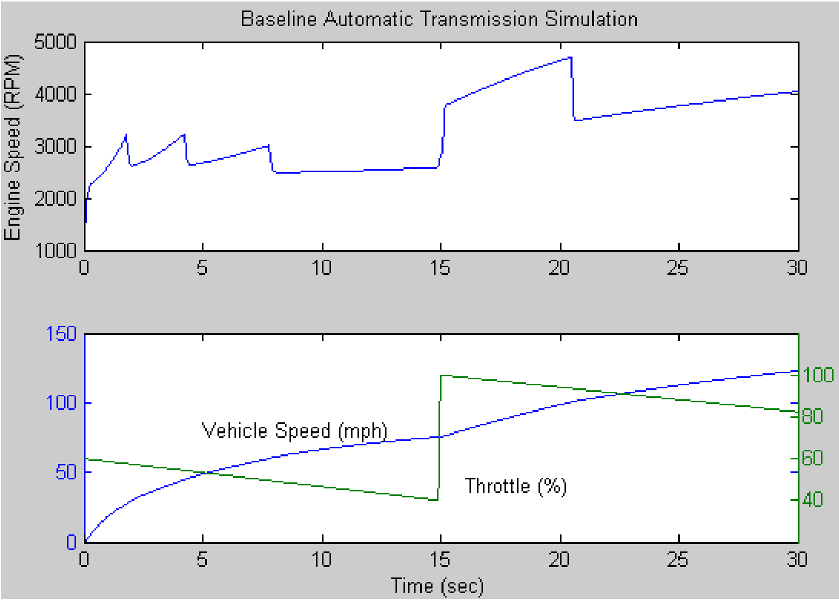

Figure 14. Simulation of maneuver time

4. Conclusions

The development of gear shift transient optimization is introduced in this paper with system enhancements in the manner of modular manner by replacing the transmission or engine with complex modeling. Thus, to build a big system inside the proposed structure through step-wise refinements, the SIMULINK signal processing and state flow control logic enables the model construction in both visually intuitive and efficient techniques. In this work, we aimed at connecting the gaps in transmission modeling for designs and control, between simple models for EV models for separate component design optimizations, to fast explore the extensive electric vehicle design space. The design and optimization framework is instantiated for many types of transmissions by systematically creating a formation, an analytic model of the component that it comprises, and optimizing the shift control with a global optimal guarantee. This paper introduces the following path for future research; first of all, our frameworks can be validated more extensively with a high-fidelity model. Second, the impacts of a high number of gears, possibly combined with more challenging performance requirements, can be willingly explored with our frameworks. Lastly, we could combine our transmission frameworks with EV and battery size to holistically design electric vehicles.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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