11th International DAAAM Baltic Conference
“INDUSTRIAL ENGINEERING”
20-22nd April 2016, Tallinn, Estonia

MODELING AND SIMULATION OF DUAL CLUTCH TRANSMISSION AND HYBRID ELECTRIC VEHICLES

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Abstract: *Worldwide, dual clutch transmission (DCT) is highly integrated into automotive industry for its unique effectiveness, in terms of cost and fuel efficiency. This paper presents the main features of dual clutch transmission gearbox in conventional vehicle, developed and presented, along with a series-parallel hybrid vehicle model; both are modeled and simulated using MATLAB and Simulink. To verify the validity of the presented model, a comparative study is elucidated between the simulation results of both DCT conventional vehicles and the presented HEV model. The significance of this paper is to compare between DCT conventional vehicles and hybrid vehicles in terms of fuel consumption and performance efficiency.*

Key words: hybrid, modeling, dual clutch transmission, simulation, powertrain, conventional vehicles.

1. INTRODUCTION

This paper studies the modeling and simulation of the (DCT) vehicle as a transmission architecture, which uses two clutches, without having a clutch pedal, acting independently. The transmission is controlled by sophisticated electronics, solenoids and hydraulics. In other words, gear shifting is automatically controlled, while its actual construction is two parallel manual transmissions. The two clutches are alternatively engaged to produce different speed arrangements, and through the controlling of clutch engagement condition, the power transmitted through the whole system [1].

It is considered that (DCT) has much more sensitivity to input torque, compared to the conventional automatic transmission, as the torque converter is not present in (DCT) [1] [2]. On the other hand, Hybrid cars generally can be classified to three main types; series, parallel and series-parallel, according to the powertrain architecture and configuration. The third option is the series-parallel configuration, which combine the advantages of both previous configurations and can be characterized by providing the necessary power flow for driving the wheels from the engine, and if needed, the electrical power provided by the electrical path, devised by the planetary gear used in the configuration, together [3] [4]. Therefore, considering hybrid vehicles as an option is an advanced step towards a cleaner environment with the possibility to have several power resources with an electric battery along with the traditional gasoline resource.

Previous researches investigated the performance of hybrid vehicles using specific configuration, different control methods, and drive cycles. In [4], UDDS and HWFET drive cycles were used to evaluate efficiency simulation results using supervisory control runs at different modes, demonstrated by flowcharts. In [5], US06 HWY and UK BUS drive cycles were used to examine the HEV (Hybrid Electric Vehicle) model’s performance with a Stateflow control method.

While in [9] [10], fuzzy control method was applied for optimizing the operational efficiency for hybrid. Design of a controller for a vehicle tracking on optimal path is referred in [11].

This paper carries the modeling design and simulations of DCT and compared to HEV. The contents of the paper are as follows: part 2 presents the design of DCT model, part 3 introduces the design of HEV model, part 4 briefs on the controllers, part 5 summaries resulted simulations, and finally, part 6 concludes key outcomes and recommendations.

2. DESIGN OF DCT MODEL

As shown in figure 1, (DCT) working principle can be explained as it consists of two main clutches and each clutch is connected to a set of gears, odd and even. In the case mentioned here, odd and even gears are connected to clutch 1 and 2 respectively. Therefore, for example, in case of moving from standing still position to an accelerating behavior, as the motor will be ready to drive the vehicle to make it operating in electric mode after the second gear is selected, there will be no power loss during shifting between gears. The main characteristic that differs (DCT) than any other transmission architecture is the ability to preselect the next gear used based on the predicted vehicle speed; this can be done using Stateflow control or fuzzy control methods. Thus, using a modified dual clutch transmission modeled by MATLAB and Simulink, including the clutches, gears and transmission controller, will be adequate and convenient for that purpose [5] [6].

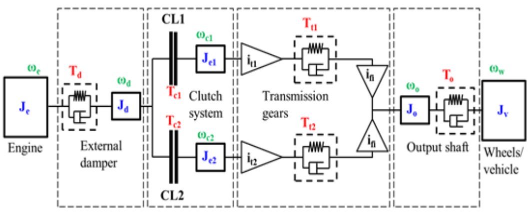

Fig. 1. Powertrain model of the (DCT) [7]

Dual clutch transmission, as shown in fig. 1, is modeled in SimDriveline. It can be noticed that it contains two main clutches with set of odd and even gears connected to each one of them both. Gear ratio is based on the torques and motion of the base and follower axes, and can be given by:

$$G_{fb} = T_f / T_b = \omega_b / \omega_f \quad (1)$$

The friction clutch, which is responsible for transferring the torque between the two axes, is defined by three different operating states.

1-Engaged but slipping:

$$T_{transfered} = C\mu(\Delta\omega)P \quad (2)$$

2-Unengaged: $T_{transfered} = 0$

3-Locked: $T_{transfered} = T$

Synchronizers used to adopt the clutch models in the SimDriveline environment. The logic for the synchronizer model shows the transmission shift controller. The differential is modeled as a planetary bevel gear train using SimDriveline, and simple transforming torque with a variable term i depending on the selected gear transmission ratios [3] [5], as shown in the following equation.

$$\omega_b = 0.5 * i_a * (\omega_{f1} + \omega_{f2}) \quad (3)$$

The transmission controller of (DCT) consists of shift state controller; it preselects the gear according to the current and desired vehicle speed, as mentioned above. This can be characterized by gearshift schedule.

3. DESIGN OF HEV MODEL

The sketch of the HEV model is shown in fig. 2. It consists of several main components; ICE (Internal Combustion Engine), electric motor and DC-DC converter, battery, vehicle dynamics, it will be discussed separately, and all the abbreviations used in the equations will be in appendix A. Equations are withdrawn for each element as follows [3] [5] [6]:

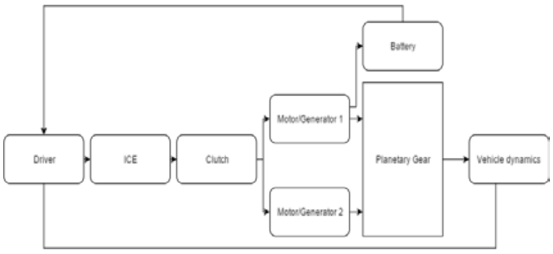

Fig. 2. HEV model sketch

3.1 Driving Cycle and Driver

Driving cycle is acting as the first input to the driver, which can be characterized by the acceleration and velocity profile as function of time. Driving cycles can be downloaded directly from the internet, as there are several standard driving cycles to test different powertrains using distinguished driving styles. FTP75 (Federal Test Procedure) and NYCC (NewYork City Cycle) will be used in the presented configuration. The forces affect the driver behavior are Gravitational force, Aerodynamic force, Rolling Resistive force. They all can be summed to provide the total force demanded to know the torque required by the Driver, as in Eq. (4), (5):

$$T_{TR} = rF_v = r(F_r + F_g + F_a + ma + PI) = r[mg(C_0 + C_1 v_{dc}) + 0.5\rho C_d A_f v_{dc}^2 + Mg\sin\theta + K_p \Delta v + K_i \int \Delta v dt] \quad (4)$$

$$\Delta v = v_{dc} - v_{actual} \quad (5)$$

3.2 Internal Combustion Engine

The engine is a spark-ignition type, which is modeled by specifying the demanded torque as a fraction of maximum torque possible. Therefore, it can be said that the torque of the engine is simply a function of v_{dc} and the driver signal distinguished by the pedal.

$$T_{engine} = f(v_{dc}, \text{throttle signal}) \quad (6)$$

3.3 Electric Motor and converter

In this case, the DC-DC converter is used to boost the voltage from the battery to the volts value required in the DC network, which is used to drive the motor. The Motor is modeled using SimElectronics and DC-DC converter was modeled using SimScape. The motor is a servomotor model with closed-loop torque control, and has the connections to the mechanical part and the electrical part of the HEV.

3.4 Battery

The battery model is a basic generic battery, which can be described with this equation:

$$V = V_0 * [1-(\alpha(1-x)/(1-\beta(1-x)))] \quad (7)$$

The battery also is a function of State of Charge (SOC), which will be discussed in mode logic description.

3.5 Vehicle and tire dynamics

It is developed via SimDriveline models, which vehicle parameters can be specified and taken into consideration easily. Volkswagen Golf R was chosen and all the specifications required for the vehicle model parameters are found in appendix B.

4. DESIGN OF CONTROLLER

4.1 HEV controller

Stateflow method is chosen due to its fidelity and reliability in complex transitions between modes [6]. The whole HEV controller is based on Mode Logic and modes are assigned using the vehicle speed, SOC, engine speed and brake signal data to choose either enabling the motor, the generator or the engine. The exact modes, which the vehicle can operate in.

4.2 Engine speed controller

This controller is a PI controller, the throttle output value determined by three input parameters; the control command coming from the mode logic block, engine speed demand, and actual engine speed.

4.3 Generator controller

This controller is a PI controller, the Generator torque output required is controlled by five different input parameters; first is the enabling signal comes from mode logic block, second is engine speed demanded, third is the motor speed demanded, and then the obtained torque demanded from the battery and finally the Generator speed.

4.4 Motor controller

The Motor torque required is controlled by three input parameters. First, the enabling signal from the mode logic block, and then the motor speed demanded, and finally the actual speed of the motor.

4.5 Battery Charge Controller

The battery charge controller is responsible for providing the generator torque demanded to lunch the generator in case it has the order to be activated in the mode logic. The input signals used to provide that characteristic is the engine speed and the state of charge (SOC).

4.6 Transitions between Modes

To change between modes, the main parameters that have to be taken into consideration are the current speed, the old speed and the state of charge (SOC). Transition from Start Mode to Normal Mode is done when engine speed exceeds the rpm value assigned to the signal, which enables the engine and vice versa. Transition from the Accelerate Mode to the Cruise Mode is done when the state of charge is above 30% and the speed required is above 0.998 of the old speed and below 1.002 of the old speed. Transition from Charge-Cruise Mode to the (No-Charge) Cruise Mode is when the SOC>99.9% and the opposite is applicable, when SOC<30%.

5. SIMULAITON RESULTS

The drive cycles used in the tests performed on the hybrid electric vehicle and dual clutch transmission architectures are two of the driving cycles conducted in USA, FTP75 (Federal Test Procedure) and NYCC (NewYork City Cycle). The driving cycle generally is a fixed schedule of vehicle operation, which are defined in terms of vehicle speed and gear selection as a function of time [8]. FTP75 is one of the tests acknowledged by EPA (Environmental Protection Agency) in USA; it is devised, along with NYCC, as low speed urban driving cycle tests. In the coming figures, it is compared, in terms of following the reference speed of drive cycle, fuel consumption between DCT and HEV, (FTP75), and (NYCC), as original drive cycles.

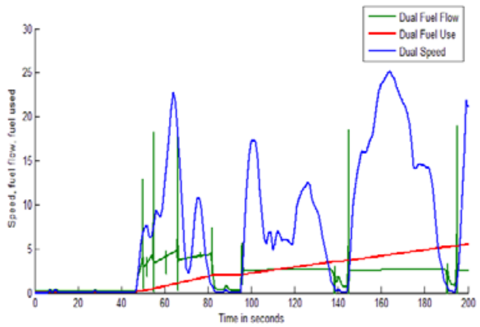

Fig. 3. DCT performance (NYCC)

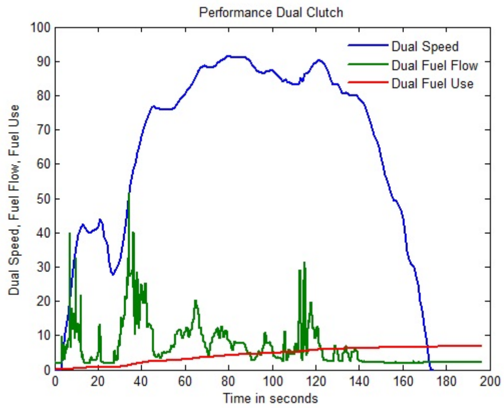

Fig. 4. DCT performance (FTP75)

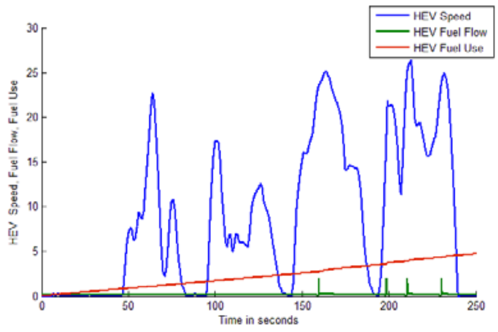

Fig. 5. HEV performance (NYCC)

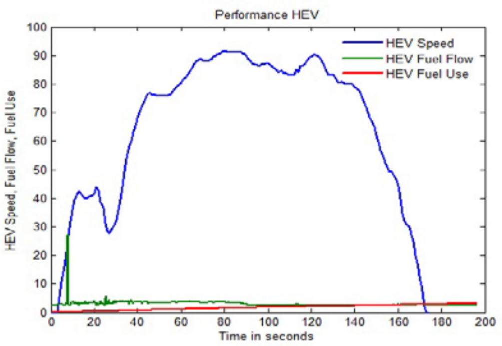

Fig. 6. HEV performance (FTP75)

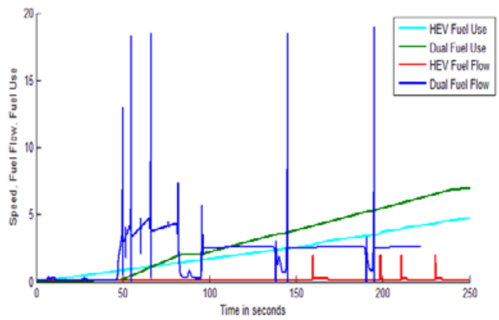

Fig. 7. Compared Fuel economy according to NYCC

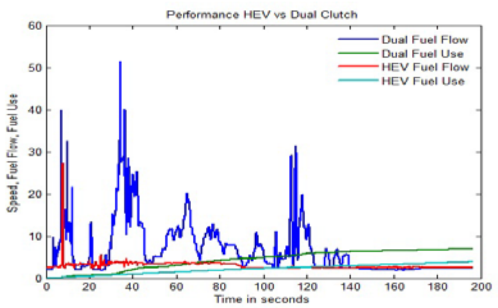

Fig. 8. Compared Fuel economy according to (FTP75)

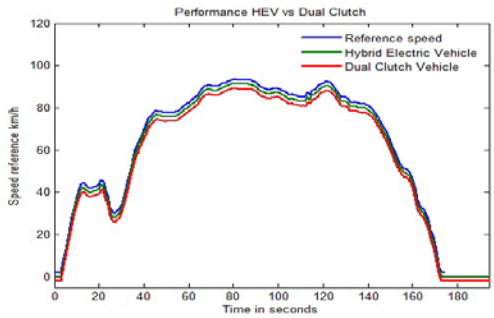

Fig. 9. Reference FTP75, compared to DCT and HEV performance

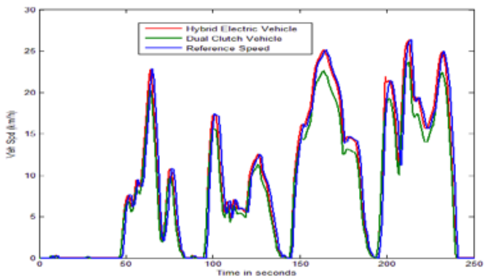

Fig. 10. Reference NYCC, compared to DCT and HEV performance

6. CONCLUSION

In this paper, HEV model was presented compared to conventional DCV, using Stateflow control method, along with mode logic with seven different scenarios, including transitions between them. The simulations were done with two different drive cycles, FTP75 and NYCC, to compare the fuel consumption and performance. The results were acceptable, as there is a slight difference between the obtained and original drive cycle performance, as in fig. 9-10. HEV was closer to the reference drive cycle than DCT, and its performance was better. The fuel used in case of HEV was 73.97% of the fuel used in DCT for (NYCC), and 73.55% for (FTP75), which indicates a better fuel economy in HEV than conventional cars with DCT. However, the future objective is modifying, and tuning within the model to have better, matching results with the drive cycles. In the next step, HIL testing can be performed, along with further tests using other drive cycles to provide much more realistic, reliable results, which can be a concrete verification of the model.

7. REFERENCES

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8. ADDITIONAL DATA

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Appendix A: Abbreviations

T_{TR}	Demanded Torque by Driver
r	Wheel Radius
F_v	Total Force Demand
F_r	Rolling Resistive Force
F_g	Gravitational Force
F_a	Aerodynamic Force
m	Vehicle Mass in Kg
C_0	Constant Rolling Coefficient between Tire and Road
C_1	1st order Rolling Coefficient between Tire and Road
C_d	Aerodynamic Coefficient
v_{dc}	Drive Cycle Speed
ρ	Air Density
A_f	Frontal Area of Vehicle
θ	Angle of Slope (Degrees)
K_p	Proportional Gain of PI Controller
K_i	Integral Gain of PI Controller
V_0	The voltage when the battery is fully charged
α, β	Constants calculated to provide a reciprocal relationship between voltage and remaining charge.
x	The ratio of the ampere-hours left to the number of ampere-hours, AH, for which the battery is rated
ω_b	Base angular velocity
ω_f	Follower angular velocity
μ	Friction coefficient

i_a	Final Drive Ratio

Appendix B: Vehicle data

Mass	1515 kg
Frontal Area	3.1 m^2
Tire Radius	0.4572 m
Drag Coefficient	0.32
Final Drive Ratio	4.24