Automatic Transmission Controller Using State Flow

<u>Abstract</u>: Hydraulic technology can be used to capture and transfer high levels of energy extremely quickly and have a longer operating life compared with similarly sized electric systems. This technology replaces a conventional drive train with a hydraulic one, which eliminates the need for a mechanical transmission and driveline. To explore an optimal gear shifting strategy with best fuel economy for a seven-speed automatic transmission used on a hydraulic hybrid vehicle, a strategy is designed with a highest possible gear criterion as long as the torque requirement can be satisfied, except for braking process and torque demanding situations. The optimization strategy takes several other criteria into consideration, such as high motor displacement criterion, to improve efficiency and fuel economy.

Features of drive train system

In many systems, though, supervisory functions like hanging modes or invoking new gain schedules must respond to events that may occur and conditions that envelope over time. As a result, the environment requires a language capable of managing these multiple modes and developing conditions. In the following example, State flow shows its strength in this capacity by performing the function of gear selection in an automatic transmission. This function is combined with the drive train dynamics in a natural and intuitive manner by incorporating a State flow block in the Simulink block diagram.

A. Analysis and Physics:

Fig.1. shows the power flow in a typical automotive drive train. Nonlinear ordinary Differential equations model the engine, four-speed automatic transmission, and vehicle. The model discussed in this example directly implements the blocks from Fig 1 as modular Simulink subsystems. On the other hand, the logic and decisions made in the Transmission Control Unit (TCU) do not lend themselves to well-formulated equations. TCU is better suited for a State flow representation. State flow monitors the events which correspond to important relationships within the system and takes the appropriate action as they occur.

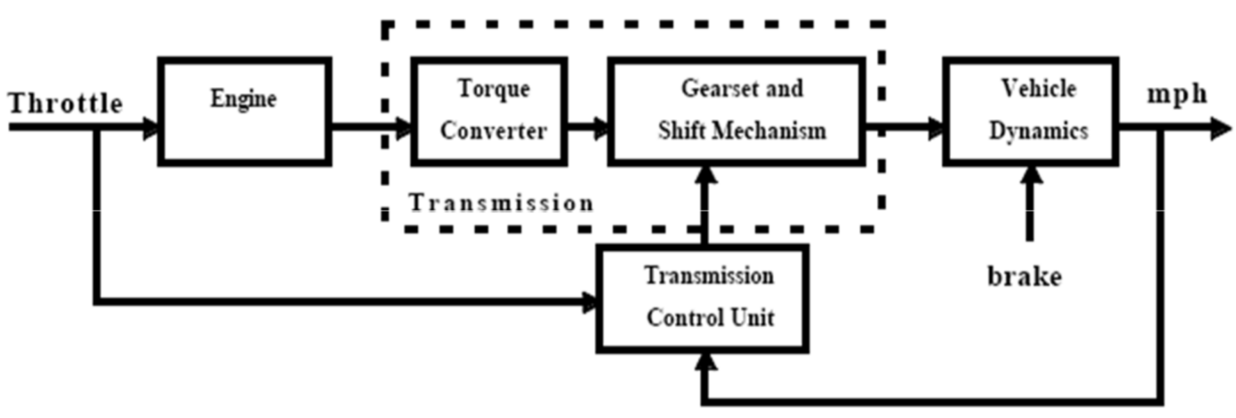


Fig.1: Generic block diagram for a drive train system

B. Equations:

Equation 1

$$I_{ei}\dot{N}_e = T_e - T_i$$

$I_{ei} =$ moment of inertia of the engine and the impeller

$N_e =$ engine speed (RPM) $T_e, T_i =$ engine and impeller torque

The input-output characteristics of the torque converter can be expressed as functions of the engine speed and the turbine speed.

Equation 2

$$T_i = \frac{N_e^2}{K^2}$$

$K = f_2\frac{N_{in}}{N_e} =$ K-factor (capacity)

$N_{in} =$ speed of turbine (torque converter output) $=$ transmission input speed (RPM)

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

The transmission model is implemented via static gear ratios, assuming small shift times (see Equation 3).

Equation 3

$R_{TR} = f_4(gear) =$ transmission ratio

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

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

$T_{in}, T_{out} =$ transmission input and output torques

$N_{in}, N_{out} =$ transmission input and output speed (RPM)

The final drive, inertia, and a dynamically varying load constitute the vehicle dynamics (see Equation 4).

Equation 4

$$I_v\dot{N}_w = R_{fd}(T_{out} - T_{load})$$

$I_v =$ vehicle inertia

$N_w =$ wheel speed (RPM)

$R_{fd} =$ final drive ratio

$T_{load} = f_5(N_w) =$ load torque

The load torque includes both the road load and brake torque. The road load is the sum of frictional and aerodynamic losses (see Equation 5).

Equation 5

$$T_{load} = sgn(mph)(R_{load0} + R_{load2}mph^2 + T_{brake})$$

$R_{load0}, R_{load2} =$ friction and aerodynamic drag coefficients

$T_{load}, T_{brake} =$ load and brake torques

Modelling of conventional and proposed system

The Simulink model shown in below figure is composed of modules which represent the engine, transmission, and the vehicle, with an additional shift logic block to control the transmission ratio. User inputs to the model are in the form of throttle (given in percent) and brake torque.

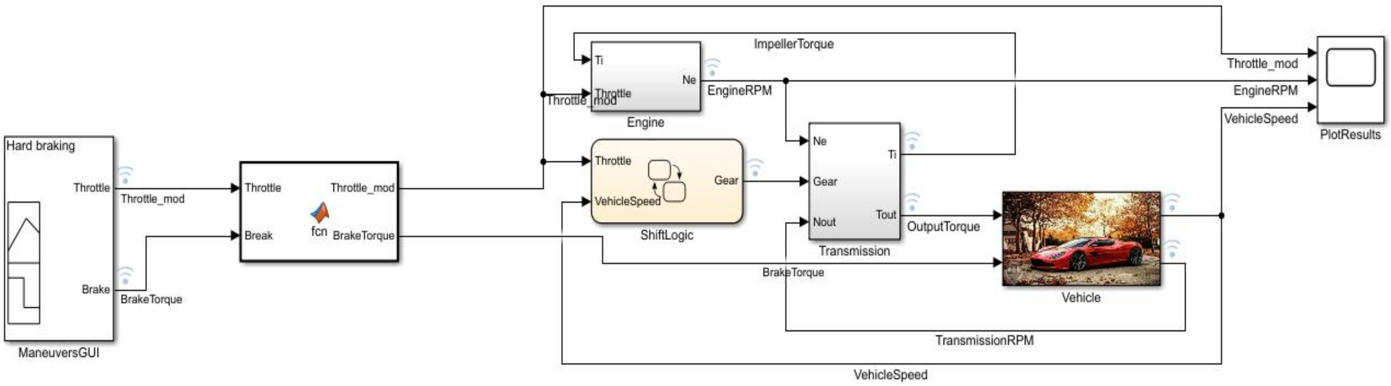


Fig.a: Model diagram and sample simulation results

➤ The Engine subsystem consists of a two-dimensional table that interpolates engine torque versus throttle and engine speed. Fig.b shows the composite Engine subsystem. Double click on this subsystem in the model to view its structure.

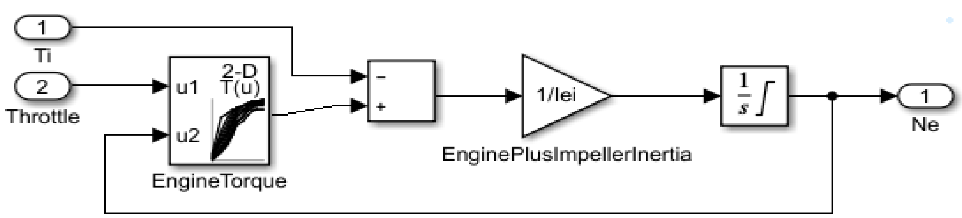


Fig.b: Engine subsystem

➤ The Torque Converter and the Transmission Ratio blocks make up the Transmission subsystem, as shown in Fig.5. Double click on the Transmission subsystem in the model window to view its components.

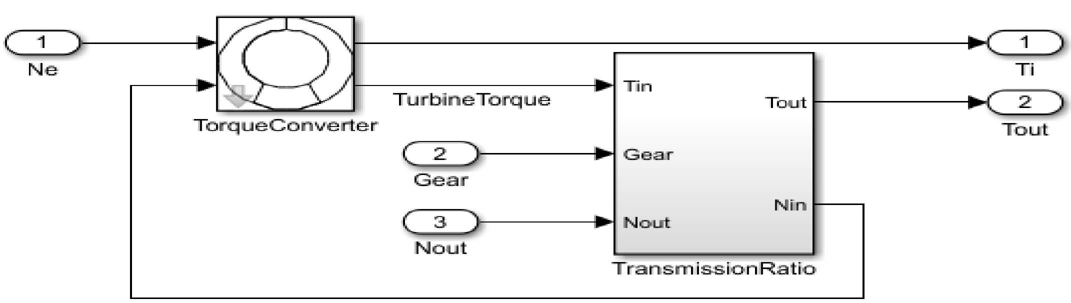


Fig.c: Transmission subsystem

The Torque Converter is a masked subsystem, which implements Equation 2. To open this subsystem, right click on it and select Mask

- Look under Mask from the drop-down menu. The mask requires a vector of speed ratios (Nin/Ne) and vectors of K-factor (f2) and torque ratio (f3).

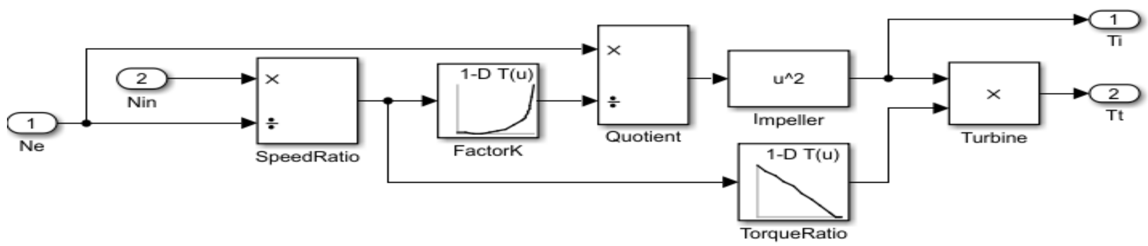


Fig.d: Torque converter subsystem

- The transmission ratio block determines the ratio shown in Table 1 and computes the transmission output torque and input speed, as indicated in Equation 3. Fig.7 shows the block diagram for the subsystem that realizes this ratio in torque and speed.

Table 1: Transmission gear ratios

Gear	Rtr = Nin/Ne
1	2.393
2	1.450
3	1.000
4	0.677

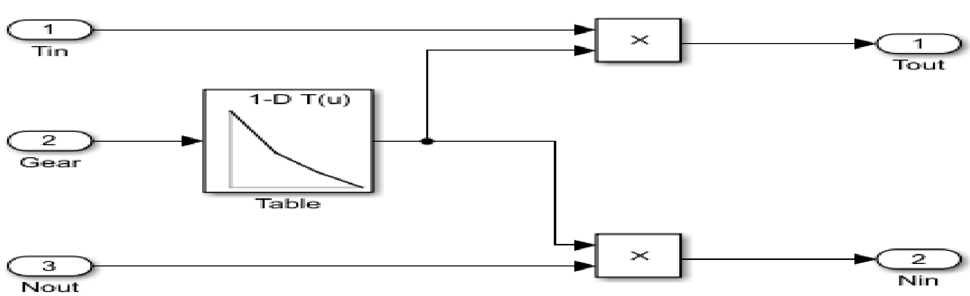


Fig.e: Transmission gear ratio subsystem

- The State flow block labelled Shift Logic implements gear selection for the transmission. Double click on Shift Logic in the model window to open the State flow diagram. The Model Explorer is utilized to define the inputs as throttle and vehicle speed and the output as the desired gear number.

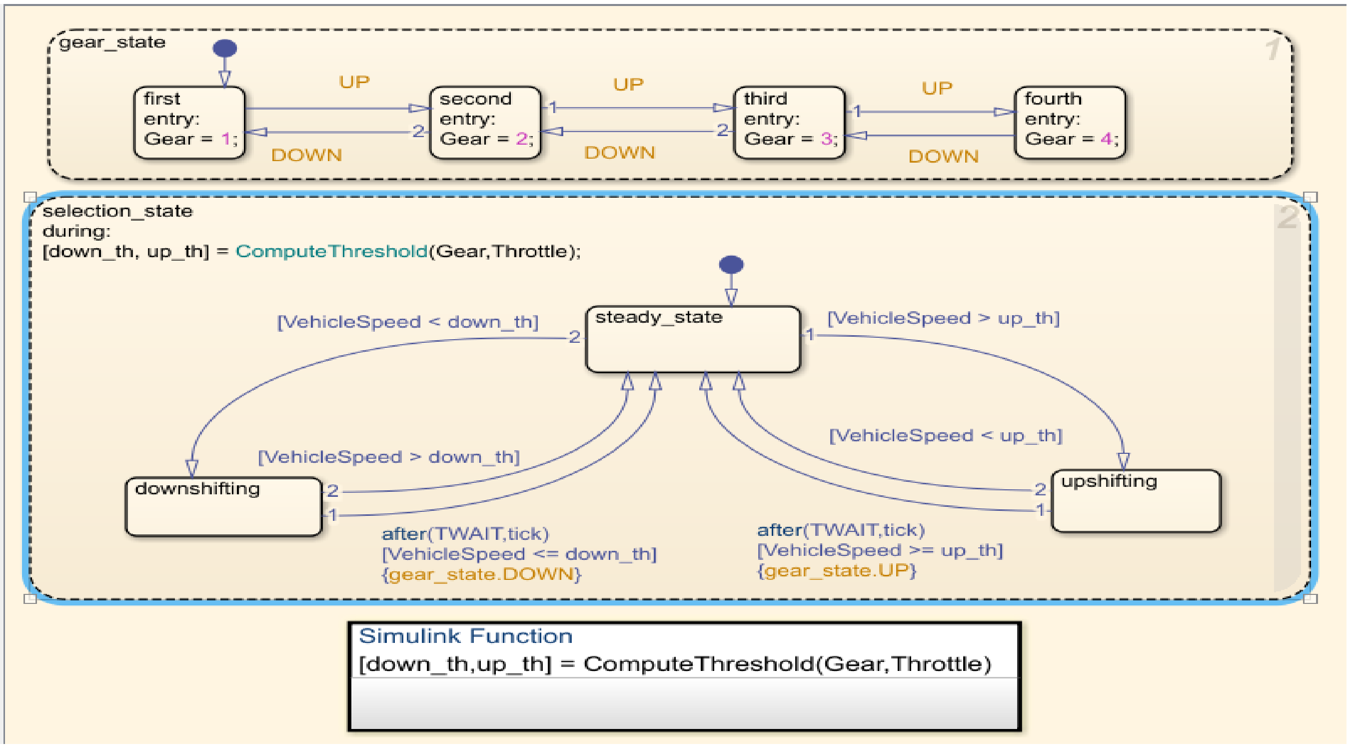


Fig f: State flow diagram of the transmission shift logic

➢ The shift logic behaviour can be observed during simulation by enabling animation in the State flow debugger. The selection state (always active) begins by performing the computations indicated in its during function. The model computes the up shift and downshift speed thresholds as a function of the instantaneous values of gear and throttle. While in steady state, the model compares these values to the present vehicle speed to determine if a shift is required. If so, it enters one of the confirm states (up shifting or downshifting), which records the time of entry.

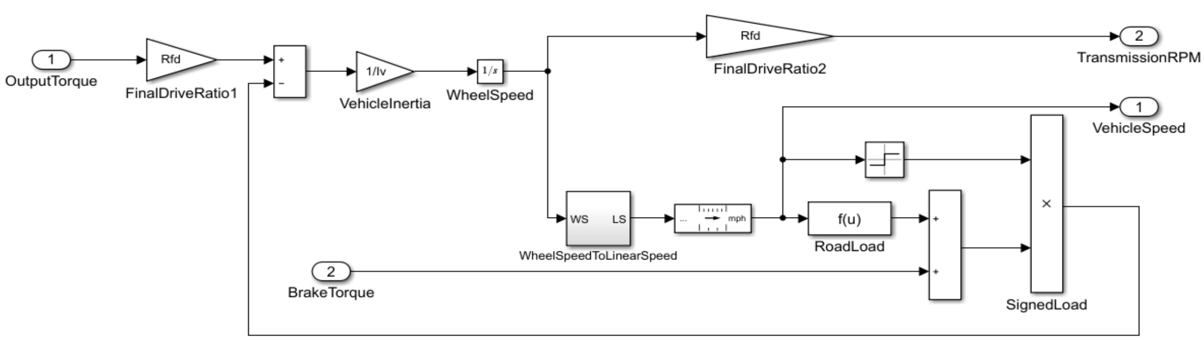
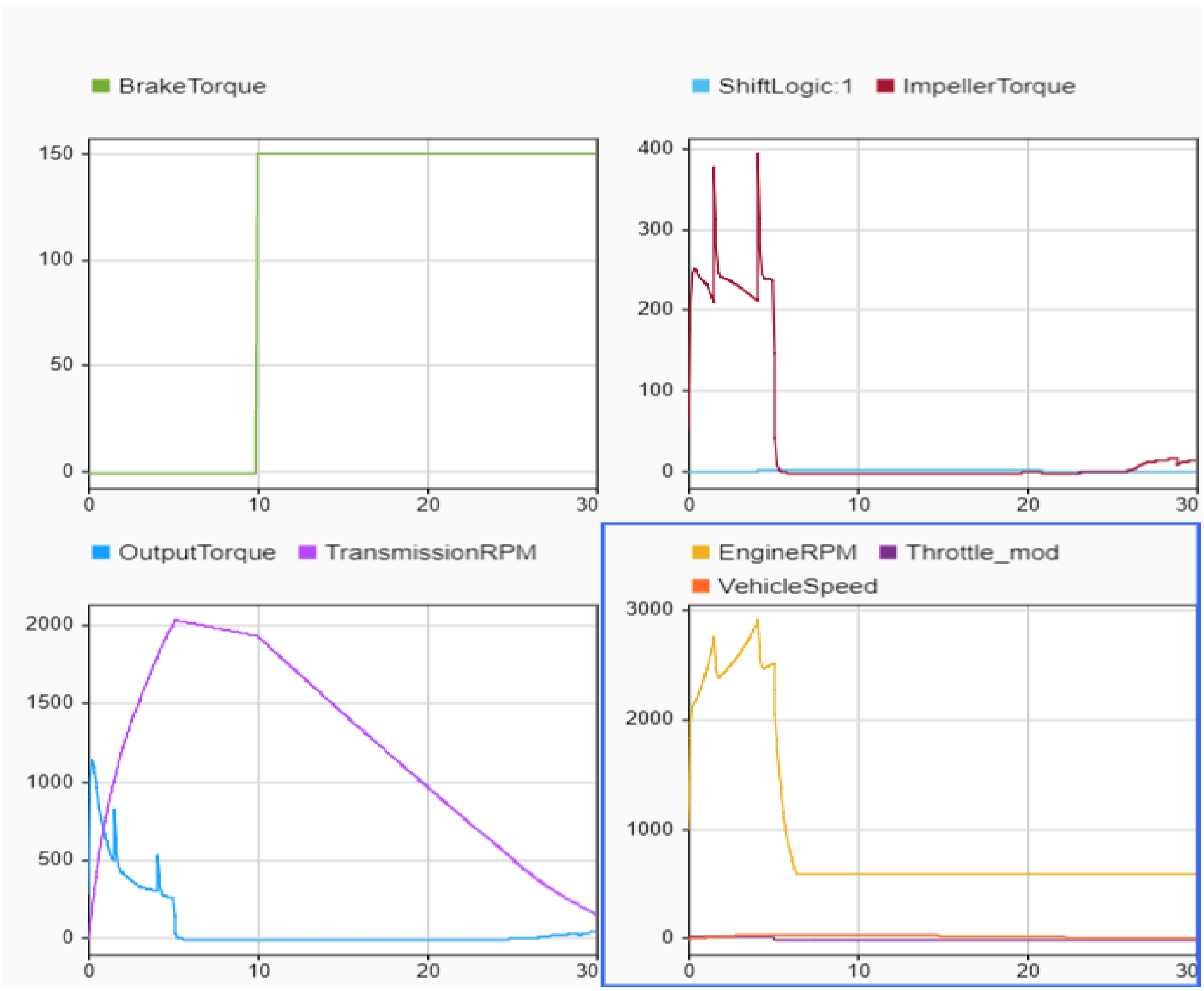


Fig g: Vehicle subsystem (masked)

- If the vehicle speed no longer satisfies the shift condition, while in the confirm state, the model ignores the shift and it transitions back to steady state. This prevents extraneous shifts due to noise conditions.
- If the shift condition remains valid for a duration of TWAIT ticks, the model transitions through the lower junction and, depending on the current gear, it broadcasts one of the shift events. Subsequently, the model again activates steady state after a transition through one of the central junctions.

- The shift event, which is broadcast to the gear selection state, activates a transition to the appropriate new gear. For ex., if the vehicle is moving along in second gear with 25% throttle, the state second is active within gear state, and steady state is active in the selection state.
- The during function of the latter, finds that an upshift should take place when the vehicle exceeds 30 mph. At the moment this becomes true, the model enters the upshifting state. While in this state, if the vehicle speed remains above 30 mph for TWAIT ticks, the model satisfies the transition condition leading down to the lower right junction.
- This also satisfies the condition [|gear == 2|] on the transition leading from here to steady state, so the model now takes the overall transition from upshifting to steady state and broadcasts the event UP as a transition action. Consequently, the transition from second to third is taken in gear state which completes the shift logic.
- The Vehicle subsystem uses the net torque to compute the acceleration and integrate it to compute the vehicle speed, per Equation 4 and Equation 5. The Vehicle subsystem is masked. To see the structure of the Vehicle block, right click on it and select Mask > Look Under Mask from the drop-down menu.
- The parameters entered in the mask menu are the final drive ratio, the polynomial coefficients for drag friction and aerodynamic drag, the wheel radius, vehicle inertia, and initial transmission output speed

Results



CONCLUSION

One can easily enhance this basic system in a modular manner, for example, by replacing the engine or transmission with a more complex model. We can thus build up large systems within this structure via step-wise refinement. The seamless integration of State flow control logic with Simulink signal processing enables the construction of a model which is both efficient and visually intuitive.